ITS Communications Document

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National ITS Communication

Executive Summary

In the last decade, many communication technologies and systems have been introduced at an ever-accelerating pace, and some are gaining wide acceptance. The complex world of telecommunications is evolving and expanding rapidly. For many application areas, including transportation, myriad communication options are available to the system architect and designer. These solutions, of course, meet the requirements at hand with varying results and implications of performance, cost, and user acceptance.

The ITS world is also broad and varied, as amply demonstrated by the tweny-nine ITS user services, their distinct needs, and their complex interactions and synergies. The National ITS Architecture can be viewed as a framework that ties together the transportation and telecommunication worlds, to enable the creation, and effective delivery, of the broad spectrum of ITS services. Throughout the Architecture effort, the emphasis has been on flexibility. This allows the local implementors and service providers to select the specific technologies, within the framework of the architecture, that best meet their needs (expressed either in terms of market realities or jurisdictional constraints). The price paid in the architecture is some added complexity. It has been critical, therefore, to espouse an architectural concept that mitigates the complexity of interconnecting many transportation systems with multiple types of communication links. The basic concept wherein the Physical Architecture has a Transportation and a Communication Layer is specifically intended to simplify the process by separating these two fairly independent domains, yet, at the same time, having them tightly coupled to meet the ITS users service requirements.

This National ITS Communication Document contains, under the same cover, the information necessary to describe and characterize all aspects of communications within the National ITS Architecture. It presents a thorough, coherent definition of the “communication layer” of the Architecture. From a National ITS Program perspective, this encompasses two broad thrusts: 1) communication architecture definition (i.e., selection of communication service and media types to interconnect the appropriate transportation systems), and 2) several types of inter-related communication analyses to ensure the feasibility and soundness of the architectural decisions made in the definition. The analyses performed comprise:

- An analysis of the data loading requirements derived from the ITS user service requirements, the Logical and Physical Architectures and their data flows, the ITS service deployment timeline, and the attributes of the candidate scenarios in the “evaluatory design”.
- A wide-ranging, balanced assessment of a broad spectrum of communication technologies that are applicable to the interconnections defined in the communication layer of the Physical Architecture. The evaluation is performed from a National ITS Architecture standpoint.
- An in-depth, quantitative analysis of the real-world performance of selected technologies that are good candidates for adoption as ITS service delivery media, and for which reliable, state-of-the-art simulation tools are available. The performance is determined under the demands of the ITS and other projected applications of the media.
- A number of supporting technical and economic telecommunications analyses that address some important architecture-related issues, such as the appropriate use of dedicated short range communication (DSRC) systems.

One of the fundamental guiding philosophies in developing the National Architecture has been to leverage the existing and emerging infrastructures, both transportation and communication. This is to maximize the feasibility of the architecture, and to mitigate the risk inherent in creating and offering intelligent transportation systems, services, and products, all of which are quite new and in need of acceptance.

The communication architecture definition adopts the same philosophy. It follows, and expands upon, a rigorous, well-accepted methodology used widely in the world of telecommunications. Several wireless systems which are tied to wireline networks have used this approach. It starts from the basic network functions and building blocks and proceeds to the definition of a network reference model, which identifies the physical communication equipment (e.g., base station), to perform the required communication functions, and the interfaces between them. These interfaces are the most salient element of the model from an ITS perspective; some of these interfaces need to be standardized to ensure interoperability.

Because of the variances in the ITS user service requirements (from a communication perspective), it is clear, even from a cursory examination, that the user services do not share a common information transfer capability. Specifically, ITS user services like electronic toll collection demand communication needs that can only be met by dedicated infrastructures for technical feasibility, notwithstanding institutional, reasons. The ITS network reference model that was developed incorporates this basic extension of the models developed for commercial telecommunication networks.

In general, the Communication Architecture for ITS has two components: one wireless and one wireline. All Transportation Layer entities requiring information transfer are supported by one, or both, of these components. In many cases, the communication layer appears to the ITS user (on the transportation layer) as “communication plumbing”, many details of which can, and should, remain transparent. Nevertheless, the basic telecommunication media types have critical architectural importance. The wireline portion of the network can be manifested in many different ways, most implementation dependent. The wireless portion is manifested in three basic, different ways:

- Wide-area wireless infrastructure, supporting wide-area information transfer (many data flows). For example, the direct use of existing and emerging mobile wireless systems. The wireless interface to this infrastructure is referred to as u1. It denotes a wide area wireless airlink, with one of a set of base stations providing connections to mobile or untethered users. It is typified by the current cellular telephone and data networks or the larger cells of Specialized Mobile Radio for two way communication, as well as paging and broadcast systems. A further subdivision of this interface is possible and is used here in the document: u1t denotes two-way interconnectivity; and u1b denotes one-way, broadcast-type connectivity.

- Short range wireless infrastructure for short-range information transfer (also many data flows, but limited to specific applications). This infrastructure would typically be dedicated to ITS uses. The wireless interface to this infrastructure is referred to as u2, denoting a short-range airlink used for close-proximity (typically less than 50–100 feet) transmissions between a mobile user and a base station, typified by transfers of vehicle identification numbers at toll booths.
- Dedicated wireless system handling high data rate, low probability of error, fairly short range, Automated Highway Systems related (AHS-related) data flows, such as vehicle to vehicle transceiver radio systems. This wireless interface is denoted by u3. Systems in this area are still in the early research phase.

The ITS network reference model has to be tied to the specific interconnections between the transportation systems or subsystem, e.g., connection between Information Service Provider (ISP) subsystem and a vehicle subsystem (VS). The key step is performed through the Architecture Interconnect Diagram (AID), actually, a whole collection of them of varying levels of detail. These marry the communication service requirements (which are generic information exchange capabilities such as messaging data) to the data flow requirements in the transportation layer, and specify the type of interface required (u1, u2, u3, w). The Level-0 AID is the top level diagram showing the types of interconnectivities between the various transportation subsystems, and, perhaps, is the best description of the communication framework in the ITS architecture. The AID Level-0 is broken down further to show subsets of it depicting the data flows that, say, use broadcast (u1b), or those that use either broadcast or two-way wide area wireless (u1t).

Various media and media types are applicable as possible candidates for each type of interconnection. The best communication technology family applicable to each data flow is specified. This still remains above the level of identifying a specific technology or system. In practice, i.e., in a real-world ITS deployment, the final step of selecting a given technology would be performed by the local ITS implementor or service provider. A proffered specification here would clearly transcend the boundaries of architecture and into the realm of system design. It is therefore avoided to the extent possible in the communication architecture definition phase.

To assist the implementors and service providers in the ITS community, a broad technology assessment is performed. It attempts to use as much factual information as is available to identify and compare key pertinent attributes of the different communication technologies from a National ITS perspective. This, at least, facilitates the identification of which technologies are suitable for the implementations of what data flows.

A host of land-mobile (i.e., cellular, SMR, paging, etc.), FM broadcast, satellite, and short range communication systems have been assessed. The assessment addresses the maturity of the candidate technologies and analyzes their capability for supporting ITS in general, and the architecture in particular. Within the limits of reliable publicly available information, the following attributes are assessed: infrastructure and/or service cost as applicable, terminal cost, coverage, and deployment time-line (if not yet deployed). Furthermore, interface issues (i.e., open versus proprietary) are also addressed from a national ITS perspective. Whenever possible, analysis is performed to determine: 1) system capacity, i.e., supported information rate, 2) delay throughput, 3) mobility constraints, etc. The ITS Architecture data flow specifications are used in the analysis, including message sizes and update frequencies. The key comparison characteristics are finally summarized in tables.

Another area focus in this document is ITS communication performance evaluation. The objective is to determine whether the National ITS Architecture is feasible, from the standpoint that communication technologies exist and will continue to evolve to meet its demands, both technically and cost effectively. To set the stage for this, data loading analyses have been completed for the wide area wireless interfaces u1t, u1b, and the wireline interface w-- data loading for the u2 and u3 interfaces is not as useful, so link data rates have been determined instead.

The data loading analyses define all of the messages that flow between all of the physical subsystems. Deployment information from the evolutionary deployment strategy has been used to define which services, and therefore which messages would be available for each of the scenario and time frames specified by the Government. The three scenarios provided are addressed, namely, Urbansville (based on Detroit), Thruville (an inter-urban corridor in NJ/PA), and Mountainville (a rugged rural setting based on Lincoln County, Montana).

Seven user service groups with distinct usage patterns have been defined, along with the frequency of use of the messages by each user group. Messages have been assigned to the u1t, u1b, and w interfaces based on suitability, and are allowed to flow over multiple interfaces with a fraction assigned to each one. The resulting data loading analyses provide the data loads and a complete description of the message statistics, on all of the above interfaces and links. These data are used to drive the communications simulations.

For the u1t interface (two way wide area wireless), the data loading results indicate that for Urbansville in 2002 the largest data loads result from the CVO-local user service group, followed closely by transit and private vehicles. In Thruville, for the same time period, CVO-local and transit are alone the largest data users. For Urbansville in 2012, private vehicle and CVO-local are the largest data users, at about twice the rate of transit, with the others far below. For Thruville in 2012, CVO-local remains the largest data user, followed by transit. The Mountainville data loads are very low, with CVO-local the largest user, followed by private vehicles.

In each of the u1t scenarios and time frames studied the forward direction data load (center to vehicle) is always higher than the reverse direction load, by a factor of two to three. The consistent users of the reverse direction are CVO and transit.

The ITS Architecture data loading results have been used as input to the communication simulations. Due to the relative scarcity of wireless communications (relative to wireline), emphasis has been placed on the evaluation of wireless system performance. However, network end-to-end performance, comprising both the wireless and wireline components, given in terms of delay and throughput, is also obtained. Furthermore, representative analyses of wireline networks have also been included.

The wireless simulations performed were for Cellular Digital Packet Data (CDPD), primarily because it is an open standard with a publicly available specification, and because validated, state-of-the-art simulations were made available for use on the ITS Architecture Program. These simulations accurately reflect the mobile system conditions experienced in the real world, including variable propagation characteristics, land use/land cover, user profiles, and interference among different system users (voice and data). The simulations also handle the instantaneous fluctuations and random behavior in the data loads whose peak period averages are derived in the data loading anlysis sections. The simulation modeling tools have been tested and validated in the deployment and engineering of commercial wireless networks by GTE.

Simulations have been run for the three scenarios provided by the Government. Since the number of users is very small in Mountainville, only cellular coverage was obtained to ascertain its adequacy in that remote area. For both Urbansville and Thruville, scenarios with both ITS and Non-ITS data traffic projected for the CDPD network were run, under normal peak conditions and in the presence of a major transportation incident.

The Government-provided scenario information was substantially augmented with information on actual cellular system deployment obtained directly from FCC filings. A minor amount of radio engineering was performed to fill a few gaps in the information obtained. The commercial wireless deployment assumed in the simulation runs, therefore, is very representative of the real operational systems. In fact, because of the continuous and rapid expansion of these systems, the results of the simulations are worst case in nature.

The wireless simulation results have shown that the reverse link delay (the data sent from the vehicle to the infrastructure), even in presence of non-ITS data, and in the case of an incident during the peak period, is very low (150 ms for ITS only; 300 ms for ITS plus non-ITS; with a 10% increase in the sectors affected by the incident).

The results of the CDPD simulations are further validated by the results of an operational field trial that was performed in the spring of 1995, jointly by GTE and Rockwell, in the San Francisco Bay Area. The application demonstrated was commercial fleet management (dispatch), using GPS location, and CDPD as an operational commercial wireless network. A synopsis of the trial and its results are presented in an Appendix.

The above results for CDPD should be interpreted as a “proof by example”. A commercial wireless data network is available today to meet the projected ITS requirements. Other networks also exist, and can be used, as indicated in the technology assessment sections. Future wireless data networks, and commercial wireless networks in general, will be even more capable.

The simulation results for the wireline network example deployment indicate that extremely small and completely insignificant delays are encountered, when the system is designed to be adequate for the projected use. With the capacities achievable today with fiber, whether leased or owned, wireline performance adequacy is not really an issue. The key issues there pertain to the costs of installation versus sustained operation for any given ITS deployment scenario.

The overarching conclusion from the communication system performance analyses is that commercially available wide area wireless and wireline infrastructures and services adequately meet the requirements of the ITS architecture in those areas. These systems easily meet the projected ITS data loads into the foreseeable future, and through natural market pull, their continued expansion will meet any future ITS growth. Hence, from that particular standpoint, the National ITS Architecture is indeed sound and feasible.

This National ITS Communication document also contains additional analyses to support some of the architectural decisions taken during the course of the project, and reflected in the architecture definition. One such decision is avoiding the use of dedicated beacon systems for wide area applications, such as traveler information, route guidance, mayday an so on. The technical and economic drivers are addressed in an appendix and synopsized in the technology assessment section.

1. INTRODUCTION

1.1 Purpose of Document

In the information age, the world of telecommunications is indeed very large, with many diverse systems and technologies, offering a very broad range of capabilities and features. This world is evolving and expanding rapidly. On the other hand, the world of ITS is also broad, and complex. This is amply demonstrated by the many ITS user services, and their myriad interactions and possibilities.

The National ITS Architecture can be viewed as a framework that defines the interactions between the transportation and telecommunication domains that enable the creation and offering of the ITS user services throughout the nation. This architectural framework thus encompasses various transportation systems with many information flows among them. It also encompasses various choices of telecommunication services and media needed to carry this information and to ensure the proper connectivity between the transportation systems involved. The ITS Architecture, through its structure, aims to mitigate the complexity involved in dealing with so many entities. One of its basic concepts is the decoupling of the transportation and telecommunication domains into two, fairly independent, yet tightly coupled “layers”.

This National ITS Architecture Communications document presents, under a single cover, a comprehensive, cohesive treatment of communications within the National ITS Architecture. This comprises two broad, major thrusts: 1.) communication architecture definition (also referred to as the definition of the “communication layer” of the ITS Architecture); and 2.) analysis of communication systems performance to meet the connectivity and data loading requirements of the ITS Architecture. The objective of this analytical thrust is to demonstrate the feasibility of the architectural decisions made in the definition of the communication layer and to present the key supporting tradeoffs. This feasibility is from the standpoint that communication technologies exist and will evolve to continue to meet the architecture’s demands in a predictable, cost effective manner. The communication analysis thrust thus includes:

- A comprehensive analysis of the data loading requirements of the architecture for different scenarios and time frames.
- A balanced assessment of a wide array of wireless and wireline communication techniques and systems applicable to the ITS Architecture.
- An in-depth, quantitative performance evaluation of specific example system implementations.
- A compilation of the supporting technical and economic telecommunication analyses.

This document is intended to provide both the telecommunication and transportation engineer, i.e., the specialist and non-specialist engineer, with all the details pertinent to the definition of the

ITS communication architectural framework and all its supporting analyses. To achieve this formidable objective, the document is divided into nine sections and 10 supporting appendices. This two-tier structure allows for an accessible presentation of the over-arching communication definition issues and analysis results, yet does not sacrifice much of the in-depth, detailed developments essential to arriving to the main findings presented in the nine sections.

This document was prepared for the Rockwell and Loral Teams – and for the ultimate customer, the FHWA – by a team of telecommunication engineering specialists from GTE Laboratories. Work was performed in close collaboration with Rockwell, Loral and the other members of the Architecture Development and Government teams. This development environment ensured a treatment of ITS communication that balances the real-world experience from the telecommunications industry with the broader perspective, and distinct needs, of the transportation community.

1.2 Structure of Document

This document consists of nine sections and 10 appendices. The contents of each section and appendix is briefly described below.

Section 1	**Introduction** Introduction to the document.
Section 2	**Introduction to the ITS Communications Architecture** An introduction to the ITS Communications Architecture in a concise tutorial. This section also presents the philosophical approach and the objectives of the communications architecture, and its relationship to the evaluatory design analyses.
Section 3	**Communication Architecture Definition** A complete description of the Communication Architecture, including definitions of terms, communication services, and a description of the linkage of the communication and transportation layers through the Architecture Interconnect Diagrams (AID's).
Section 4	**Scenarios and Time Frames** Presents information on the evaluatory design, with baseline information for the scenario regions, number of potential users by group, penetrations, and usage profiles.
Section 5	**Message Definition** Describes the message definition methodology starting from the logical architecture, and introduces the structure adopted for the messages, and the message set.
Section 6	**Data Loading Methodology and Results** Provides an analysis of the data loading requirements and results for both wireless and wireline communication based on the architecture definition.
Section 7	**Assessment of Communications Systems and Technologies** A comprehensive analysis and assessment, from a National ITS Architecture perspective, of a wide array of applicable communication systems. Analysis approach, results and summary tables.

Section 8	**Communication Systems Performance – A Case Study** An in-depth, quantitative performance analysis, using state-of-the-art simulations, of specific wireless and wireline system implementations of the ITS Architecture. Includes wireless, wireline and end-to-end communication system performance.
Section 9	**ITS Architecture Communication - Conclusions** The conclusions and salient findings of this report.
Appendix A	**Communication Architecture Development and Definitions** The definitions of the pieces comprising the communication architecture.
Appendix B	**Architecture Interconnect Diagrams – Level 1** The interconnections and data flows are represented in a detailed Level 1 AID format.
Appendix C	**Communication Architecture Renditions and Applicable Technologies** Describes the development of the Communication Architecture Renditions (classes of communication system implementations-- not specific technologies, for the architecture).
Appendix D	**Technology Assessment Sources** Provides a compilation of the many sources, printed and electronic, that were used in establishing the technology assessment.
Appendix E	**Potential Users According to User Service Group** Analysis of potential buyers for each user service group.
Appendix F	**Message Definitions and Data Loading Models** Presents the message definitions and data loading models listed by user service group for each scenario.
Appendix G	**Use of Beacons for Wide Area Delivery/Collection of ITS Information** Examines alternative architectures in which services are provided by wireless dedicated short-range communication (DSRC) between vehicles and roadside beacons.
Appendix H	**Wireless and Wireline Protocols** Descriptions of wireless and wireline protocols, primarily for the systems analyzed .
Appendix I	**Simulation Tools** Describes the wireless and wireline simulation tools used in the communication analysis.
Appendix J	**CDPD Field Trial Results** Presents a synopsis of the results of a CDPD field trial for an ITS application.

2. Introduction to the ITS Communication Architecture

2.1 Role of the Communication Architecture

The complex world of telecommunications is evolving and expanding rapidly. The ITS world is also broad and quite varied, as demonstrated by the ITS user services, their distinct needs, and the complex interactions and synergies. The National ITS Architecture can be viewed as a framework that ties together the transportation and telecommunication worlds. This framework enables the creation and effective delivery of the broad spectrum of ITS services.

For the transportation engineer and planner, myriad communication options are available to consider. The telecommunication solutions meet the transportation requirements at hand with varying results and implications of performance, cost, and user acceptance. There are also many challenges in interconnecting the disparate components of any end-to-end ITS solution, encompassing various transportation and communication issues.

Throughout the Architecture effort, the emphasis has been on flexibility. This allows the local implementors and service providers to select the specific technologies, within the framework of the architecture, that best meet their needs (expressed either in terms of market or jurisdictional constraints). The price paid in the architecture is some added complexity. It has been critical, therefore, to espouse an architectural concept that mitigates the complexity of interconnecting many transportation systems with multiple types of communication links.

The basic architectural concept, wherein the Physical Architecture has a Transportation and a Communication Layer, is specifically intended to simplify the process by separating these two fairly independent domains. At the same time, the two domains should be tightly coupled to meet the ITS users' service requirements. Through this unified, logically derived, and structured framework, the interconnectivity requirements between the transportation systems can be drawn from the ITS user services. Then, various communication choices can be considered and objectively evaluated for their ability to meet those connectivity requirements. Furthermore, the structure of the communication architecture is designed to facilitate the identification of the critical communication technology interoperability and interface issues. In so doing, these issues can be addressed and resolved in order to facilitate the deployment of ITS on a national scale.

The communication layer of the ITS physical architecture, therefore, aims to provide answers for the following questions:

- What types of communication infrastructures are required to connect the transportation subsystems to enable a given set of ITS user services?
- What types of communication services (information transfer capabilities) are needed to carry the information that flows between the transportation subsystems services (i.e., the ITS data flows) in order to provide the ITS user?
- What modes of communication connectivity (packet, circuit, etc.) are required for the various ITS data flows?
- What types of communication systems, or technology classes, are available to meet these communication requirements (which are driven by the ITS user service requirements)?
- How do these candidate communication solutions compare from the perspective of meeting the goals of the National ITS Architecture?
- In light of the many available candidates, what are the critical points of communication systems interface that may need to be standardized to enable national interoperability?

2.2 The Telecommunication Infrastructure and the ITS Communication Architecture Development Philosophy

Over the last two decades, a massive telecommunication infrastructure has evolved, both for wired and wireless communication. The reliability and capacity of wireline networks has increased exponentially, enabling a wide array of new services and capabilities. At the same time, prices of most wireline telecommunication services which are subject to competition have dropped remarkably. The wireless arena, on the other hand, was born and has since witnessed unprecedented growth. As an example, roughly $20 billion has been invested in the cellular infrastructure until 1995. The wireless industry, in its varied incarnations, now holds tremendous promise into the future, as evidenced by the fierce competition for its spectrum and the value attached to it. In fact, wireless’s predicted growth may alter many of the traditional paradigms of communication. Today, wireline and wireless networks can take various forms, public and private, as depicted conceptually in Figure 2.2-1.

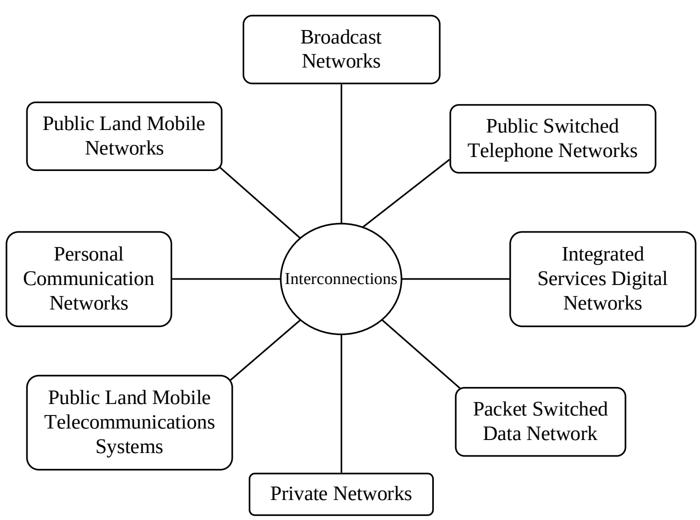


Figure 2.2-1 Overview of the Telecommunications Arena

Over the next twenty years, many new communication technologies and techniques, from multiple access to transport to switching, will be introduced at a rapid pace to support the demands of our information age. Presently available and emerging technologies will offer extensive opportunities to handle many ITS user services. The technology projections depicted in Table 2.2-1 identify the predicted availability of various communication technologies and infrastructures that could be exploited.

The natural competitive evolution of wireline and wireless infrastructures will yield communication systems that will:

1. Support communication services which include: voice (speech), data, image, video, and signaling.
2. Accommodate a wide variety of terminals, i.e., fixed, portable mobile, and in-vehicle mobile.
3. Preserve upward/downward terminal compatibility.
4. Allow mobile and fixed users to utilize the services regardless of geographical location (i.e., seamless communication).
5. Provide service flexibility, so that any combination of services may be used.
6. Make efficient and economical use of the spectrum.
7. Provide user authentication and billing functions.
8. Provide varied degrees of network security that preserve user privacy.
9. Have modular structures which will allow the systems to start from small and simple configurations then grow as needed in size and complexity.
10. Use, in many cases, open architectures which will permit the easy introduction of technology advancement and support of new applications.

As a reflection of the very desirable attributes delineated above, one of the fundamental guiding philosophies in developing the National ITS Architecture has been to leverage, to the extent possible, the existing and emerging telecommunication infrastructures. Doing so not only benefits ITS from the tremendous financial investment in the deployed and planned infrastructures, but also from the large time and effort expended in developing standards to allow interoperability and interconnectivity among disparate systems. Moreover, this enables the ITS users to share many of the scarce and valuable resources, and distribute their cost over a significantly broader population.

By embracing the heritage of the broad telecommunications industry, the cornerstone of whose success has been fulfilling users’ needs and meeting with their acceptance, ITS will be on the proper path towards a wide scale presence. This evolutionary approach is essential to maximizing the feasibility of the architecture, and to mitigate the risk inherent in creating and offering intelligent transportation systems, services, and products, all of which are quite new and in need of acceptance.

Table 2.2-1 Communications Technology Projections for the Next 15 Years

Technologies	1992	1997	2002	2012
Wireless Access	FDMA Analog	FDMA and TDMA/CDMA Digital	CDMA/TDMA Digital	Mainly CDMA Digital
Wireless Capacity	Moderate	High (3-5x AMPS)	High (5-10x AMPS)	High (10-15x AMPS)
Wireless Signal Coverage	All Urban, Most Inter-Urban, Some Rural	All Urban and Inter-Urban, Most Rural	All Urban and Inter-Urban All inhabited Rural	Ubiquitous
Wireless Media • Terrestrial: • Satellite:	 Most Macro Limited GEO	 Full Macro, Initial Micro Some GEO, Initial LEO	 Full Macro, Most Micro Full GEO, Partial LEO	Transparent, Hybrid Terrestrial Satellite Integrated Macro/Micro Full GEO/ Full LEO
Wireline Availability	Widespread Copper Limited Fiber for LAN's and Backbone	Fiber Backbone with Copper Drops Very Limited Hybrid Fiber-Coax	Limited Fiber to Curb Some Hybrid Fiber-Coax	Partial Fiber to Curb Limited Fiber to Home
Transfer Mode	Full Circuit-Switching Packet-Switching Initial Frame-Relaying	Partial Frame-Relaying Very Limited Asynchronous Transfer Mode (ATM)	Most Frame-Relaying Initial Fast-Packet Switching Partial ATM	Most Fast-Packet Switching Most ATM
Data Protocol	X.25, X.21	Frame-Relay ATM	Frame-Relay ATM	Mostly ATM
Transport Network Characteristics	Service Dependent Disconnected LAN's Slow Speed Interconnection	Initial Service-Independent Initial LAN Connectivity through Metropolitan Area Networks (MAN)	Partial Service-Independent Partial MAN's	Widespread Service Integrated Broadband Network—B-ISDN Most Service Independent
Intelligent Network Characteristics	Partial Wireline Support: • Number Translation	Most Wireline Support Partial Wireless Support • Mobility Services (Personal, Terminal)	Full Wireline Support Most Wireless Support	Fully Integrated Wireline/Wireless Support • Seamless Operation • Multi-Mode Terminal • Profile Portability • Dynamic Resource Allocation • Information Format Adaptation

2.3 Development of a Communications Architecture

The development of a communication architecture comprises a set of steps which, more or less, parallel those of a generic system architecture. A few basic steps can be identified. The first is the development of the communication services description, using widely accepted description conventions. (Communication services are generic information transfer capabilities, such as conversational speech or messaging data). The detailed definition of the communication service is based on the communication needs to be fulfilled. This first step is analogous, in some sense, to the development of the ITS user services. (Note that from a communication architecture perspective, the ITS user services are applications; this is explained in considerable detail in Section 3.) The second step in the development of a communication architecture is determining the network's logical functions (e.g., wireless access, registration) to meet the requirements of the communication service. This step is analogous to the definition of the logical architecture. The third step, which is equivalent to the physical architecture, has two elements, the first is the identification of the functional entities (e.g., switch, base station) that can be used to perform the logical functions, and the second is matching those functional entities to established or revised network reference models, which identify reference interfaces between the physical equipment (standards are usually written for those reference interfaces.)

This framework has been used often, in developing new telecommunication services and systems with open specifications, such as cellular (AMPS, GSM, CDMA, CDPD, etc.), PCS, and others. It has also been used extensively in developing inter-system operation and interface standards. This structured, generic methodology will be followed in defining the communication architecture for ITS, but will be adapted and extended to meet the distinct needs of the various ITS user services. The network reference model approach is very well suited to the ITS architecture needs, where particular importance is attached to the identification of key inter-operability interfaces and their standards requirements.

2.4 Elements of the Communications Layer of the ITS Architecture

The communication architecture provides information transfer for the transportation layer subsystems. The communication architecture includes all of the communications entities, i.e., wireline and wireless transmitters, receivers, satellites, etc., and the information management and transport capabilities necessary to transfer information among the transportation entities. The application data content and the transportation application requirements are, in general, transparent to the communications architecture. The communications architecture's view of the transportation layer is that of many distributed users, some of them mobile, which require information transfer services.

The communication architecture must be technically and economically feasible as well as sensitive to the potential institutional and regulatory barriers. Because of the variances in the ITS user service requirements (from a communication perspective), it is clear from a cursory examination that the user services do not share a common information transfer capability. Specifically, some ITS user services will be best served by leveraging commercial telecommunication infrastructures that provide services to users and applications that transcend ITS, others will require specialized, dedicated communication systems. The differences in these architectural choices can lead to dramatic differences in cost, deployability, risk of acceptance and performance.

The communication architecture definition, then, entails the appropriate selection of communication services, communication media and interface types, communication technology groups (with common salient attributes) to interconnect the appropriate transportation systems.

The steps for developing the communication architecture are depicted in Figure 2.4.-1. The lower branch to the left is basically the generic communication architecture development process. The upper branch, and the rest of the steps, represent the transportation/ communication linkage process through which a generic communication architecture becomes tailored to the specific needs of the ITS architecture, driven by the requirements of the ITS user services. This linkage is accomplished through the following steps:

1. Mapping the generic communication services to the data flows identified in the Transportation Layer.
2. Generating the Architecture Interconnect Diagrams (AIDs) which define the interconnections between transportation subsystems and modules defined in the Transportation Layer.
3. Identifying the Architecture Renditions (ARs) which are examples, based on the network reference model, of how to provide communication technology groups to provide connections between users defined in the Transportation Layer.
4. Mapping of the AIDs to the AR's (each AR stays one level above technology specification, and comprises a family of systems with similar attributes, e.g., wireless packet data networks).
5. Identifying the Architecture Interconnect Specifications (AISs) which are examples of specific systems to implement an applicable communication technology to a particular rendition, for example, the use of CDPD for cellular wide-area wireless data communication.

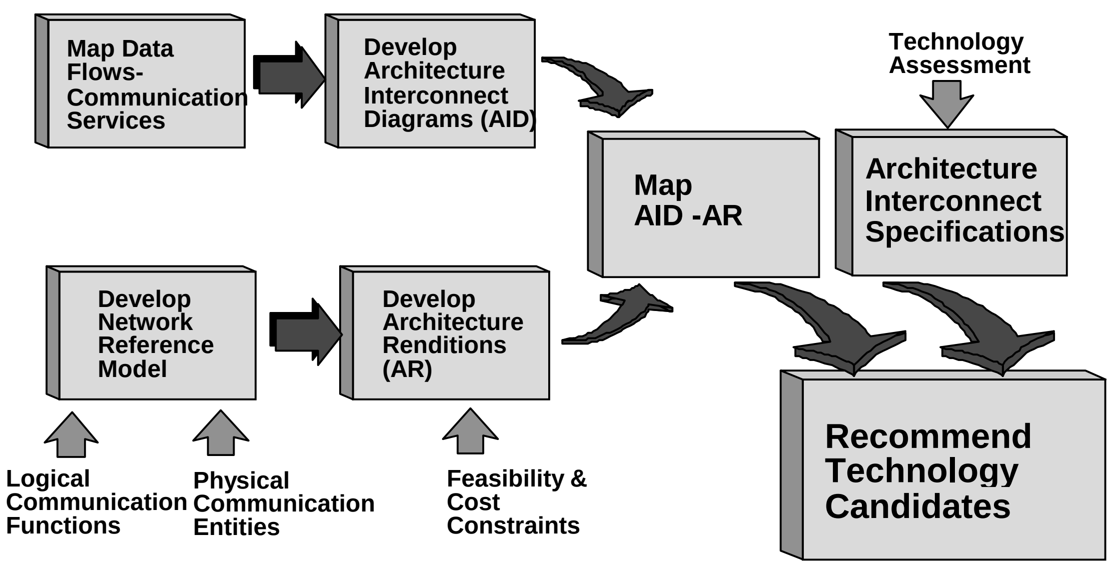


Figure 2.4-1 Communication Architecture Development Process

Within the AIS, various media and media types are applicable as possible candidates for each interconnection. The best communication technology family applicable to each data flow is specified. This definition remains one level above that of identifying a specific technology or system. In practice, i.e., in a real-world ITS deployment, the final step of selecting a given technology would be performed by the local ITS implementor or service provider. A proffered specification transcends the boundaries of architecture and into the realm of system design. It is therefore avoided to the extent possible in the communication architecture definition phase.

To assist the implementors and service providers in the ITS community, an extensive and broad technology assessment is performed subsequent to the architecture definition. It attempts to use as much factual information as is available to identify and compare key pertinent attributes of the different communication technologies from a National ITS perspective. This, at least, facilitates the identification of which technologies are suitable for the implementations of what data flows.

2.5 Relationship of the Communication Architecture Definition to the Data Loading Analysis and Simulations

From a National ITS Program perspective, the ITS architecture development activities in the area of communication encompass two broad thrusts: 1) communication architecture definition, i.e., selection of communication service and media types to interconnect the appropriate transportation systems, and 2) several types of inter-related communication analyses, to ensure the feasibility, and soundness, of the architectural decisions made in the definition. The feasibility is from the standpoint that communication technologies exist and will continue to evolve to meet the demands of the National ITS Architecture, both technically and cost effectively.

The analyses performed comprise:

- An analysis of the data loading requirements derived from the ITS service requirements, the Logical and Physical Architectures and their data flows, the ITS service deployment timeline, and the attributes of the candidate scenarios in the “evaluatory design”, developed based on Guidance provided by the Government.
- A wide-ranging, balanced assessment of a broad spectrum of communication technologies that are applicable to the interconnections defined in the communication layer of the Physical Architecture. The evaluation is performed from a National ITS Architecture standpoint.
- An in-depth, quantitative analysis of the real-world performance of selected technologies that are good candidates for adoption as ITS service delivery media, and for which reliable, state-of-the-art simulation tools are available. The performance is determined under the demands of the ITS and other projected applications of the media.
- Supporting technical and economic telecommunication analyses that address some important architecture-related issues, such as the appropriate use of dedicated short range communication (DSRC) systems.

The data loading analyses define all of the messages that flow between all of the physical subsystems. Deployment information from the evolutionary deployment strategy is used to define which services, and therefore which messages would be available for each of the scenario and time frames specified by the Government. The three scenarios provided are addressed, namely, Urbansville (based on Detroit), Thruville (an inter-urban corridor in NJ/PA), and Mountainville (a rugged rural setting based on Lincoln County, Montana).

User service groups with distinct usage patterns are defined as are the frequency of use of the messages by each user group. Messages are assigned to the different interfaces defined in the architecture definition, specifically, the ITS network reference model, based on suitability. The results provide the data loads on all of the different interfaces and links, with a complete description of the message statistics, which are used to drive the communications simulations.

The communication simulations take the quantitative analysis of the evaluatory design one step further. They use validated, state-of-the-art simulation models to determine the real world performance of select communication systems when used to carry the data loads derived from the ITS architecture definition. The instantaneous variations and random behavior of the average loads for the peak periods derived in the data loading anlysis are handled by these sophisticated simulations. The example systems simulated are among the candidate technologies identified in the architecture definition and are determined to be strong contenders in the broad technology assessment performed.

The results sought from the wireless and wireline simulations are intended to serve as “proof by example”. That is, certain viable communication systems, for example commercial wireless data networks, are available today to meet the projected ITS requirements (for a certain set of data flows). Since future systems will only be significantly more capable than today’s, favorable performance results obtained for future time frames, e.g., the year 2002, for present systems, would clearly indicate the soundness of the decisions made in the communication architecture definition.

3. COMMUNICATION ARCHITECTURE DEFINITION

The overall ITS physical architecture consists of three layers: the Transportation Layer, the Communication Layer, and the Institutional Layer. This section presents an overview of the Communication Layer. It is divided into two main sections: Communication Architecture (Section 3.1), and Communication Layer linkage to the Transportation Layer (Section 3.2).

The Communication Architecture section (Section 3.1) first presents a top-level generic communication model which illustrates the basic relationship between the ITS Physical Architecture's Transportation and Communication Layers. This generic communication model, which should not be confused with the ITS communication network reference model, is based on the International Standards Organization's (ISO) Open Systems Interconnection (OSI) model. The ISO OSI model consists of seven layers: application, presentation, session, transport, network, data link, and physical layer. In general, the application, presentation, and session layers are supported by the Transportation Layer while the transport, network, data link and physical layers are supported by the Communications Layer.

The Communication Architecture Section (Section 3.1) also provides definitions of the various components that make up the communication layer. Some of these components include: communication services, communication logical functions, communication functional entities, and communication network reference model. The communication network reference model is the primary ITS communication model.

The communication architectures for commercial communication systems such as Personal Communication Services (PCS), Groupe Speciale Mobile (GSM), TIA-IS-41, Cellular Digital Packet Data (CDPD), to name a few, use communication network reference models. A network reference model is used to identify physical equipment that perform communication functions, and is used to identify reference interfaces between these physical equipment (standards are usually written for these reference interfaces). The ITS network reference model is based on, and presents extensions of, several reference models that were developed for the above mentioned standard communication systems. The model provides a structure that shows how various communication technologies can implement the ITS Architecture Interconnect Diagrams (AIDs), which are presented later in the Communication Layer Linkage Section (Section 3.2).

The Communication Layer Linkage section also identifies the relationship between the Transportation Layer and Communication Layer definitions. This is accomplished through the following steps:

1. Mapping the communication services to the data flows identified in the Transportation Layer.
2. Generating the Architecture Interconnect Diagrams (AIDs) which define the interconnections between transportation subsystems and modules defined in the Transportation Layer.
3. Identifying the Architecture Renditions (ARs) which are examples, based on the network reference model, of how to provide communication connections between users defined in the Transportation Layer.
4. Mapping of the AIDs to the AR's (each AR stays one level above technology specification, and comprises a family of systems with similar attributes, e.g., wireless packet data networks).
5. Identifying the Architecture Interconnect Specifications (AISs) which are examples of specific systems to implement an applicable communication technology to a particular rendition, for example, the use of CDPD for cellular wide-area wireless data communication.

To summarize, the Communication Layer Linkage Section presents the communication services/data flow mapping, AIDs, ARs, AID/AR mapping, and AISs.

In general, the Communication architecture for ITS will have two components: one wireless and one wireline. All Transportation Layer entities requiring information transfer are supported by one or both of these components. In most cases, the wireless component merely provides a tetherless user, usually one in a vehicle, with access to fixed (or wireline) network resources. The wireless portion will be manifested in three different ways:

- Wide-area wireless infrastructure supporting wide-area information transfer (many data flows). For example, the direct use of existing and emerging mobile wireless systems.
- Short range wireless infrastructure for short-range information transfer (also many data flows, but limited to specific applications), similar to systems used for electronic toll collection.
- Dedicated wireless system handling high data rate, low probability of error, fairly short range, Advanced Highway Systems related (AHS-related) data flows, such as vehicle to vehicle transceiver radio systems.

Because of the variances in the ITS user service requirements (from a communication perspective), it is clear from a cursory examination that the user services do not share a common information transfer capability. Specifically, ITS user services like electronic toll collection demand communication needs that can only be met by dedicated infrastructures for technical and feasibility, notwithstanding institutional, reasons. The ITS user services information transfer needs are supported by a sample deployment of the communication network reference model described in Section 3.1.4. Implementation candidates are identified as a result of a broad, balanced communication technology assessment task. After examining the assessment results for these candidates, an ITS implementor or service provider can decide on the mix of communication technologies that are best suited to the implementation scenario at hand.

The wireline portion can be manifested in many different ways, most of them implementation dependent. Note that in defining the Communication Layer, no assumptions have been made regarding media type.

The process of developing the communications layer (architecture) is illustrated in Figure 3.0-1, and starts from the data flows in the transportation layer. In the following sections, the reader is referred to this figure at each step of the design process description.

The upper left block in Figure 3.0-1 shows the mapping of the identified data flows to communication services. The data flows are derived from the Architecture Flow Diagram (AFD) provided in the Physical Architecture document, which is used to specify which transportation subsystems communicate directly with each other. The communication services are described in Section 3.2.1 in terms of flow response and capabilities. (They should not be confused with the ITS user services, which from a communications standpoint, are applications. These will be discussed shortly.) The mapping provides one or more communication services for each of the data flows between transportation entities. The Architecture Interconnect Diagrams (AIDs) encapsulate the type of partition between each of the transportation layer subsystems as wireline or wireless. This is accompanied by a description of the communication service and operation mode for all the data flows between each pair of entities.

In parallel, a Network Reference Model (lower left block in Figure 3.0-1) is derived from models for standard commercial communication systems to fit ITS needs. This communication model is then used, in combination with feasibility and cost constraints, to develop renditions, or examples, of how to realize the required communication services. These renditions are based on the communication interface type, and are one level above specific technology.

As shown in Figure 3.0-1, the MAP AID-AR block is done in an abstract way, identifying which data flows are supported by each rendition. At the same time, the results of the Technology Assessment are used to develop Architecture Interconnect Specifications, which identify and assess specific features of the technology which are important to interconnecting the transportation layer entities. The AIS involves further specification of the renditions, and completes the description of the ITS Communications Architecture. To illustrate, mobile wireless packet data networks are considered a rendition. Several technologies, like CDPD, RAM, and so on, are specific technologies that belong to this rendition that could be used in the implementation. The AIS section here is kept brief, and includes a few examples of the results of the communication technology assessment (from an ITS architecture standpoint) which is summarized in Chapter 7 and detailed in Appendix D. The AIS leads to technology recommendations, to be interpreted as implementation examples of the communication elements in the ITS architecture. In a real-world ITS implementation, this last step would be performed by the communication system designer.

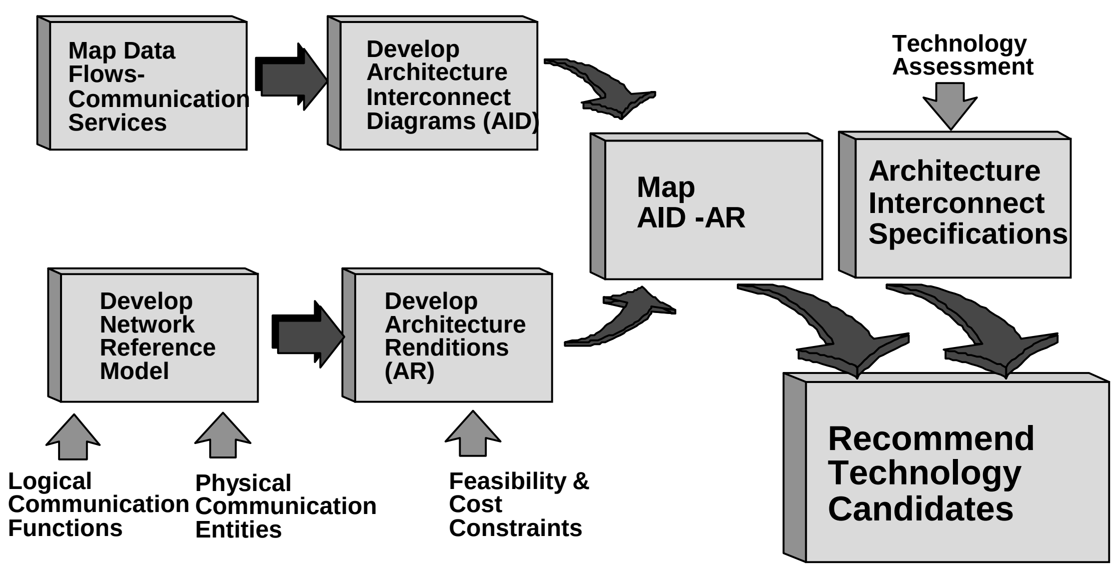


Figure 3.0–1 Communications Architecture Development Process

3.1 Communication Architecture

The generic communication hierarchical model presented in Figure 3.1-1 shows the relationship between the Transportation and Communication Layers. Each data user can be one entity in the Transportation Layer (e.g., the Information Service Provider Subsystem or Personal Vehicle Subsystem in an information exchange). The user does not care about and should not be concerned with the specifics of this information transfer layer. In fact, the Communication Layer can be viewed as plumbing that carries information from one user to another.

The complex makeup of the network is usually defined by system architectures developed to meet specific requirements, performance objectives, and socio-economic drivers. In the absence of crisp specifications and because of the jurisdictional-independence of this particular architecture, the end framework precludes the design of low level implementation details. However, to properly evaluate the communication architecture candidates, select technologies and detailed designs are recommended in an evaluatory design (see the later chapters of this document.)

The generic hierarchical communication model shown in Figure 3.1-1 follows the Open Systems Interconnection model which organizes the communication network in a highly structured format to reduce its overall design complexity. This model is structured as a series of layers each with the function of providing certain services to the layer above and capable of conversing with the corresponding layer at the other end of the link. Thus the high level layers (e.g., ITS application) are shielded from the actual implementation details of the communication services. Different networks can use layers different from the OSI model, such as the IBM SNA (Systems Network Architecture). When different protocols are used in different networks, an interworking function must provide the conversion between the protocols at the various levels.

The lowest layer in the OSI model is the physical layer (layer 1), which provides the transmission of bits over wires or radio links.

Layer 2 is the data link layer, which is concerned with making the link appear to the receiver as bit error-free as possible by implementing error detection and correction (EDAC) coding schemes in the transceiver. One example of this is the use of a cyclic redundancy code (CRC) to a block or frame of the data. When the data passes the CRC check at the receiver, the returned acknowledgment indicates whether re-transmission is needed.

Layer 3 is the network layer, which controls the operation of the network. Here, the key issue is routing packets, which are also used to generate billing information for the communications service provider (billing is tied to IP addresses).

Layer 4 is the transport layer, which mediates between the session layer and the network layer, providing end-to-end accounting (sequencing, non-duplication, etc.) for all the data at the receiving end. It also isolates the top layers from the changing physical technologies.

Layer 5 is the session layer, which allows users on different machines to establish communications, or sessions, between them. This involves ordinary data transport but with enhanced services such as remote log-in or file transfer.

Layer 6, the presentation layer, performs syntax and semantic operations on the information transmitted between the users, such as encoding data in a standard way, or compressing or encrypting that data.

Layer 7 is the application layer, which provides commonly used protocols for such tasks as terminal emulation, file transfer, electronic mail and remote job entry. (Note that for many ITS applications, layers 5 and 6 are absorbed into the application layer, layer 7.)

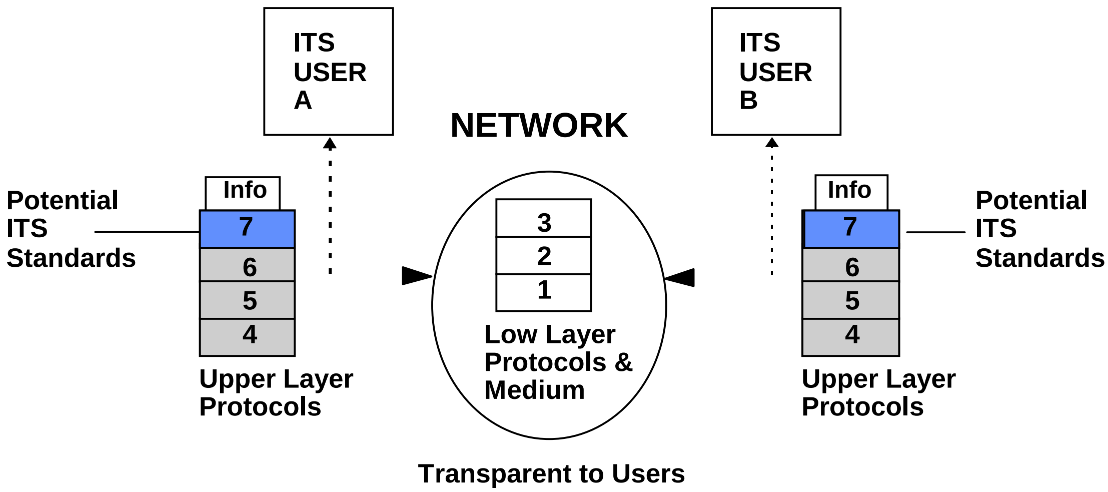


Figure 3.1-1 Generic Hierarchical Communication Model

From the Communication layer perspective, the term "services" is defined according to communications governing bodies (*e.g.*, ITU, TIA, etc.), and should be used with care. That is, when describing a communications architecture, one should not refer to Route Guidance or Pre-trip Planning as services. Rather, they are applications in need of a communication service. Elaborating more along these lines, ITS appears to the Communication Layer as a collection of applications with markedly different communication requirements. Thus the service provided by the communication model is characterized more by 1) the application's directionality requirements (*e.g.*, one-way or two-way) for information transport, 2) whether it is between mobile elements, mobile and stationary elements or stationary elements, 3) the amounts of data to be transported, and 4) the urgency rather than the precise description as Route Guidance or Pre-trip Planning.

The next section identifies various communication services to which the Transportation Layer data flows can be matched. Subsequently, a matching process will assign broad generic communication services to the ITS data flows without specifying a particular technology.

3.1.1 Communication Services

The communication services define the exchange of information between two points and are independent of the media and application (i.e., ITS user service). In essence, they are a specified set of user-information transfer capabilities provided by the communication layer to a user in the transportation layer. Figure 3.1-2 illustrates the hierarchy of communication services. A brief description of the services is presented below; more detailed information is given in Appendix A.1.

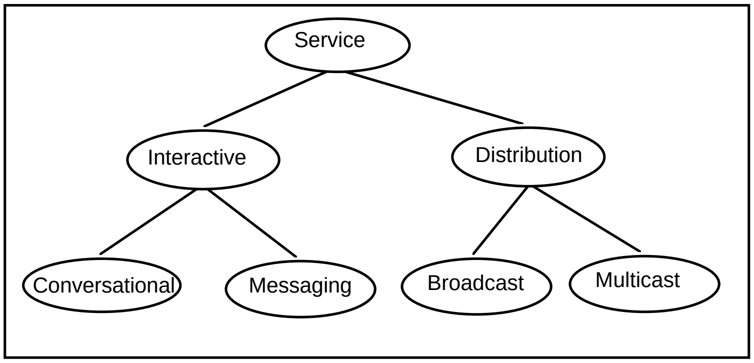


Figure 3.1-2 Communication Services Hierarchy

Communication services consist of two broad categories, interactive and distribution. Interactive services allow the user to exchange data with other users or providers in real or near real time, asking for service or information and receiving it in the time it takes to communicate or look up the information. Distribution services allow the user to send the same message to multiple other users.

Interactive services may be either conversational or messaging. Conversational implies the use of a two-way connection established before information exchange begins and terminated when the exchange is completed. Messaging, on the other hand, works more like electronic mail being exchanged between users. The messages are exchanged without establishing a dedicated path between the two sites. Each message is addressed and placed on the network for transmission, intermixed with messages from other users. The communications community labels this mode of communication a “datagram” service.

Distribution services may be either broadcast or multicast and may be used over wireline and/or wireless communication links. Broadcast messages are those sent to all users while multicast messages are sent only to a subset of users. Multicast differs from broadcast in its use of a designated address for all users and user groups. Examples of broadcast information might include current weather or road conditions, whereas multicast information might be information sent to all drivers working for a specific company. A changing group membership could be the set of users traveling between two locations or with a certain destination, for which unique information must be transmitted. The services that can be supported using circuit or packet connection mode include voice, video, image and data. (see Appendix A.1 for a complete description.)

Not shown in the Figure 3.1-2 are location services. These fall in two categories: (1) the services that do not use the communication network (i.e., GPS, and stand alone terrestrial systems); (2) location services that use the network for providing the service (e.g., cellular based systems). In the latter case, the location services fall under the interactive services. The service will be rendered by a service provider in response to a request for information or help. (See detailed description in Appendix A.1).

3.1.2 Logical Communication Functions

Based on the objectives of the communication architecture, a list of logical functions to support the ITS system communication requirements are identified. The primary logical communication functions can be confined to: wireless and wireline access, switching, routing, registration authentication, interworking, validation, billing, and operations (see Appendix A.2 for a detailed description).

3.1.3 Functional Entities

The functional entities that make up the communication layer were derived from existing and emerging infrastructure specifications and standards (*e.g.*, TIA, ITU, Bellcore, ANSI). These basic building blocks form the foundation of a generic communication system. As with the transportation layer, each functional entity consists of one or more logical functions. These entities include: 1) user device, 2) user profile module, 3) switch, 4) wireless controller, 5) wireless base station, 6) interworking platform, 7) profile data base, and 8) wireline network. A detailed description of these functional entities is presented in Appendix A.3.

3.1.4 Communication Network Reference Model

As shown previously in Figure 3.0-1, the communication architecture design process consists of several steps. The previous sections listed the communication logical functions and physical entities. The architecture design process now starts on the lower leg of Figure 3.0-1 with the development of the Communication Network Reference Model. This model provides an architecture or structure that shows how various communication technologies can implement the Architecture Interconnect Diagrams developed in the next section.

The network reference model for ITS is depicted in Figure 3.1-3, and is a generic abstraction which builds upon several reference models developed for standard commercial systems. Boxes represent the various physical equipment (with descriptive uppercase letters) that perform the communication functions. The interfaces that are important to ITS are identified by lowercase letters (s, v, u_1, u_2, u_3).

- s signifies a plug-in, smart card interface.
- v signifies any kind of wireline connection (for instance, RS-232) or even a bus if the UT and WT are integrated.

The most important reference point is the wireless interface (u) connecting the WBS and the wireless transceiver. To meet the objectives of the national ITS Architecture it will be necessary in some cases for the air interface to be standard. The wireless portion (u) of the architecture is manifested in three different ways: u_1, u_2, u_3. Each interface corresponds to one of the wireless manifestations as follows:

- u_1 defines the wide area wireless airlink with one of a set of base stations providing connections to mobile or untethered users. It is typified by the current cellular telephone and data networks or the larger cells of Specialized Mobile Radio for two way communication, as well as paging and broadcast systems for one way communication.
- u_2 defines the short-range airlink used for close-proximity (typically less than 50–100 feet) transmissions between a mobile user and a base station, typified by transfers of vehicle identification numbers at toll booths.
- u_3 addresses the vehicle-vehicle (AHS-type) airlink, for high data rate, burst, usually line-of-sight transmission with high reliability between vehicles where standards are in their infancy. Note that the wide area wireless (U1) interface encompasses both two-way (U1t) and broadcast (U1b) as shown in Figure 3.1-4.
- b, c, d, and e correspond to well-established wireline interfaces as documented in Section 7.5.2.

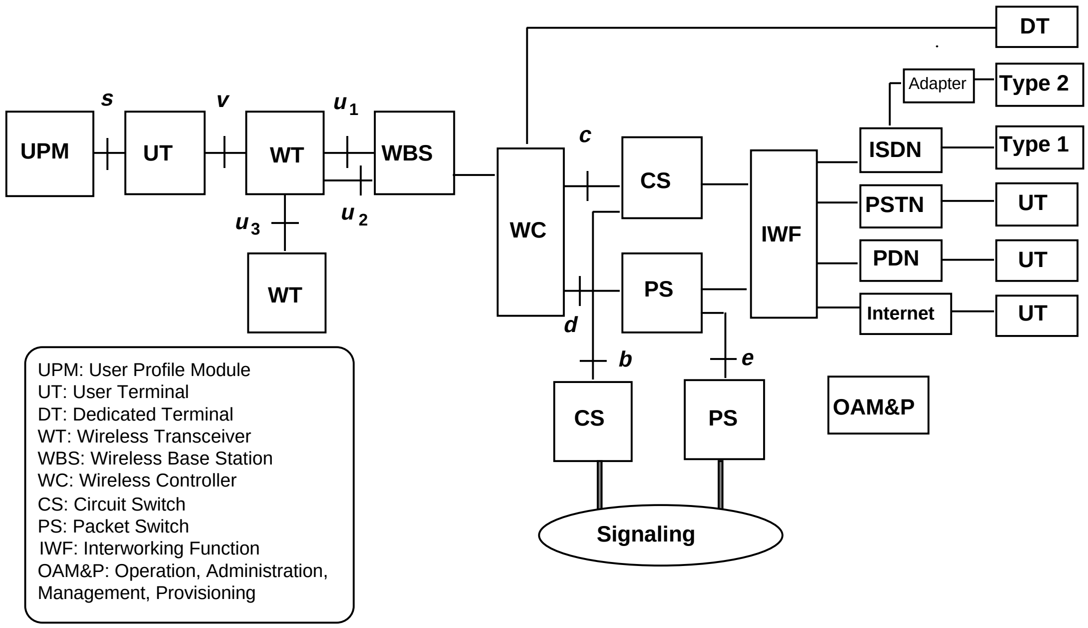


Figure 3.1.-3 Network Reference Model for the Communications Layer

The National ITS architecture provides for implementation flexibility. Various of the data flows in the Architecture can be carried over a multiple of these interfaces, and the final choices would be made by the local implementors. This flexibility is depicted conceptually in Figure 3.1.-4.

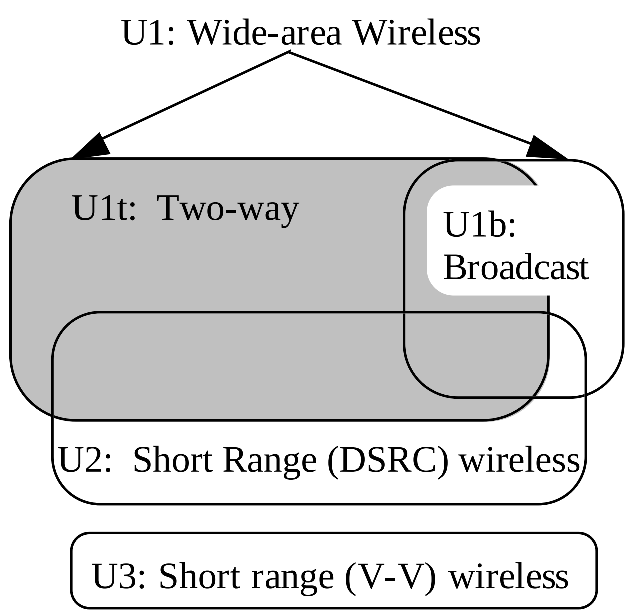


Figure 3.1-4 Implementation Flexibility of ITS Architecture Data Flows

Since the wireline segment encompasses standard wireline configurations, the ITS-critical elements from a standards perspective are those comprising the wireless portion on the left side of Figure 3.1-3. The wireless portion consists of the User Profile Module (UPM), the User Terminal (UT), the Wireless Transceiver (WT) and the Wireless Base Station (WBS). The connections through the Dedicated Terminal and various User Terminals are shown in the column of boxes on the right. The equipment in the center is the existing public telecommunications services, so the details are transparent to ITS, which is a major benefit to the ITS community. *All management, operations, expansion, and improvement costs are shared with the wider set of all telecommunications users.*

This is an important point to jurisdictions and agencies who prefer to procure and trench their own network along the right-of-way. Whereas a financial sensitivity analysis may point to a private solution, it frequently does not fully consider the large and sustained Operation, Administration, Management , and Provisioning (OAM&P) fees that the agency will have to pay the telecommunications vendor during the system's life cycle.

Appendix A.4 presents a detailed description of the wireline side of the above network reference model, in addition to a more thorough treatment for required interfaces such as switches, controllers, and terminals. Appendix A.4 also presents the network entities, interfaces, and signaling plane, and includes a discussion on circuit connection and data packet transmission.

3.2 Communication Layer Linkage

This Communication Layer Linkage section further identifies the relationship between the Transportation Layer and Communication Layer definitions. This is accomplished by mapping the communication services to the data flows identified in the Transportation Layer, generating the Architecture Interconnect Diagrams (AIDs), identifying the Architecture Renditions (ARs), mapping the AIDs to the ARs, and finally identifying the Architecture Interconnect Specifications (AISs) based on the technology assessment.

3.2.1 Mapping Communication Services to Data Flows

Mapping of the communication services to the data flows establishes the first link between the transportation layer and the communication layer. This initial link depends on the completion of two technical architecture milestones. First, the message sizes and data transfer requirements are broadly identified. Second, the physical architecture that allocates logical functions (see Logical Architecture Document) to subsystems necessitates a partitioning exercise which defines the data flows that require communication. This mapping is an iterative procedure that is calibrated by feedback from the logical and physical architectures (and in turn the ITS stakeholders) by retracing the steps shown in Figure 3.0-1.

Appendix A.5 details the mapping process. It also depicts the assigned communication service for each data flow with the corresponding rationale.

3.2.2 Architecture Interconnect Diagrams

As denoted in Figure 3.1-1, this section presents the development of the Architecture Interconnect Diagrams (AIDs). These diagrams show the subsystem-to-subsystem communication interfaces of all transportation subsystem entities (defined in the transportation part of the Physical Architecture). The diagrams identify the communication mode and partition, either wireline or one of three types of wireless connection, as well as documenting the rationale for each of these choices when needed for clarification. The diagrams identify the requirements, developed from the physical relationships of the various subsystem entities, but do not advocate any specific communication technology to be used. The information contained in the AIDs can be traced to the information provided in the Data Flow-Communications Service Mapping Table (Appendix A.5).

A template is used to illustrate the interconnections between entities and between modules (described in the next sub-section). At this stage in the physical architecture, no AIDs are defined for inter-module information transfer within a simple entity. In fact, from the communication layer perspective, this is not necessary. The most important goal is to identify the inter-entity interconnectivity.

The subsections that follow describe the AID template, and present the Level 1 and Level 0 (top level) AID’s.

3.2.2.1 AID Template

As depicted in Figure 3.2-1, each AID shows the two communicating transportation subsystem entities, the interconnection partition (i.e., wireline, wireless, or both), and a characterization of the interconnection. The latter is not a link-specific description, which the AIS provides, but a high-level interpretation in terms of services and operation modes. When not obvious, the choice of operation mode is based on the rationale provided in Table 3.2-1. The interconnect description for each AID provides a data flow and a service and operation mode description for each data flow between the two entities. The Data Flow information also provides directionality when more than one data flow exists between the entities, not all of which are in the same direction. If all the data flows are in the same direction, no indication is given and the data flows from the left entity to the one on the right.

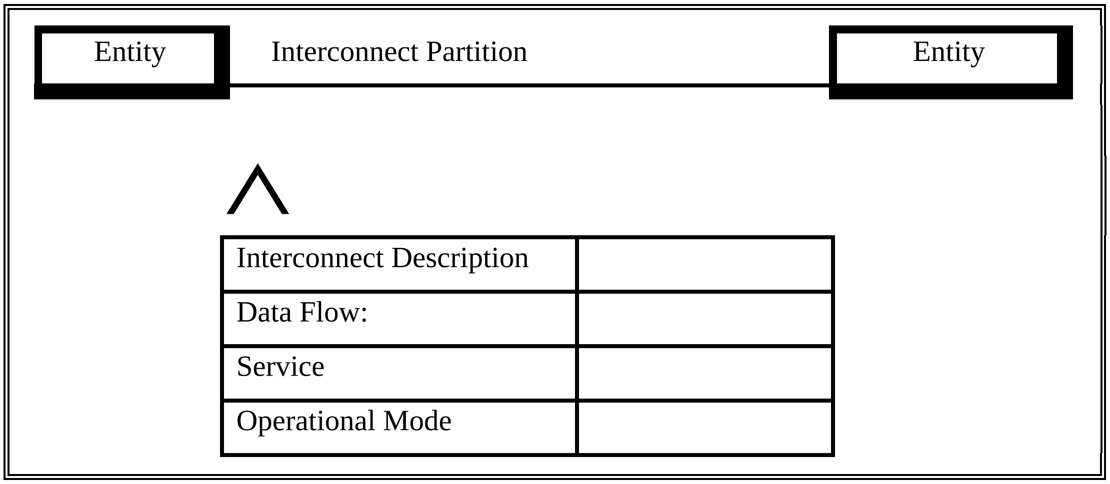


Figure 3.2-1. Template for the Architecture Interconnect Diagram (AID)

3.2.2.2 Level 1 AIDs

Using the AID template and Table A.5-1, Data Flow – Communication Services Mapping Table (located in Appendix A of this document), the data flows are represented in an Architecture Interconnect Diagram (AID) format. A single example is presented here in Figure 3.2-2, and various others are compiled in Appendix B.

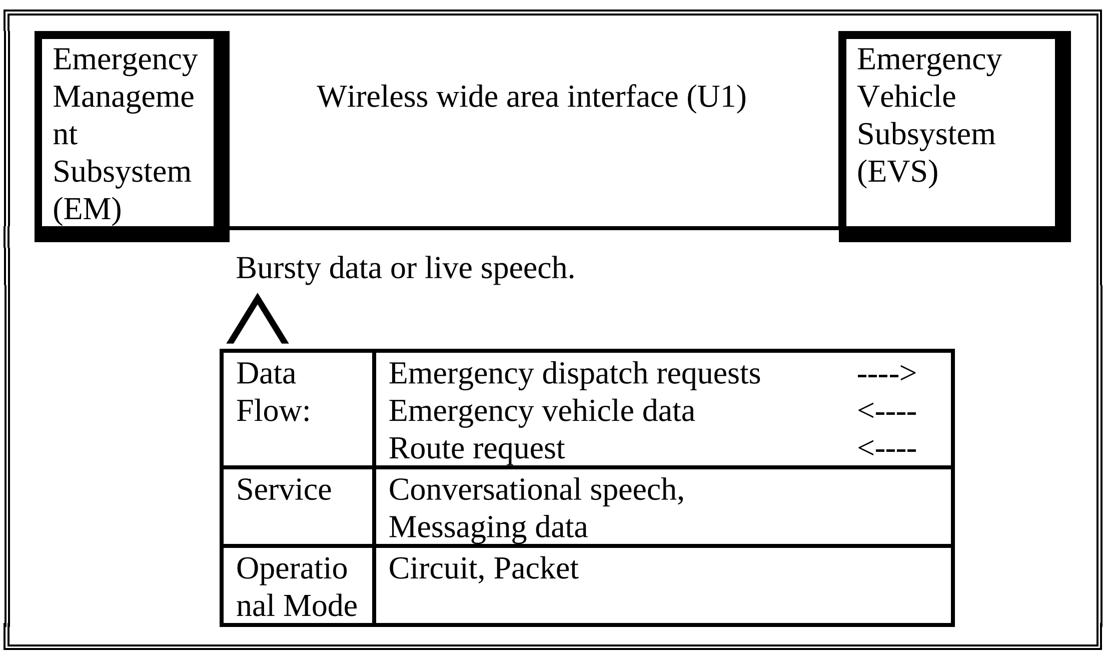


Figure 3.2-2 Example of AID Level-1

3.2.2.3 Level 0 AID

Figure 3.2-3, shows the Level 0 Architecture Interconnect Diagram (AID). The level 0 AID is a percolation to a top level of all the detailed, level 1 AID's. It presents the all the interfaces between the physical subsystem entities, capturing the wireline (*w*) or wireless (u_1, u_2, or u_3) nature of the interfaces in the ITS architecture. As such, it is a comprehensive, albeit not complete, representation of the ITS communication architecture. More detailed variations can be easily derived from it. For example, Figure 3.2-4 shows the data flows using the u1b wide area wireless broadcast "sub-interface". Figure 3.2-5 shows the subset that uses either of u1t (two-way wide area wireless) or u1b (wide area wireless broadcast). Note that u1b does not imply a certain technology. FM subcarrier, paging, and messaging data networks are possible implementations and they all tend to use a broadcast protocol in the forward, i.e.; fixed to mobile, direction.

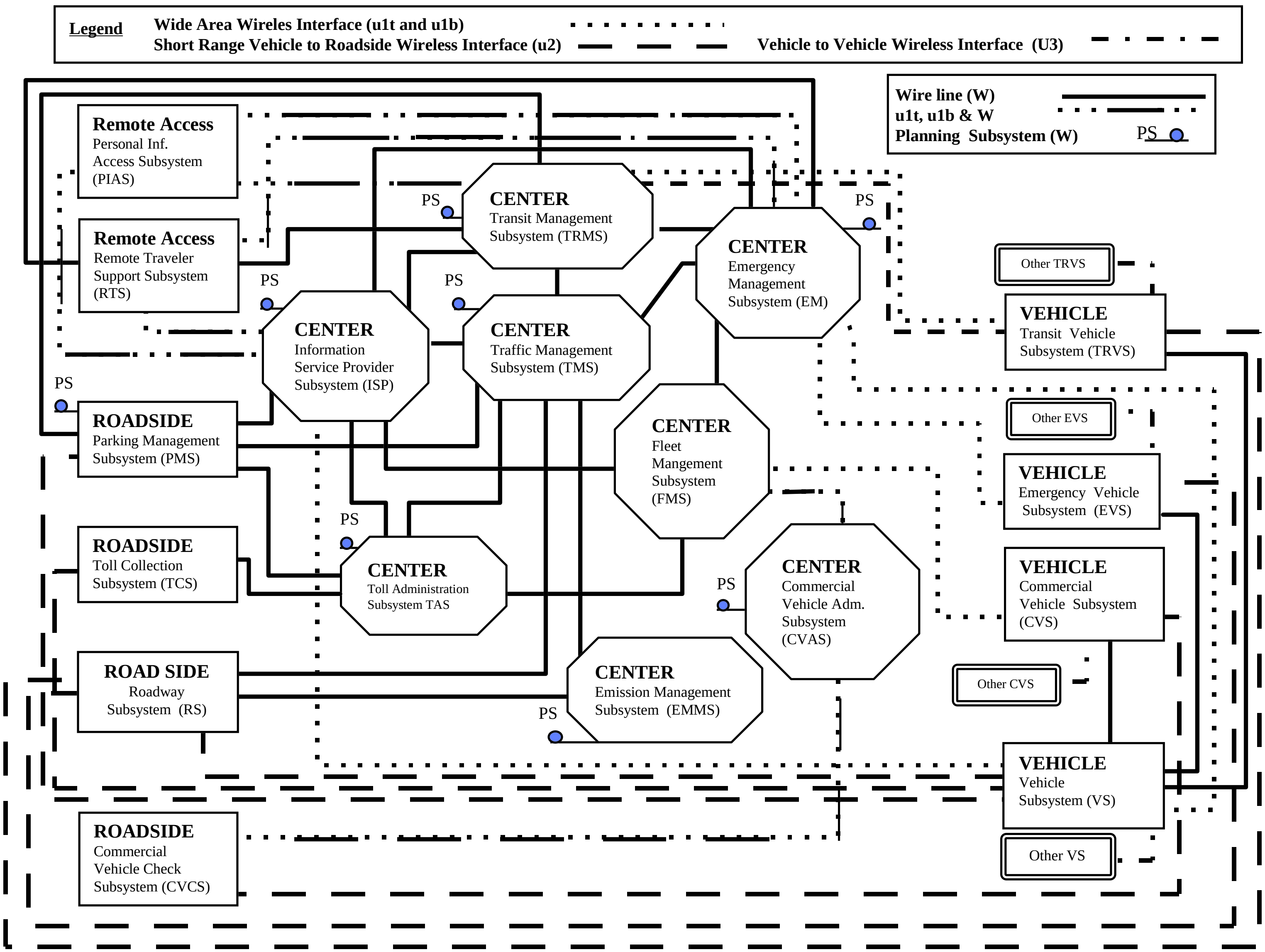


Figure 3.2-3 Level 0 Architecture Interconnect Diagram for the National ITS Architecture

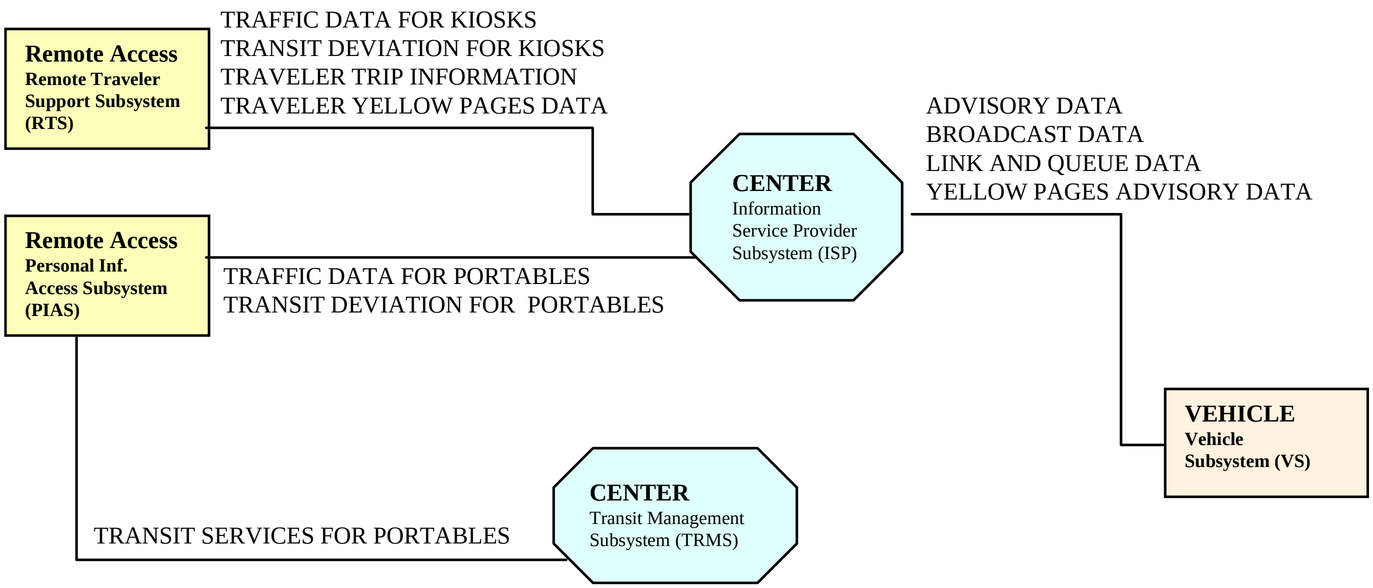


Figure 3.2-4 Level 0 Architecture Interconnect Diagram for the National ITS Architecture

(Subset showing U1b data flows)

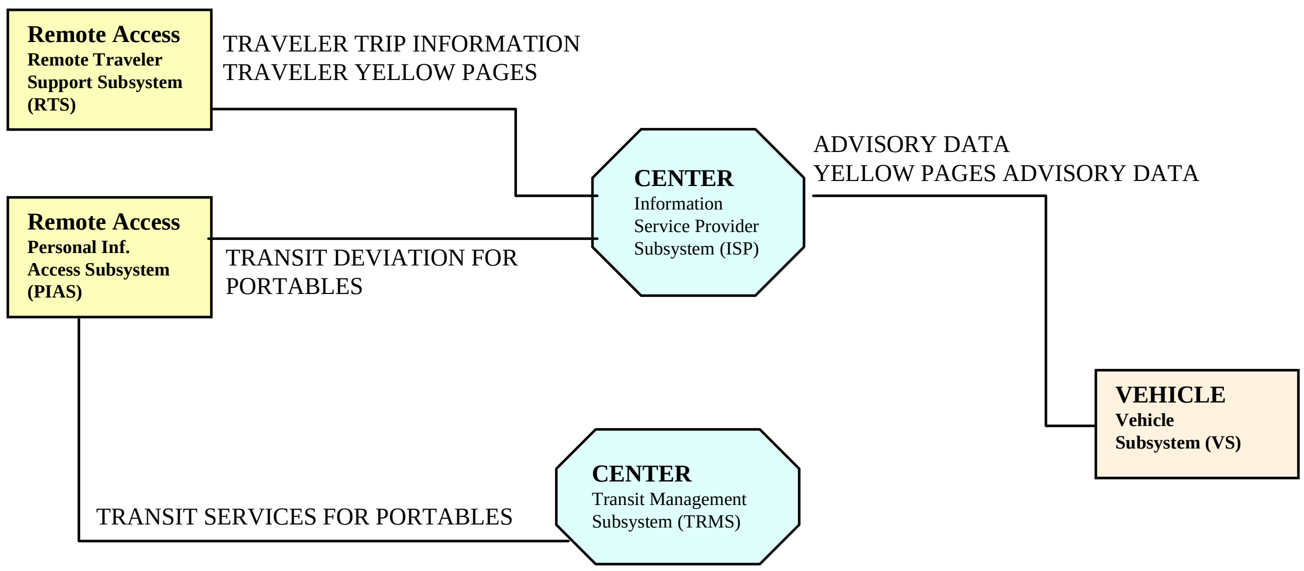


Figure 3.2-5 Level 0 Architecture Interconnect Diagram for the National ITS Architecture;

(Subset showing data flows using either U1t or U1b)

3.2.3 Architecture Renditions

The next step in the communications architecture design process is the development of the communication Architecture Renditions, as depicted in Figure 3.0-1. Combining elements from the Generic Heirarchical Communication Model (Figure 3.1-1) and the ITS Communication Network Reference Model (Figure 3.1-3) provides a more detailed view of the flow of information between two users. This information includes communication services and operational modes (i.e., circuit switched, packet switched, etc.). The architecture renditions are essentially examples of how to provide connections between users based on the communications network reference model and the evaluations of classes of feasible implementations.

Two levels of renditions are generated. A Level 1 rendition is generated for each of the possible interconnections between services. The Level 0 Rendition (the top level) shows the full connectivity between users over multiple links. The details of the renditions, how they are generated, and those that apply to the different interconnections in the architecture are provided in Appendix C. An example of a Level-1 rendition and the Level-0 will be provided here to support the subsequent task of AIS generation.

3.2.3.1 Level 1 Rendition

Figure 3.2-6 depicts Level 1 renditions for the two-way wide-area wireless communication link (u_1) through switched networks. This figure depicts interconnection between tetherless users or tetherless and stationary users, utilizing two distinct classes of two-way wide-area wireless technologies. Several technologies or systems can fit within each rendition. For example, CDPD, RAM, ARDIS and so on are possibilities for implementing the packet-switched wireless data network rendition (shown on the right-hand-side of the diagram in Figure 3.2-6).

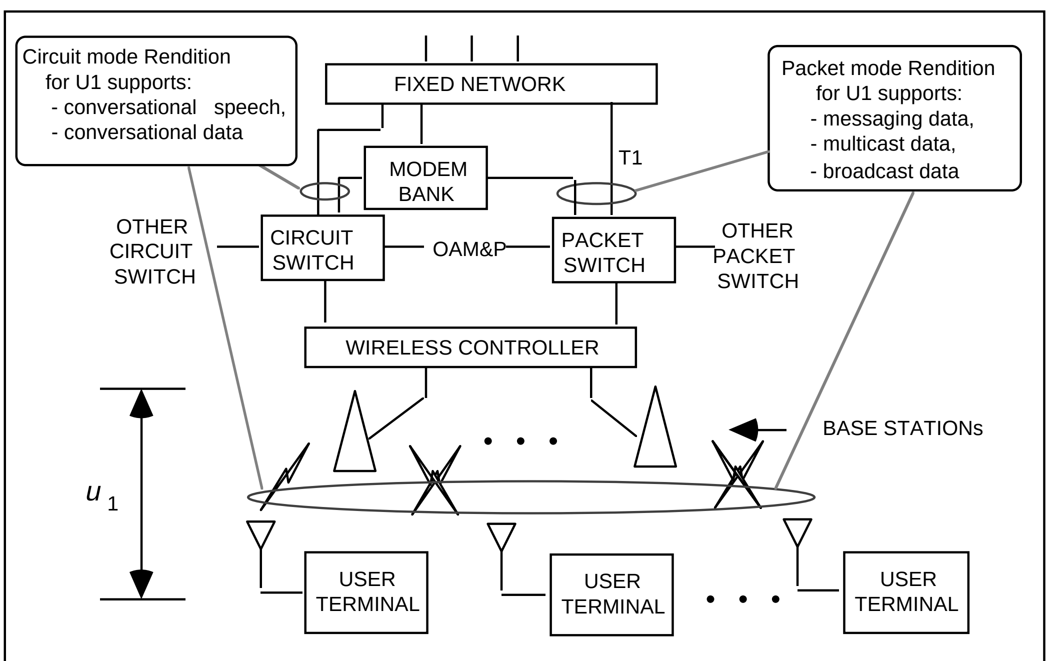


Figure 3.2-6 Rendition 1 — Wide-Area Wireless (u1) Link Through Switched Networks

Figure 3.2-7 depicts the rendition for wide area one way wireless link u_{1b}. It uses broadcast systems which include paging and FM subcarrier technologies for transmitting data to subscribers over the paging and FM frequency channels, respectively.

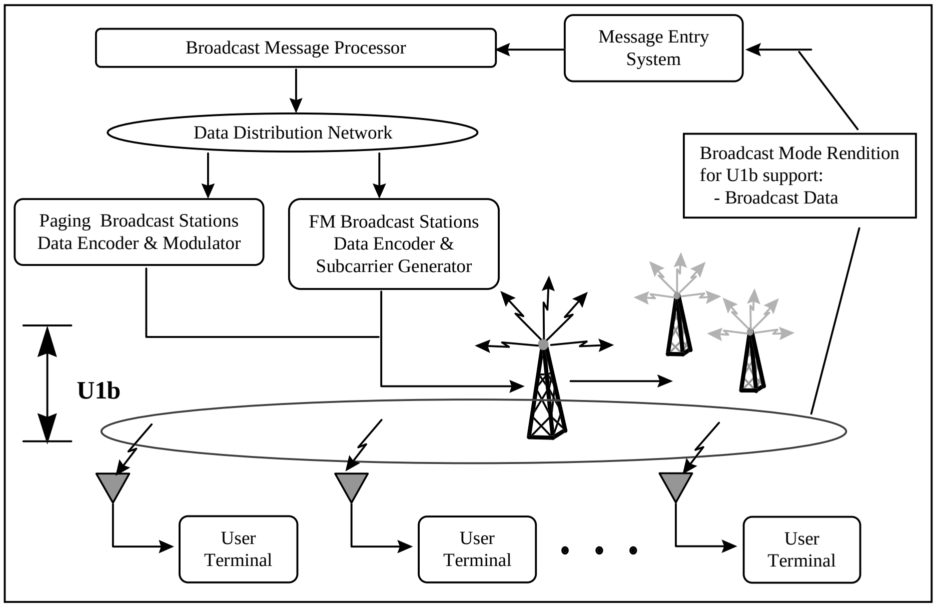


Figure 3.2-7 Rendition 1 for Wide-Area One-Way Wireless (u1b) Links

3.2.3.2 Level 0 Rendition

Figure 3.2-8 illustrates the Level 0 rendition. It represents a composition of all the renditions to reflect the combined needs of the architecture. This rendition shows a user communicating to another user, central office or a base station over various communication links such as u_1, u_2, u_3 and w. Again, the details of this mapping are provided in Appendix C.1.1.

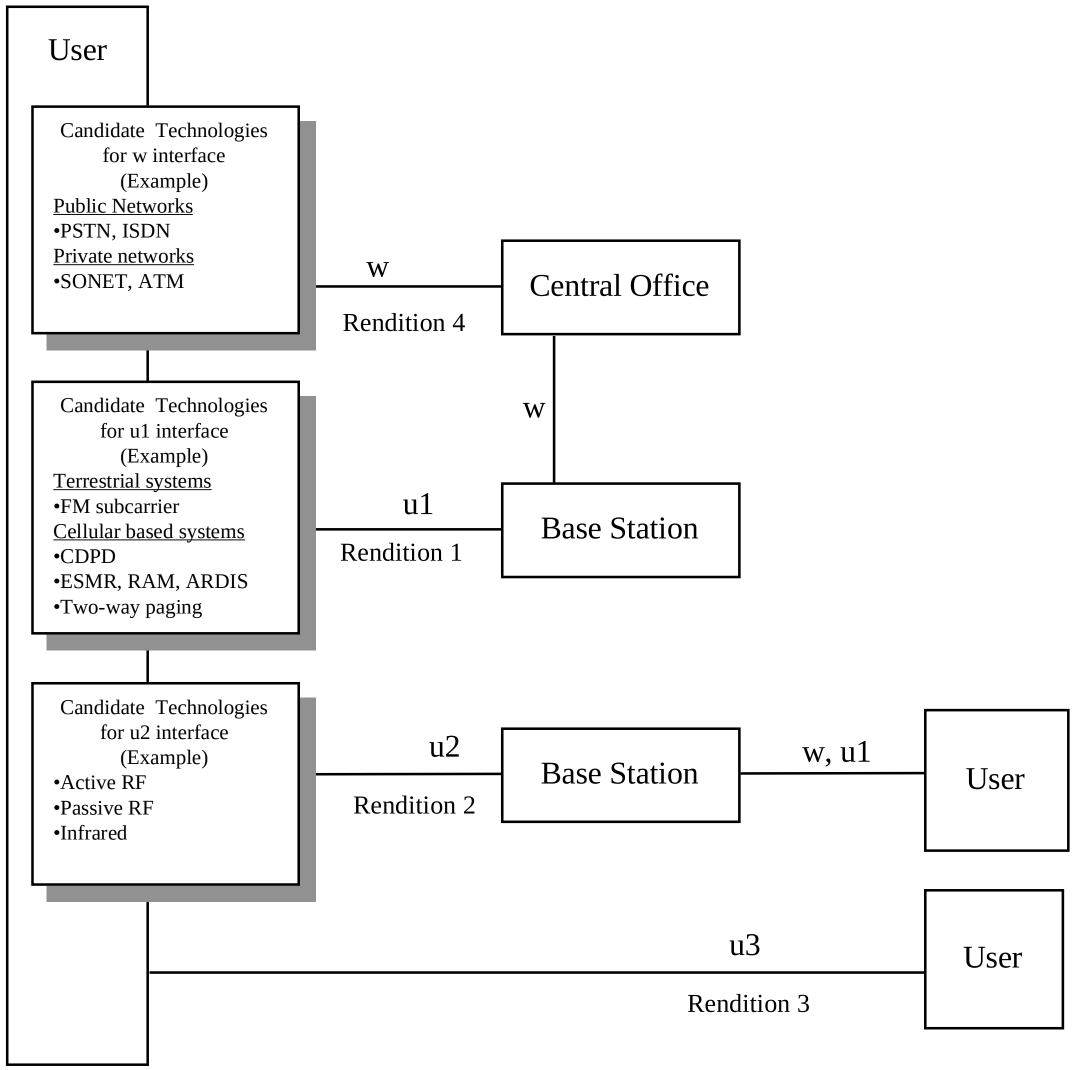


Figure 3.2-8 Level 0 Rendition

3.2.4 Architecture Interconnect Specifications

The Architecture Interconnect Specifications (AISs) are now developed from the technology assessment and refined by combining the renditions with applicable technologies and evaluating the achievable performance (Figure 3.0-1). This involves mapping the applicable communication technologies to the renditions.

To facilitate the mapping of the communication technologies to the renditions, the candidate wireless and wireline technologies are surveyed. The candidate technologies are further assessed and their performance is evaluated from the National ITS Architecture standpoint. For example, the assessment includes: short range and wide area, one-way and two-way wireless data communication. Systems analyzed include terrestrial networks (e.g., cellular, ESMR), FM broadcast, and satellite systems for mobile and fixed services. The details of this survey, as well as the sources of information, are presented in Appendix D; the assessment results are summarized in Chapter 7.

The results of this assessment are used in identifying the candidate technologies to support level 0 and level 1 renditions. The results of this mapping are summarized below.

It is apparent from the matrices provided in the Technology Assessment Section (Section 7.5) that for the foreseeable future, wireless data networks (such as CDPD, RAM, etc.) form the class of communication systems most suitable to interactive wide area wireless ITS links (u1t). The infrastructure is already largely available (short, in some areas, of adding the appliqué equipment). Service costs are already low, and equipment costs are coming down. Coverage nationally is excellent with the possible shortcoming that it may not be available for some time in rural and remote areas. Yet, with the advent of innovative solutions like circuit-switched CDPD – which utilizes the AMPS cellular infrastructure in a manner transparent to a CDPD subscriber – this problem would be largely mitigated. In any event, for ITS users who insist on uninterrupted coverage in remote areas, holes in the coverage of terrestrial cell-based systems can be supplemented by satellite communication systems.

Figure 3.2-9 depicts the use of CDPD in a u1 communication architecture rendition to create an example of Architecture Interconnect Specification.

According to internal market research and analysis, users are concerned with two overshadowing factors: cost and quality. The Architecture Development Team believes that the market will determine the winning technologies which will gain wide scale acceptance.

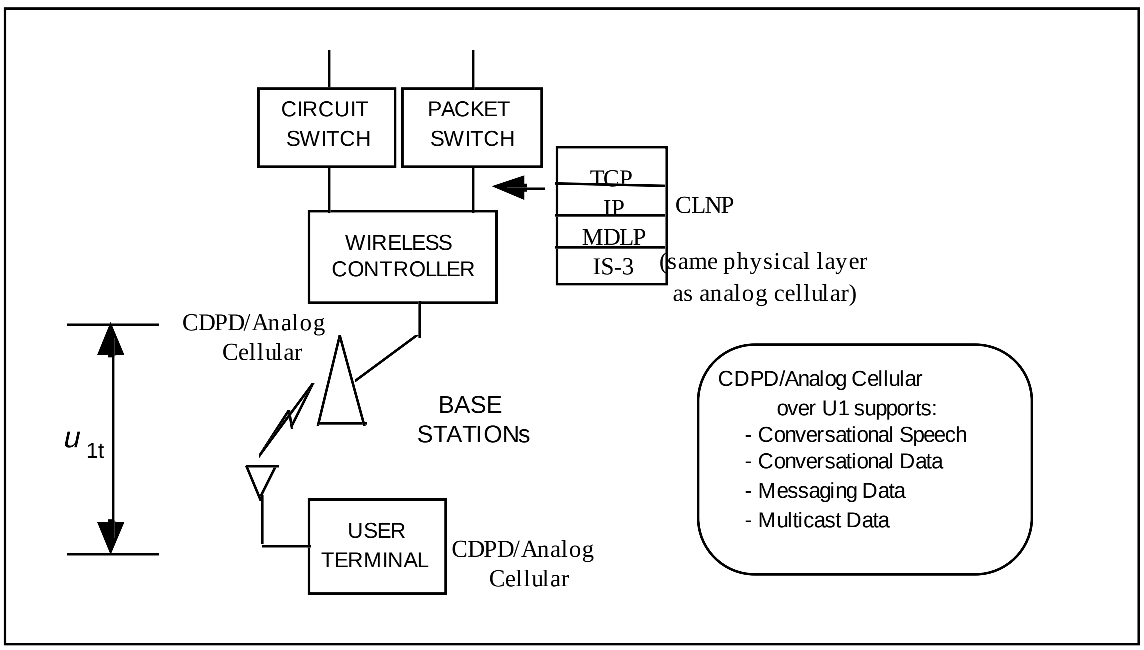


Figure 3.2-9 AIS Example Using CDPD for Wide Area Wireless (u1)

Table 3.2-1 provides an illustration of candidate technologies for the different wireless data flows within the context of the communication layer of the ITS Architecture. In addition to wireless data networks, for wide area ITS data flows, the short range wireless interface u_2 comprises a distinct set of communication services and supporting radio technologies. In a real world ITS implementation, the system designer makes use of the technology assessments of Chapter 7, and the ITS architecture communication renditions presented above, to select the specific communication systems/technologies most appropriate for the deployment at hand.

Table 3.2-1 Examples of Candidate Technologies for Wireless Data Flows

u1t - Packet switched wireless data (e.g., CDPD, RAM, ARDIS) for wide-area wireless interface (messaging services; bursty data transfers)		
Source	**Architecture Flow**	**Destination**
CVAS	**Electronic credentials**	FMS
CVAS	**Safety information**	CVCS
CVS	**Driver & vehicle information**	FMS
CVS	**On board vehicle data**	FMS
EM	**emergency dispatch requests**	EVS
EM	**emergency acknowledge**	VS
EM	**emergency acknowledge**	RTS
EM	**emergency acknowledge**	PIAS
EVS	**Emergency vehicle driver status update**	EM
EVS	**Emergency vehicle driver input**	EM
EVS	**Emergency vehicle dispatch acknowledge**	EM
FMS	**fleet to driver update**	CVS
PIAS	**Demand responsive transit request**	TRMS
PIAS	**Traveler information request**	ISP
PIAS	**Emergency notification**	EM
RTS	**Emergency notification**	EM
TRMS	**Demand responsive transit request**	PIAS
TRMS	**Request for vehicle measures**	TRVS
TRMS	**Route assignment**	TRVS
TRVS	**Emergency notification**	TRMS
TRVS	**Vehicle probe data**	TRMS
TRVS	**Traveler information request**	TRMS
VS	**vehicle probe data**	ISP
VS	**emergency notification**	EM
VS	**Traveler information request**	ISP
VS	**map update request**	X23

u1t - Circuit switched wireless data (e.g., Cellular, ESMR) (Messaging; larger data transactions, e.g., compressed image)		
Source	**Architecture Flow**	**Destination**
ISP	**Traveler information**	PIAS
ISP	**Traveler information**	VS
X23 MAP Update Provider	**Map updates**	PIAS
X23 MAP Update Provider	**Map updates**	VS

u1t - Circuit Switched Voice (e.g., Cellular, SMR)
(live voice interaction; early implementations)

Source	Architecture Flow	Destination
EM	**Assigned route**	EVS
EM	**Hazmat information**	EVS
EM	**Emergency dispatch requests**	EVS
EM	**Emergency status**	RTS
EVS	**Emergency vehicle dispatch acknowledge**	EM
EVS	**Emergency vehicle driver input**	EM
RTS	**Emergency notification**	EM
VS	**Emergency notification**	EM

u1b - Broadcast (subcarrier or paging-type) services
(Broadcast of free services and services that require subscription; e.g., traveler information,)

source	Architecture Flow	destination
ISP	**Broadcast information**	PIAS
ISP	**traveler information**	VS
ISP	**broadcast information**	VS
ISP	**broadcast information**	RTS

u1t - Packet switched wireless data multicast Services (Distribution services that require subscription; e.g., map updates)

source	Architecture Flow	destination
ISP	**traveler information**	PIAS
ISP	**traveler information**	VS
ISP	**broadcast information**	VS
ISP	**broadcast information**	RTS
X23 MAP update provider	**map updates**	PIAS
X23 MAP update provider	**map updates**	VS

u2 - beacon for close-proximity wireless communication between vehicle and roadside

Source	Architecture Flow	Destination
CVS	**Border crossing ID**	CVCS
CVS	**on board safety data**	CVCS
CVCS	**safety inspection record**	CVS
CVCS	**Pull in message**	CVS
EVS	**Emergency vehicle preemption request**	RS
PMS	**Tag update**	VS
RS	**AHS control data**	VS
RS	**roadway signage data**	VS
RS	**intersection status**	VS
TCS	**Request tag data**	VS
TRVS	**signal priority request**	RS
VS	**Tag data**	TCS
VS	**AHS vehicle data**	RS
VS	**Tag data**	PMS

4. SCENARIOS AND TIME FRAMES

Three scenario regions will be studied (Urbansville, Thruville, and Mountainville), for three time frames (1997, 2002, and 2012). These nine total scenarios were modeled through the use of government-supplied information, along with statistical data and assumptions related to the evaluatory design that is a subset of the National ITS Architecture definition effort.

The goal of this part of the modeling task is to determine the number of users of each of the user service groupings defined for the data loading analysis task. In most cases, this is the number of vehicles because most of the messages are handled per vehicle. The exception is the traveler information user (PIAS user) service group where no user vehicle is involved.

Because communications systems must be designed for the peak load, the important number of users to be derived is that for the peak period. The off-peak period number will be defined as a fraction of the peak period number.

4.1 Evaluatory Design

The evaluatory design is a candidate ITS deployment with a set of assumptions for the number of users and vehicles, and the number of centers, sensors, etc. The important assumptions in the wireless data loading are the number of vehicles and users for each of the user service groups. The total set of assumptions for the evaluatory design are contained in the Evaluatory Design Document.

4.2 Baseline Information for the Scenario Regions

The information supplied by the Government on the nine scenario regions and time frames includes the regional population and number of household vehicles. This information was used along with national statistical data to derive the number of vehicles or users that are potential users of ITS services by user service category within each scenario. Table 4.2-1 lists the supplied population and vehicle data.

Table 4.2-1 Supplied Population and Household Vehicle Data

Region	Time Frame	Population	Household Vehicles
Urbansville	**1997**	2814950	1688970
Urbansville	**2002**	3106674	1842105
Urbansville	**2012**	3788627	2273176
Thruville	**1997**	1005185	851272
Thruville	**2002**	1055445	893836
Thruville	**2012**	1166015	987476
Mountainville	**1997**	17480	6735
Mountainville	**2002**	17920	6904
Mountainville	**2012**	18845	7260

4.3 Number of Potential Users by User Service Group

In order to enhance the understanding of the data loads generated by ITS services, the analyses were performed for seven distinct user service groups, each with its own population, message set, peak period definition, and message frequency of use. The user service groups include private vehicles, CVO-Local vehicles, CVO-long haul vehicles, travelers (PIAS users), transit management, emergency management, and probes.

The number of potential users that might buy a service was determined for each of the nine scenarios through the use of national statistics. The methods used are shown in detail in Appendix E. The numbers are the same as those found in the Evaluatory Design Document.

The lack of a particular service (e.g., fixed route transit in the rural scenario) was handled later in the data loading models with the lack of an entry in the database table of market packages of services for that scenario, preventing messages related to that service from being included in the message set for that scenario. This process is defined in Section 5.3, as it defines the available message set for that scenario.

In the case of the Thruville scenario, the added traffic traveling completely through the entire scenario region must be added to the model. This was modeled by increasing the number of private vehicles and CVO long haul vehicles that would be expected from the resident population (as derived from national statistics) by one-third. The other user service groups do not travel beyond the scenario region by definition.

The number of potential users was derived for the peak period defined for that particular user service group. The number of potential users for the off-peak period was then defined as a fraction of the peak period number.

Number of Potential Users Summary

Table 4.3-1 shows the summary of the number of potential users for each of the nine scenarios. These are the same values as in the Evaluatory Design Document.

Table 4.3-1 Number of Potential Vehicles or Users for Each of the Seven User Service Groups and Each of the Nine Scenarios.

	Pr. Veh.	CVO-LH	CVO-Lo.	Trav.	Transit	Emerg.	Probes
Urbans. 1997	760037	5797	81155	200750	1661	4444	7704
Urbans. 2002	828947	6397	89565	262920	1833	4850	7704
Urbans. 2012	1022929	7802	109226	432310	2235	5981	7704
Thru. 1997	383072	2753	28979	99610	593	2128	3900
Thru. 2002	402226	2891	30428	125500	623	2319	3900
Thru. 2012	444364	3194	33616	184870	688	2562	3900
Mount. 1997	3031	36	504	830	0	7	800
Mount. 2002	3107	37	517	1010	11	7	800
Mount. 2012	3267	39	543	1420	11	8	800

4.4 Penetrations

A penetration factor was applied to each of the potential number of users figures to arrive at the actual number of users. The penetrations were applied by market package for the 1997, 2002, and 2012 time frames. These penetrations are from the Evaluatory Design Document, using the “high” penetration estimate for the equipment package most appropriate for that market package. The penetration factors for market packages by time frame are shown in Table 4.4-1. Each of the seven user service groups was allowed access to any of the market packages that were of use to them. The penetration is applied to the frequency of use value that is assigned later to each message for each user service group to account for the variations in the amount of usage that might occur in the user service groups. The result is that the messages each have a penetration value associated with them. There is not simply a single penetration value for an entire user service group.

Table 4.4-1 Penetration Factor by Market Package and Time Frame

Market Package Name 1997	2002	2012	
Transit Vehicle Tracking	0.33	1	1
Transit Fixed-Route Operations	0.66	1	1
Demand Response Transit Operations	0.66	1	1
Transit Passenger and Fare Management	0.66	1	1
Transit Security	0.33	1	1
Transit Maintenance	0.66	1	1
Multi-modal Coordination	0.66	1	1
Broadcast Traveler Information	0.03	0.1	0.5
Interactive Traveler Information	0.01	0.1	0.2
Autonomous Route Guidance	0.01	0.1	0.2
Dynamic Route Guidance	0.01	0.1	0.2
ISP Based Route Guidance	0.01	0.1	0.2
Integrated Transportation Management/Route Guidance	0.01	0.1	0.2
Yellow Pages and Reservation	0.01	0.1	0.2
Dynamic Ridesharing	0.01	0.1	0.2
In Vehicle Signing	0	0.01	0.05
Network Surveillance	0.004	0.02	0.05
Probe Surveillance	0.004	0.02	0.05
Surface Street Control	0.2	0.5	0.9
Freeway Control	0.75	1	1
HOV and Reversible Lane Management	0.07	0.2	0.4
Traffic Information Dissemination	1	1	1
Regional Traffic Control	0	0	1
Incident Management System	1	1	1
Traffic Network Performance Evaluation	0.5	1	1
Dynamic Toll/Parking Fee Management	0.5	0.75	1
Emissions and Environmental Hazards Sensing	1	1	1
Virtual TMC and Smart Probe Data	0.004	0.02	0.05
Vehicle Safety Monitoring	0.02	0.2	0.5
Driver Safety Monitoring	0	0.05	0.25
Longitudinal Safety Warning	0	0.02	0.15
Lateral Safety Warning	0	0.05	0.15
Intersection Safety Warning	0	0.001	0.02
Pre-Crash Restraint Deployment	0	0	0.05
Driver Visibility Improvement	0	0	0.05
Advanced Vehicle Longitudinal Control	0	0.02	0.15
Advanced Vehicle Lateral Control	0	0	0.05
Intersection Collision Avoidance	0	0	0.02
Automated Highway System	0	0	0.01
Fleet Administration	0.25	0.5	0.8
Freight Administration	0.05	0.1	0.5
Electronic Clearance	0.25	0.5	0.85
CV Administrative Processes	0.25	0.5	0.85
International Border Electronic Clearance	0.25	0.5	0.85
Weigh-In-Motion	1	1	1
Roadside CVO Safety	1	1	1
On-board CVO Safety	0	0.02	0.1
CVO Fleet Maintenance	0.05	0.1	0.5
HAZMAT Managment	0.05	0.1	0.5
Emergency Response	0.5	1	1
Emergency Routing	0.5	1	1
Mayday Support	0.5	1	1
ITS Planning	0	1	1

4.5 Assignment of Users to Communications Interfaces

Messages are assigned to flow over any appropriate communications media, and individual messages are allowed to flow over multiple media. The u1t interface is the wide area two-way wireless interface, and the u1b interface is the wide area broadcast interface. The u_2 interface is the short range vehicle-to-roadside wireless interface. The w interface is the wireline interface.

Messages shared between the u1t and u1b interfaces include traffic advisories and data, and transit deviations and services. In order to study the worst case, it was assumed in the data loading analysis that the broadcast transmission does not reduce the use of u1t data traffic. Therefore, the u1t fraction may be shown as 1 in cases where a message is assigned to other interfaces as well.

Messages shared between the u1t and u_2 interfaces include transit management and services, and parking advance payment. In order to study the worst case, it was assumed in the data loading analysis that the u_2 transmissions do not reduce the use of u1t data traffic.

For the case of messages shared between the u1t and w interfaces, it was assumed that 50% of the traveler user service group (PIAS users) use the w interface and 50% use the u1t interface. It was also assumed that 90% of the kiosks are connected over the w interface, and 10% use the u1t interface. In addition, 90% of the commercial vehicle check subsystems and fleet management subsystems use a wireline interface, and 10% use the u1t interface, because they are not at fixed locations. In the case of very large messages, it was decided not to include them on all applicable interfaces. For example, messages (flows) for map updates, including the associated requests and payment responses were not included on the u1t interface because their large size would make it unlikly that any user would choose that means of update. A wireline connection, such as during an evening, or substitution of an updated CD are the assumed map update mechanisms. Another example is “link_and_queue_data”, which, because of its size, is assigned to the u1b interface.

Map and link + queue data updates of a more limited geographic extent, or incremental updates, when included in future versions of the logical architecture would make sense for the u1t interface.

The message “vehicle_guidance_probe_data” from VS to ISP appears in its own user service group, probes. Finally, it was assumed that display and map updates, because of their very large size (and therefore transmission cost) would not be used by any of the above users unless connected at that moment by wireline access. They would simply choose to perform updates while connected over a w interface or use another transfer media such as a CD.

The message assignments to interfaces are shown in Table 4.5-1. They are sorted by physical architecture source and sink. An “x” is placed in the interfaces over which a particular message is allowed to flow in this analysis. The column labeled “u1t Fraction” indicates the fraction of that message’s data that is assigned to the u1t interface. The balance is assigned to the other interface(s). In a few cases, the u1t Fraction value was reduced on some individual messages relative to others for that user type to include a factor to account for the lower usage of a particular user service feature because, for instance, it is less suitable for use from a mobile location (e.g., ISP to VS message advisory_data, which is large and will be costly to transmit on the u1t interface, is assigned a fraction of 0.5 instead of 1).

Table 4.5-1 Communications Interfaces Assigned to Each of the Messages
Note: Data flows to terminators are all wireline (w).

PA Source	PA Sink	Message Data Flow	u1t	u1t Fraction	u1b	u_2	u_3	w
CVAS	CVCS	cv_credentials_database_update	x	0.1				x
CVAS	CVCS	cv_credentials_information_response	x	0.1				x
CVAS	CVCS	cv_safety_database_update	x	0.1				x
CVAS	CVCS	cv_safety_information_response	x	0.1				x
CVAS	FMS	cf_clearance_enrollment_confirm	x	0.1				x
CVAS	FMS	cf_enrollment_information	x	0.1				x
CVAS	FMS	cf_enrollment_payment_confirmation	x	0.1				x
CVAS	FMS	cv_enrollment_information	x	0.1				x
CVAS	FMS	cv_enrollment_payment_confirmation	x	0.1				x
CVAS	PS	cv_operational_data						x
CVCS	CVAS	cv_credentials_information_request	x	0.1				x
CVCS	CVAS	cv_roadside_daily_log	x	0.1				x
CVCS	CVAS	cv_safety_information_request	x	0.1				x
CVCS	CVAS	cv_update_safety_problems_list	x	0.1				x
CVCS	CVS	cv_inspection_data_output				x		
CVCS	CVS	cv_on_board_pull_in_output				x		
CVCS	CVS	cv_on_board_screening_record				x		
CVCS	CVS	cv_request_electronic_clearance_data				x		
CVCS	CVS	cv_request_on_board_data				x		
CVS	CVCS	cv_electronic_clearance_data				x		
CVS	CVCS	cv_on_board_data				x		
CVS	FMS	cf_driver_route_instructions_request	x	1				
CVS	FMS	cf_on_board_vehicle_data	x	1				
CVS	FMS	cv_driver_enrollment_payment_request	x	1				
CVS	FMS	cv_driver_enrollment_request	x	1				
CVS	FMS	cv_driver_route_request	x	1				
CVS	FMS	cv_driver_storage_request	x	1				
CVS	FMS	cv_static_route_data	x	1				
EM	EVS	emergency_vehicle_driver_outputs	x	1				
EM	FMS	cf_hazmat_request	x	0.1				x
EM	ISP	emergency_vehicle_route_request						x
EM	ISP	incident_information						x
EM	PIAS	emergency_request_personal_traveler_acknowledge	x	0.5				x
EM	PS	emergency_vehicle_operational_data						x
EM	RTS	emergency_request_kiosk_traveler_acknowledge						x
EM	TMS	emergency_vehicle_green_wave						x
EM	TMS	incident_details						x
EM	TMS	incident_response_status						x
EM	TRMS	transit_incident_coordination_data						x
EM	VS	emergency_request_driver_acknowledge	x	1				
EM	VS	emergency_request_vehicle_acknowledge	x	1				
EMMS	PS	pollution_operational_data						x
EMMS	RS	pollution_state_vehicle_acceptance_criteria						x
EMMS	TMS	pollution_incident						x
EMMS	TMS	pollution_state_data						x
EMMS	TMS	wide_area_pollution_data						x
EVS	EM	emergency_driver_dispatch_acknowledge	x	1				
EVS	EM	emergency_driver_status_update	x	1				

Table 4.5-1 Communications Interfaces Assigned to Each of the Messages
Note: Data flows to terminators are all wireline (w).

PA Source	PA Sink	Message Data Flow	u1t	u1t Fraction	u1b	u_2	u_3	w
EVS	EM	emergency_vehicle_driver_inputs	x	1				
EVS	RS	emergency_vehicle_preemptions				x		
FMS	CVAS	cf_enroll_clearance_data	x	0.1				x
FMS	CVAS	cf_enrollment_payment_request	x	0.1				x
FMS	CVAS	cf_enrollment_request	x	0.1				x
FMS	CVAS	cv_enrollment_payment_request	x	0.1				x
FMS	CVAS	cv_enrollment_request	x	0.1				x
FMS	CVS	cf_driver_route_instructions	x	1				
FMS	CVS	cf_request_on_board_vehicle_data	x	1				
FMS	CVS	cv_driver_enrollment_information	x	1				
FMS	CVS	cv_driver_enrollment_payment_confirmation	x	1				
FMS	CVS	cv_driver_route_data	x	1				
FMS	CVS	cv_static_route_request	x	1				
FMS	EM	cf_hazmat_route_information	x	0.1				x
FMS	EM	cf_hazmat_vehicle_information	x	0.1				x
FMS	ISP	cf_route_request	x	0.1				x
FMS	ISP	cv_route_request	x	0.1				x
ISP	EM	emergency_vehicle_route						x
ISP	EM	incident_information_request						x
ISP	FMS	cf_route	x	0.1				x
ISP	FMS	cv_route	x	0.1				x
ISP	PIAS	traffic_data_for_portables			x			x
ISP	PIAS	transit_deviations_for_portables	x	0.05	x			x
ISP	PIAS	traveler_guidance_route	x	0.05				x
ISP	PIAS	traveler_map_update_payment_response		0.5				x
ISP	PIAS	traveler_personal_display_update_payment_response						x
ISP	PIAS	traveler_personal_payment_confirmation	x	0.5				x
ISP	PIAS	traveler_personal_transaction_confirmation	x	0.5				x
ISP	PIAS	traveler_personal_trip_information	x	0.05				x
ISP	PIAS	traveler_personal_yellow_pages_data	x	0.5				x
ISP	PMS	advanced_other_charges_request						x
ISP	PMS	advanced_traveler_charges_request						x
ISP	PMS	parking_lot_data_request						x
ISP	PMS	parking_lot_reservation_request						x
ISP	PS	current_other_routes_use						x
ISP	PS	current_other_routes_use						x
ISP	PS	current_road_network_use						x
ISP	RTS	advanced_tolls_and_charges_roadside_confirm	x	0.1				x
ISP	RTS	traffic_data_for_kiosks			x			x
ISP	RTS	transit_deviations_for_kiosks			x			x
ISP	RTS	traveler_payment_confirmation	x	0.1				x
ISP	RTS	traveler_transaction_confirmation	x	0.1				x
ISP	RTS	traveler_trip_information	x	0.1	x			x
ISP	RTS	traveler_yellow_pages_data	x	0.1	x			x
ISP	TAS	advanced_other_tolls_request						x
ISP	TAS	advanced_traveler_tolls_request						x
ISP	TMS	commercial_vehicle_incident						x
ISP	TMS	confirm_incident_data_output						x

Table 4.5-1 Communications Interfaces Assigned to Each of the Messages

Note: Data flows to terminators are all wireline (w).

PA Source	PA Sink	Message Data Flow	u1t	u1t Fraction	u1b	u_2	u_3	w
ISP	TMS	current_other_routes_use						x
ISP	TMS	current_road_network_use						x
ISP	TMS	current_transit_routes_use						x
ISP	TMS	low_traffic_route						x
ISP	TMS	media_incident_data_updates						x
ISP	TMS	request_incident_media_data						x
ISP	TMS	traffic_data_media_request						x
ISP	TRMS	advanced_other_fares_request						x
ISP	TRMS	advanced_tolls_and_charges_vehicle_confirm						x
ISP	TRMS	advanced_traveler_fares_request						x
ISP	TRMS	paratransit_service_confirmation						x
ISP	TRMS	paratransit_trip_request						x
ISP	TRMS	request_prices						x
ISP	TRMS	transit_services_advisories_request						x
ISP	TRMS	transit_services_guidance_request						x
ISP	TRMS	transit_vehicle_deviations_details_request						x
ISP	VS	advanced_fares_and_charges_response	x	1				
ISP	VS	advanced_tolls_and_fares_response	x	1				
ISP	VS	advisory_data	x	0.5	x			
ISP	VS	broadcast_data			x			
ISP	VS	link_and_queue_data			x			
ISP	VS	yellow_pages_advisory_data	x	1	x			
PIAS	EM	emergency_request_personal_traveler_details	x	0.5				x
PIAS	ISP	traffic_data_portables_request	x	0.5				x
PIAS	ISP	transit_deviations_portables_request	x	0.5				x
PIAS	ISP	traveler_map_update_payment_request						x
PIAS	ISP	traveler_personal_current_condition_request	x	0.5				x
PIAS	ISP	traveler_personal_display_update_payment_request						x
PIAS	ISP	traveler_personal_payment_information	x	0.5				x
PIAS	ISP	traveler_personal_transaction_request	x	0.5				x
PIAS	ISP	traveler_personal_trip_confirmation	x	0.5				x
PIAS	ISP	traveler_personal_trip_request	x	0.5				x
PIAS	ISP	traveler_personal_yellow_pages_information_request	x	0.5				x
PIAS	ISP	traveler_route_accepted	x	0.5				x
PIAS	ISP	traveler_route_request	x	0.05				x
PIAS	TRMS	transit_services_portables_request	x	0.5				x
PMS	ISP	advanced_other_charges_confirm						x
PMS	ISP	advanced_traveler_charges_confirm						x
PMS	ISP	parking_lot_availability						x
PMS	ISP	parking_lot_reservation_confirm						x
PMS	TMS	parking_lot_charge_change_response						x
PMS	TMS	parking_lot_current_occupancy						x
PMS	TMS	parking_lot_current_state						x
PMS	TMS	vms_parking_guidance_for_highways						x
PMS	TMS	vms_parking_guidance_for_roads						x
PMS	TRMS	parking_lot_price_data						x
PMS	TRMS	parking_lot_transaction_reports						x
PMS	TRMS	parking_lot_transit_request						x

Table 4.5-1 Communications Interfaces Assigned to Each of the Messages

Note: Data flows to terminators are all wireline (w).

PA Source	PA Sink	Message Data Flow	u1t	u1t Fraction	u1b	u_2	u_3	w
PMS	VS	advanced_parking_lot_charges_confirm				x		
PMS	VS	parking_lot_payment_debited				x		
PMS	VS	parking_lot_payment_request				x		
PMS	VS	parking_lot_tag_data_clear				x		
PMS	VS	parking_lot_tag_data_request				x		
PMS	VS	parking_lot_tag_data_update				x		
RS	EMMS	pollution_state_roadside_collection						x
RS	EMMS	pollution_state_vehicle_collection						x
RS	EMMS	pollution_state_vehicle_log_data						x
RS	TMS	ahs_checking_details						x
RS	TMS	hov_lane_data_input						x
RS	TMS	incident_analysis_data						x
RS	TMS	indicator_input_data_from_highways						x
RS	TMS	indicator_input_data_from_roads						x
RS	TMS	roadside_fault_data						x
RS	TMS	traffic_image_data						x
RS	TMS	traffic_sensor_data						x
RS	TMS	vehicle_pollution_alert						x
RS	TMS	vehicle_pollution_message_for_highways						x
RS	TMS	vehicle_pollution_message_for_roads						x
RS	VS	ahs_check_response				x		
RS	VS	vehicle_signage_data				x		
RTS	EM	emergency_request_kiosk_traveler_details	x	0.1				x
RTS	ISP	advanced_tolls_and_charges_roadside_request	x	0.1				x
RTS	ISP	traffic_data_kiosk_request	x	0.1				x
RTS	ISP	transit_deviation_kiosk_request	x	0.1				x
RTS	ISP	traveler_current_condition_request	x	0.1				x
RTS	ISP	traveler_payment_information	x	0.1				x
RTS	ISP	traveler_transaction_request	x	0.1				x
RTS	ISP	traveler_trip_confirmation	x	0.1				x
RTS	ISP	traveler_trip_request	x	0.1				x
RTS	ISP	traveler_yellow_pages_information_request	x	0.1				x
RTS	TRMS	fare_collection_roadside_violation_information						x
RTS	TRMS	other_services_roadside_request						x
RTS	TRMS	request_roadside_fare_payment						x
RTS	TRMS	transit_roadside_fare_payment_confirmation						x
RTS	TRMS	transit_roadside_passenger_data						x
RTS	TRMS	transit_services_kiosk_request						x
RTS	TRMS	transit_services_travelers_request						x
RTS	TRMS	transit_user_roadside_image						x
TAS	ISP	advanced_other_tolls_confirm						x
TAS	ISP	advanced_traveler_tolls_confirm						x
TAS	ISP	probe_data_for_guidance						x
TAS	ISP	vehicle_toll_probe_data						x
TAS	PS	toll_operational_data						x
TAS	TCS	advanced_toll_needed						x
TAS	TCS	toll_bad_payment_check_response						x
TAS	TMS	probe_data_for_traffic						x

Table 4.5-1 Communications Interfaces Assigned to Each of the Messages
Note: Data flows to terminators are all wireline (w).

PA Source	PA Sink	Message Data Flow	u1t	u1t Fraction	u1b	u_2	u_3	w
TAS	TMS	toll_price_changes_response						x
TAS	TRMS	toll_price_data						x
TAS	TRMS	toll_transaction_reports						x
TCS	TAS	advanced_toll_transactions						x
TCS	TAS	confirm_advanced_tolls_payment						x
TCS	TAS	current_toll_transactions						x
TCS	TAS	toll_bad_payment_check_request						x
TCS	TAS	toll_payment_violator_data						x
TCS	TAS	toll_violation_information						x
TCS	VS	toll_payment_debited				x		
TCS	VS	toll_payment_request				x		
TCS	VS	toll_tag_data_clear				x		
TCS	VS	toll_tag_data_request				x		
TCS	VS	toll_tag_data_update				x		
TMS	EM	incident_alert						x
TMS	EM	incident_details_request						x
TMS	EM	incident_response_clear						x
TMS	EMMS	pollution_state_data_request						x
TMS	ISP	current_highway_network_state						x
TMS	ISP	current_road_network_state						x
TMS	ISP	incident_data_output						x
TMS	ISP	link_data_for_guidance						x
TMS	ISP	predicted_incidents						x
TMS	ISP	prediction_data						x
TMS	ISP	retrieved_incident_media_data						x
TMS	ISP	traffic_data_for_media						x
TMS	ISP	traffic_data_media_parameters						x
TMS	PMS	parking_lot_charge_change_request						x
TMS	PMS	parking_lot_input_data						x
TMS	PMS	selected_parking_lot_control_strategy						x
TMS	PMS	static_data_for_parking_lots						x
TMS	PS	ahs_operational_data						x
TMS	PS	current_incident_static_data						x
TMS	PS	current_traffic_static_data						x
TMS	PS	traffic_data_for_deployment						x
TMS	RS	ahs_control_data_changes						x
TMS	RS	indicator_control_data_for_highways						x
TMS	RS	indicator_control_data_for_roads						x
TMS	RS	indicator_control_monitoring_data_for_highways						x
TMS	RS	indicator_control_monitoring_data_for_roads						x
TMS	RS	vehicle_sign_data						x
TMS	TAS	toll_price_changes_request						x
TMS	TRMS	parking_lot_charge_request						x
TMS	TRMS	prediction_data						x
TMS	TRMS	toll_price_request						x
TMS	TRMS	transit_conditions_demand_request						x
TMS	TRMS	transit_fare_request						x
TMS	TRMS	transit_services_changes_request						x

Table 4.5-1 Communications Interfaces Assigned to Each of the Messages

Note: Data flows to terminators are all wireline (w).

PA Source	PA Sink	Message Data Flow	u1t	u1t Fraction	u1b	u_2	u_3	w
TMS	TRMS	transit_services_demand_request						x
TRMS	EM	transit_coordination_data						x
TRMS	EM	transit_emergency_data						x
TRMS	EM	transit_incident_details						x
TRMS	ISP	advanced_other_fares_confirm						x
TRMS	ISP	advanced_tolls_and_charges_vehicle_request						x
TRMS	ISP	advanced_traveler_fares_confirm						x
TRMS	ISP	paratransit_personal_schedule						x
TRMS	ISP	prices						x
TRMS	ISP	transit_deviation_data_received						x
TRMS	ISP	transit_media_emergency_information						x
TRMS	ISP	transit_media_incident_information						x
TRMS	ISP	transit_services_for_advisory_data						x
TRMS	ISP	transit_services_for_guidance						x
TRMS	ISP	transit_user_payments_transactions						x
TRMS	ISP	transit_vehicle_deviations_details						x
TRMS	PIAS	transit_services_for_portables	x	0.33	x			x
TRMS	PMS	parking_lot_transit_response						x
TRMS	PS	financial_reports						x
TRMS	PS	transit_passenger_operational_data						x
TRMS	PS	transit_services_for_deployment						x
TRMS	RTS	confirm_roadside_fare_payment						x
TRMS	RTS	other_services_roadside_response						x
TRMS	RTS	request_transit_user_image						x
TRMS	RTS	transit_roadside_fare_data						x
TRMS	RTS	transit_roadside_fare_payment_debited						x
TRMS	RTS	transit_roadside_fare_payment_request						x
TRMS	RTS	transit_services_for_kiosks						x
TRMS	RTS	transit_services_for_roadside_fares						x
TRMS	RTS	transit_services_for_travelers						x
TRMS	RTS	transit_vehicle_arrival_time						x
TRMS	RTS	transit_vehicle_user_data						x
TRMS	TMS	parking_lot_charge_details						x
TRMS	TMS	toll_price_details						x
TRMS	TMS	transit_fare_details						x
TRMS	TMS	transit_highway_overall_priority						x
TRMS	TMS	transit_ramp_overall_priority						x
TRMS	TMS	transit_road_overall_priority						x
TRMS	TMS	transit_running_data_for_demand						x
TRMS	TMS	transit_services_changes_response						x
TRMS	TMS	transit_services_for_demand						x
TRMS	TRVS	approved_corrective_plan	x	1		x		
TRMS	TRVS	confirm_vehicle_fare_payment	x	1		x		
TRMS	TRVS	other_services_vehicle_response	x	1		x		
TRMS	TRVS	paratransit_transit_driver_instructions	x	1		x		
TRMS	TRVS	request_transit_user_image	x	1		x		
TRMS	TRVS	transit_operator_request_acknowledge	x	1		x		
TRMS	TRVS	transit_services_for_corrections	x	1		x		

Table 4.5-1 Communications Interfaces Assigned to Each of the Messages
Note: Data flows to terminators are all wireline (w).

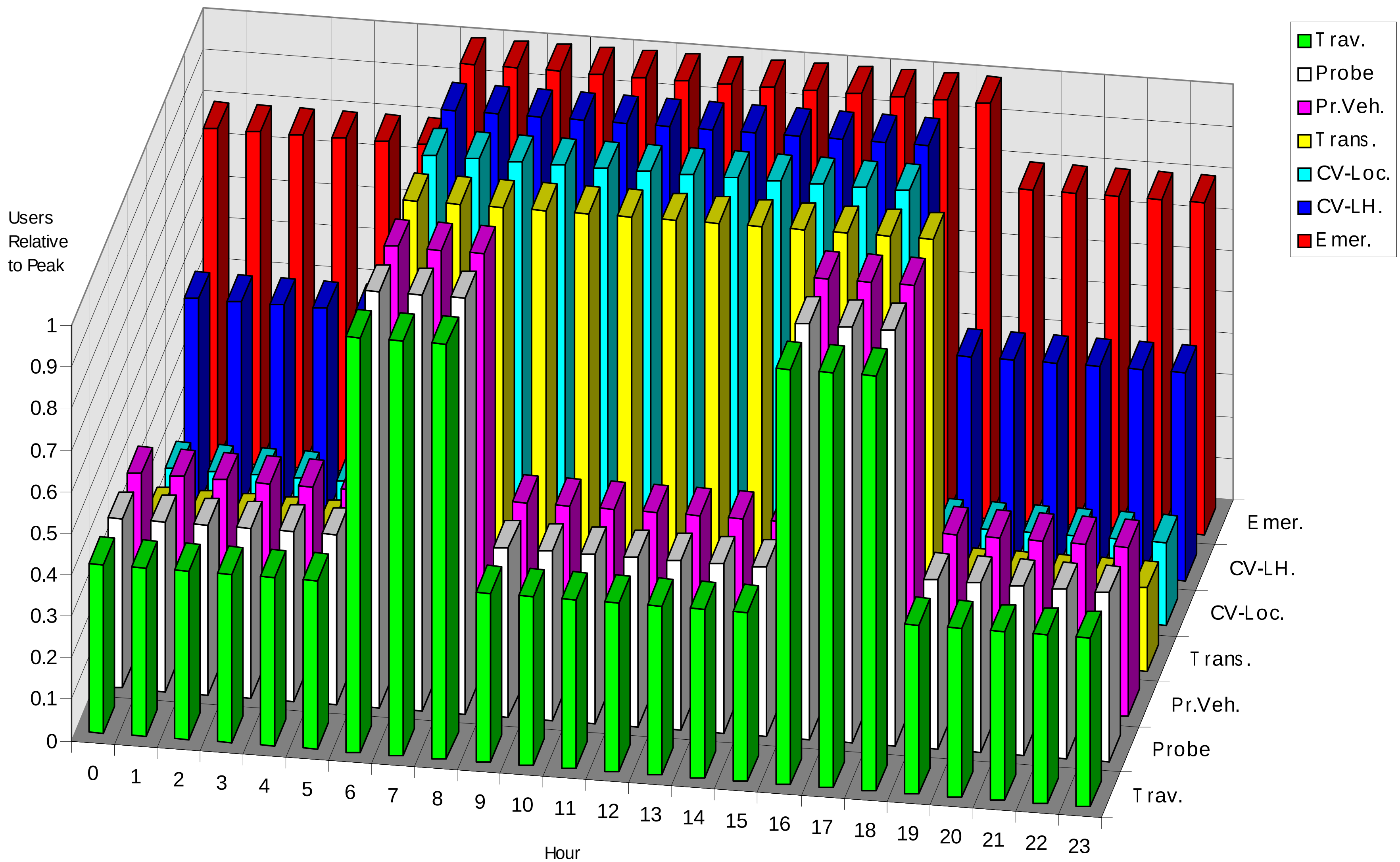
PA Source	PA Sink	Message Data Flow	u1t	u1t Fraction	u1b	u_2	u_3	w
TRMS	TRVS	transit_services_for_eta	x	1		x		
TRMS	TRVS	transit_services_for_vehicle_fares	x	1		x		
TRMS	TRVS	transit_vehicle_advanced_payment_response	x	1		x		
TRMS	TRVS	transit_vehicle_conditions				x		
TRMS	TRVS	transit_vehicle_fare_data	x	1		x		
TRMS	TRVS	transit_vehicle_fare_payment_debited	x	1		x		
TRMS	TRVS	transit_vehicle_fare_payment_request	x	1		x		
TRVS	RS	transit_vehicle_roadway_preemptions				x		
TRVS	TRMS	fare_collection_vehicle_violation_information				x		
TRVS	TRMS	other_services_vehicle_request	x	1		x		
TRVS	TRMS	paratransit_transit_vehicle_availability	x	1		x		
TRVS	TRMS	request_vehicle_fare_payment	x	1		x		
TRVS	TRMS	transit_conditions_request	x	1		x		
TRVS	TRMS	transit_emergency_details	x	1		x		
TRVS	TRMS	transit_emergency_information	x	1		x		
TRVS	TRMS	transit_operator_emergency_request	x	1		x		
TRVS	TRMS	transit_services_for_eta_request	x	1		x		
TRVS	TRMS	transit_user_vehicle_image	x	1		x		
TRVS	TRMS	transit_vehicle_advanced_payment_request	x	1		x		
TRVS	TRMS	transit_vehicle_arrival_conditions	x	1		x		
TRVS	TRMS	transit_vehicle_collected_trip_data	x	1		x		
TRVS	TRMS	transit_vehicle_deviations_from_schedule	x	1		x		
TRVS	TRMS	transit_vehicle_eta	x	1		x		
TRVS	TRMS	transit_vehicle_fare_payment_confirmation	x	1		x		
TRVS	TRMS	transit_vehicle_location	x	1		x		
TRVS	TRMS	transit_vehicle_location_for_deviation	x	1		x		
TRVS	TRMS	transit_vehicle_location_for_store	x	1		x		
TRVS	TRMS	transit_vehicle_passenger_data	x	1		x		
TRVS	TRMS	transit_vehicle_schedule_deviation	x	1		x		
VS	EM	emergency_request_driver_details	x	1				
VS	EM	emergency_request_vehicle_details	x	1				
VS	ISP	advanced_fares_and_charges_request	x	1				
VS	ISP	advanced_tolls_and_fares_request	x	1				
VS	ISP	advisory_data_request	x	1				
VS	ISP	vehicle_guidance_probe_data	x	1				
VS	ISP	vehicle_guidance_route_accepted	x	1				
VS	ISP	yellow_pages_advisory_requests	x	1				
VS	PMS	advanced_parking_lot_charges_request	x	0.5		x		
VS	PMS	parking_lot_payment_confirmation	x	0.5		x		
VS	PMS	parking_lot_tag_data_collect				x		
VS	RS	ahs_route_data				x		
VS	RS	ahs_vehicle_condition				x		
VS	RS	vehicle_status_details				x		
VS	TCS	toll_payment_confirmation				x		
VS	TCS	toll_tag_data_collect				x		
VS	Other VS	to_other_vehicle					x	
Other VS	VS	from_other_vehicle					x	

4.6 Usage Profiles for the User Service Groups

A usage profile indicating the number of users by user service group versus time was developed, and is shown in Figure 4-6.1. The peak period usage is defined as 1.0, and the usage of each user service group relative to that is graphed by user service group and time of day, for a weekday. Transit and Emergency Management each have a 13-hour peak period, CVO has a 12-hour peak period, and Private Vehicle, Traveler Information (PIAS), and Probes have two, three-hour peak periods. Although these profiles at a first glance may seem as a gross approximation, a communication system needs to be designed for the "busy hour" corresponding the peak period. Thus the exact shape of the temporal profile outside the peak period is not critical.

Usage profiles are used to adjust the number of users for each of the user service groups for both the peak and off-peak periods.

Figure 4.6-1. Usage Profile by Service



4.7 Scenario Infrastructure Model

The wireline data loading analysis for the "w" interfaces is based directly on the parameters in the Teamwork model in the logical architecture (the wireline data loading results will be shown in Section 6.3). The analysis done shows the total wireline data load between physical subsystems for all of the data flows in the logical architecture. This is the amount of aggregate data flowing between subsystems. In the case of widely-distributed subsystems, such as the RS to TMS wireline link, the result reflects the data rate along a network near the TMS where the data are fully aggregated into a total data rate that would require two DS3-rate links to carry the load (see Table 6.3-3).

The design selections made for the entire network design for the ITS deployment region under consideration are very specific to physical details of the deployment region. Design decisions will be based more on funding availability (capital funding versus lease) and the utilization of existing infrastructure than on technical limitations. Wireline bandwidth is plentiful, and inexpensive relative to any of the other ITS communications interfaces. The ITS architecture allows the use of existing infrastructure to the greatest extent possible, and a selection of a specific wireline technology will not be made here.

One design assumption that drives the second-largest data load for the RS to TMS link is the selection of a video encoding standard. In this document the MPEG-1 standard has been selected. The data rate is 1.5 Mbps. This decision was based on the fact that MPEG-1 provides a high quality full-motion video image that can be readily demonstrated today. The development of inexpensive MPEG-1 encoders and decoders has been completed, and the cost will decline rapidly in the near term. This assumption can be revisited in the future when the time for an actual deployment is nearer. The tradeoff between the cost of the encoder/decoder pair and the cost of transport should be studied then, because of the rapid developments in the area of video encoding.

5. MESSAGE DEFINITION

The data flows of the logical architecture form the messages used to provide ITS services. The only addition to the data flows to allow them to act as messages was to append a message_id header of 18 bits. The message_id header provides the receiving subsystem the information on which message is being transmitted, which in turn provides the receiver with information on the data fields that follow along with their sizes. Each message_id has a fixed definition for the information fields which are contained in that message. Each of the fields are of fixed length. Nothing has been done at this point to optimize the messages for a particular communications medium. It is likely that standards efforts and commercial ventures will optimize them to minimize the communications requirements and the cost of service.

The physical entities and the communications interfaces required for the ITS architecture are shown in Figure 5.1-1, the Level 0 AID. The interfaces are shown between the entities, with *u* interfaces indicating wireless. The wireline interfaces are indicated by a *w*.

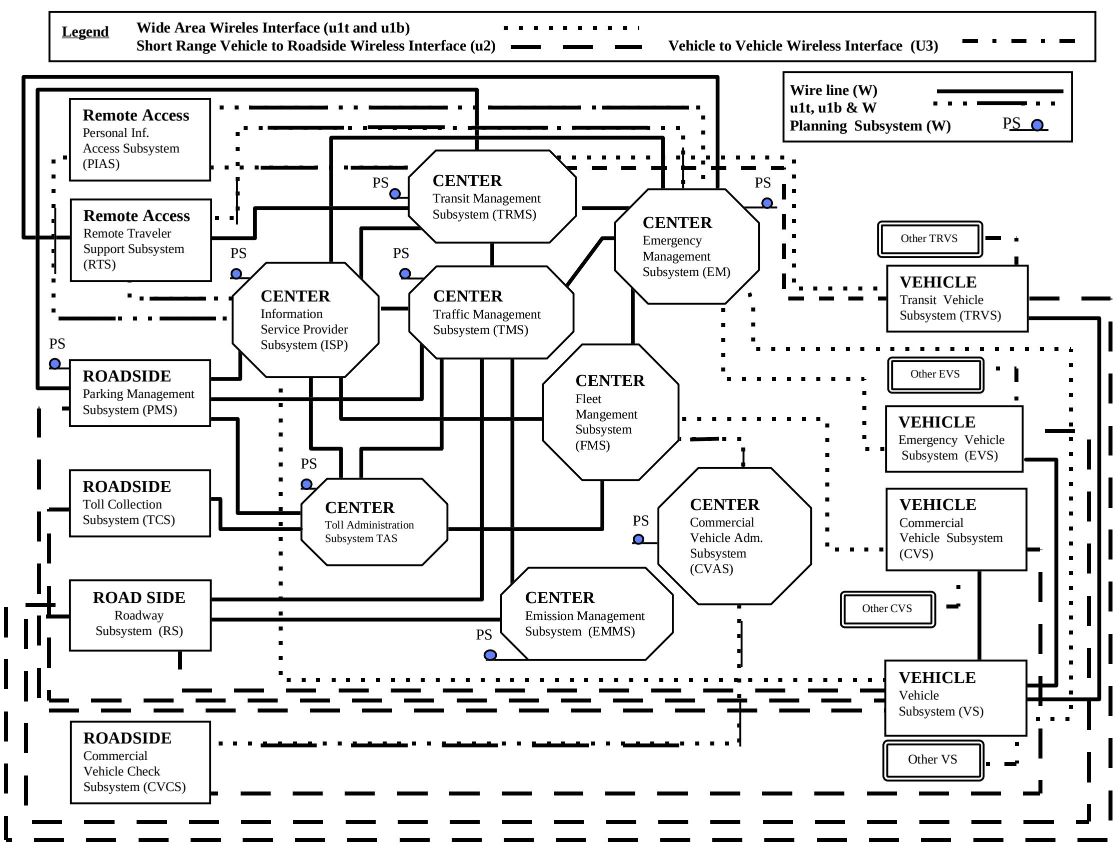


Figure 5.1-1 Level 0 Architecture Interconnect Diagram for the National ITS Architecture

5.1 Message Definition Methodology

The message set consists of the data flows that are communicated between physical subsystems for the entire logical architecture. For this analysis, the baseline logical architecture dated January 22, 1996 was used. Some changes were made to the logical architecture after that date and were tracked in the logical architecture as changes to the January 22, 1996 baseline The January 22, 1996 logical architecture had to be used to allow time for the performance of the data loading analyses, and more importantly the communication simulations (which are very time intensive) prior to the Final Program review held on Arpil 2, 1996.

5.2 Message Structure

In order to allow the data flows to form messages, an 18-bit message_id header has been added to each of the data flows. The message structure and overhead for the application layer are described in Figure 5.2-1.

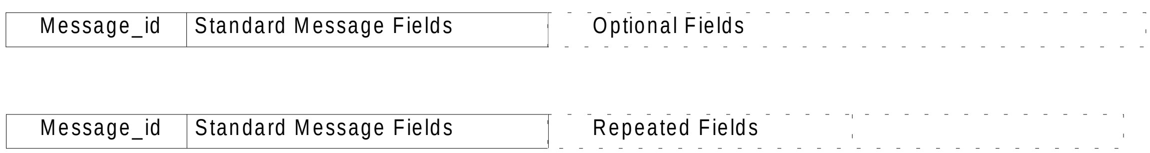


Figure 5.2-1 Examples of Message Structures
(Top) Example of a message with optional fields.
(Bottom) Example of a message with repeated fields.

Each of the message fields used is of fixed length, and the messages are all of a pre-determined length. Messages consist of a message_id header followed by a small number of pre-defined standard message fields, and possibly optional fields or repeated fields. The message_id tells the receiver which information fields follow in a given message. Most of the messages consist of a small number of standard message fields. The message_id field, shown in Figure 5.2-2, consists of the message_name, optional fields/repeat fields select bits and four bits to denote the optional fields and/or number of repeats to follow. The optional fields are large, generally text fields that are transmitted only with a minority of the messages. The longer text fields required to provide specialized data are optional fields, and are only transmitted in response to a request for text information. When transmitted, their presence is indicated in one of the four optional field bits in the message_id header. Up to 15 combinations of optional fields can be accommodated. An optional-field message is shown in Figure 5.2-3.

Many of the data flows from the logical architecture can be broken up into standard fields, optional fields, and repeated fields. This has been left for the standards bodies to complete during optimization efforts, because it is largely dependent on the communications media selected.

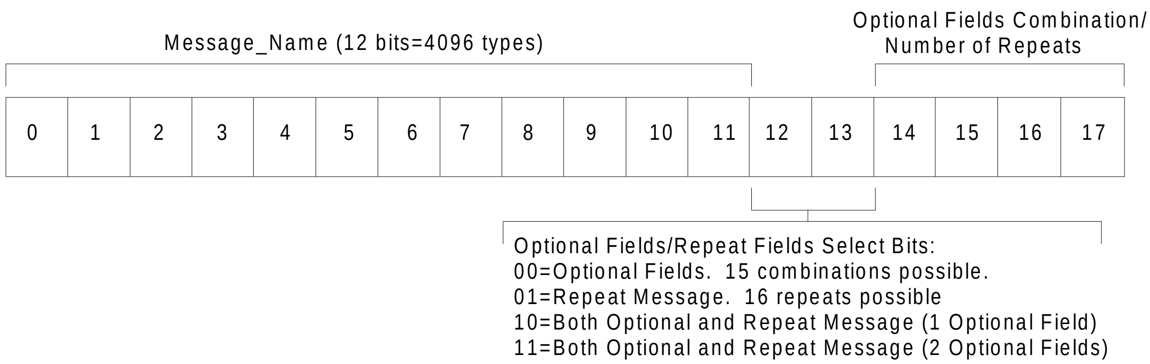


Figure 5.2-2 Details of the Message_ID Field which Allows Standard, Optional, and Repeated Fields to be Appended to the Message

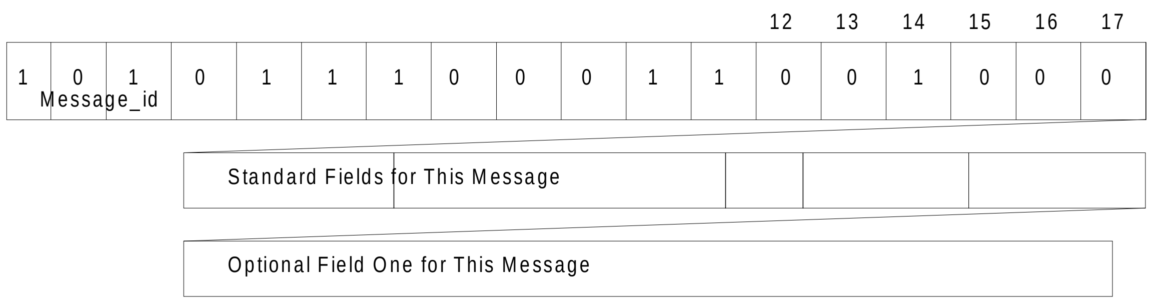


Figure 5.2-3 Example of an Optional-Field Message

Repeated fields are a subset of the initial standard message fields that are repeated to provide a complete message. They are useful when the number of fields to follow is not fixed (e.g., a route guidance message has more sets of route information for a longer route). An example of a message with three repeats of repeat fields is shown in Figure 5.2-4.

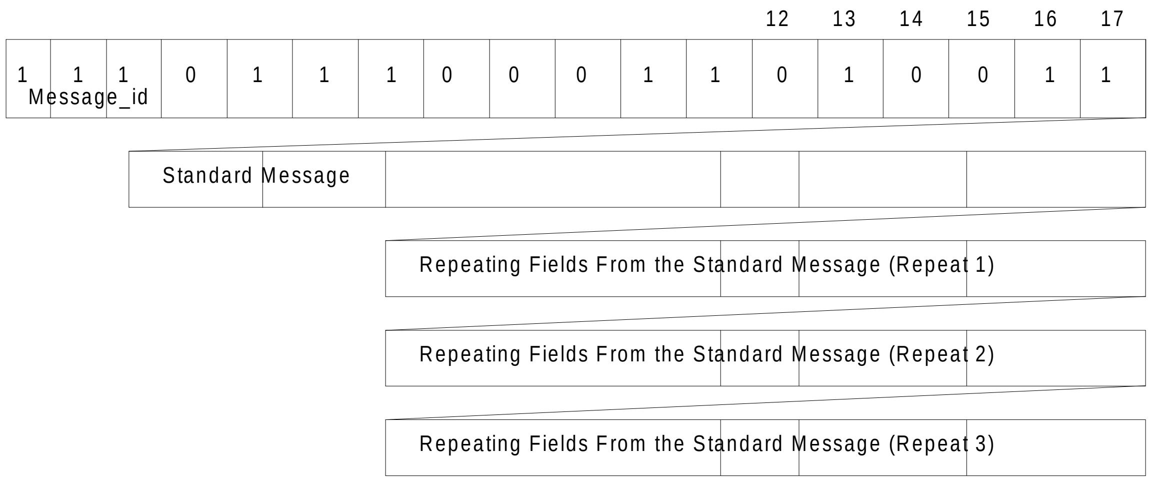


Figure 5.2-4 Example of a Message with Three Sets of Repeated Fields

The message structure also allows for both optional fields and repeat fields in the same message. This case is limited to one or two optional fields, and up to 16 repeats.

The message structure allows for 4096 different message types. If the message_id header structure is redefined, even more standard messages could be accommodated. For example, no message has been defined with 15 optional fields at this point. If the number of optional fields is limited to seven (or three), then the number of standard messages could be increased to 8192 (or 16384) - if no repeats are allowed for these new messages. This would be done by reassigning bit(s) 17 (or 16 and 17) to message_name when bits 12 and 13 are "0".

5.3 Message Set

The communications analysis accounts for services that would not be offered in a particular scenario, by using the year of deployment from the Evolutionary Deployment Strategy Document. Each of the messages was assigned to a market package. Since market packages are deployed as time progresses and may not be available in all scenario regions, the messages used in practice vary by time frame and scenario region. Table 5.3-1 lists the market packages available in each of the time frames for all three scenario regions.

Messages assigned to market packages that are not yet deployed are not included in the data loading models for that scenario/year. The table of deployment is shown below in Table 5.3-1.

Table 5.3-1 Market Package Deployment by Time Frame
(All are Deployed in Urbansville and Thruville in 2012)

Region*	Year	Market Package Name
u	1997	Transit Vehicle Tracking
u	1997	Transit Fixed-Route Operations
u	1997	Demand Response Transit Operations
u	1997	Broadcast Traveler Information
u	1997	Interactive Traveler Information
u	1997	Probe Surveillance
u	1997	Fleet Administration
u	1997	Emergency Response
u	1997	Mayday Support
u	2002	Transit Vehicle Tracking
u	2002	Transit Fixed-Route Operations
u	2002	Demand Response Transit Operations
u	2002	Transit Passenger and Fare Management
u	2002	Transit Security
u	2002	Transit Maintenance
u	2002	Multi-modal Coordination
u	2002	Broadcast Traveler Information
u	2002	Interactive Traveler Information
u	2002	Yellow Pages and Reservation
u	2002	Integrated Transportation Management/Route Guidance
u	2002	Probe Surveillance
u	2002	Fleet Administration
u	2002	Freight Administration
u	2002	Electronic Clearance
u	2002	CV Administrative Processes
u	2002	International Border Electronic Clearance
u	2002	Weigh-In-Motion
u	2002	Roadside CVO Safety
u	2002	Emergency Response
u	2002	Mayday Support
r	2002	Transit Passenger and Fare Management
r	2002	Broadcast Traveler Information
r	2002	Fleet Administration
r	2002	Freight Administration
r	2002	Electronic Clearance
r	2002	CV Administrative Processes
r	2002	International Border Electronic Clearance
r	2002	Weigh-In-Motion
r	2002	Roadside CVO Safety
r	2002	Emergency Response
r	2002	Mayday Support
r	2012	Transit Vehicle Tracking
r	2012	Transit Fixed-Route Operations
r	2012	Demand Response Transit Operations
r	2012	Transit Passenger and Fare Management
r	2012	Transit Security
r	2012	Transit Maintenance
r	2012	Broadcast Traveler Information
r	2012	Interactive Traveler Information
r	2012	Yellow Pages and Reservation
r	2012	Integrated Transportation Management/Route Guidance

Table 5.3-1 Market Package Deployment by Time Frame
(All are Deployed in Urbansville and Thruville in 2012)

Region*	Year	Market Package Name
r	2012	Fleet Administration
r	2012	Freight Administration
r	2012	Electronic Clearance
r	2012	CV Administrative Processes
r	2012	International Border Electronic Clearance
r	2012	Weigh-In-Motion
r	2012	Roadside CVO Safety
r	2012	On-board CVO Safety
r	2012	Emergency Response
r	2012	Mayday Support
i	1997	Transit Vehicle Tracking
i	1997	Transit Fixed-Route Operations
i	1997	Demand Response Transit Operations
i	1997	Broadcast Traveler Information
i	1997	Probe Surveillance
i	1997	Fleet Administration
i	1997	Emergency Response
i	2002	Transit Vehicle Tracking
i	2002	Transit Fixed-Route Operations
i	2002	Demand Response Transit Operations
i	2002	Transit Passenger and Fare Management
i	2002	Transit Maintenance
i	2002	Broadcast Traveler Information
i	2002	Interactive Traveler Information
i	2002	Integrated Transportation Management/Route Guidance
i	2002	Probe Surveillance
i	2002	Fleet Administration
i	2002	Freight Administration
i	2002	CV Administrative Processes
i	2002	Electronic Clearance
i	2002	International Border Electronic Clearance
i	2002	Weigh-In-Motion
i	2002	Roadside CVO Safety
i	2002	Emergency Response
i	2002	Mayday Support

*Region designations: u = urban; r = rural; i = inter-urban

The complete set of messages available for each scenario region and time frame are provided in the data loading models shown in Appendix F.

6. DATA LOADING METHODOLOGY AND RESULTS

The purpose of the data loading analysis is to provide an estimate of the data transmission requirements for a candidate (or evaluatory) deployment of the ITS Architecture. These estimates are used to size, and prove the feasibility of, the candidate communication systems considered as possible implementations, and, in turn, demonstrate the soundness of the ITS Architecture itself.

The results of the data loading models derived in this section are fed as inputs to the communcation simulations (discussed at length in Section 8). They also serve as an input to the cost models, since the cost of communications is a major component of the overall cost of an ITS system. In the data loading analysis, the same three scenario regions (Urbansville, Thruville, and Mountainville) are studied for the same three time frames (1997, 2002, and 2012). The candidate deployment is the evaluatory design, as defined in the Evaluatory Design Document.

The two key outputs from the data loading task determined:

- Average peak-period data loads on all of the communications interfaces.
- Statistics of message transmission to drive the communications simulations.

These simulations provide the real-time communications system performance (i.e., accounting for the instantaneous fluctuations of loading) for the evaluatory design considered. For the case where a shared infrastructure is used, the network will have already been designed for the observed peak loading throughout the ITS geographic coverage area for other applications (particularly voice or other data traffic).

The data loading task here takes inputs from the logical architecture, the physical architecture, the evaluatory design, and the implementation strategy. The data flows in the logical architecture form the messages in the data loading analysis, after the message_id header is added.

The physical architecture defines the assignment of the logical architecture specifications into physical ITS subsystems. This assignment defines which data flows cross between physical subsystems, and must therefore be transmitted on communications interfaces.

Deployment information from the implementation strategy is used to make a determination of which market packages (and therefore which messages) will be available in each of the scenario regions/time frames.

National statistics are used to determine the potential user population for the evaluatory design assumptions. Penetration values for users of ITS services are defined by market package from information from the Evaluatory Design Document.

The data loading task also entails assigning messages to communications interfaces (in many cases multiple interfaces), and defining the fraction of the total data load to be carried over each communications interface.

Because of the significant time lead required for the generation of the data loading models, and the preparation and running of the simulations, the data loading analysis presented here is for the Evaluatory Design based on the ITS National Architecture dated January 22, 1996. This design should be viewed as a candidate ITS deployment. It includes a reasonable set of assumptions to model an actual deployment. These assumptions include ITS system sizing, communications network sizing (using 1993 network deployments without any capacity upgrading or additional competing systems through the 2012 time frame), message definitions (which have not yet been optimized to provide a good balance between ITS system performance and cost, and are not compressed), frequencies of use of each message by user type, and user penetration.

It is expected that there will be variations in the design assumptions, such as penetration, message sizes and frequencies of use, etc. with specific deployments in the future. With the thousands of assumptions used in the model, some variables will increase, and others will decrease. To be extra conservative, the simulations account later for unexpected variations by using the data loading outputs with additional, severe, worst case assumptions, e.g., no cellular infrastructure expansion, no splitting of load between competing technologies, worst case traffic incident, and so on.

The fundamental conclusions based on the data loading analysis and the simulations to follow, although for a single overall design, indicate that the communications requirements can be accommodated using existing and planned technology. This single conclusion is insensitive to any expected variations in the assumptions contained within the data loading analysis. It is also intuitive, that as the communications requirements of ITS and other communications-intensive applications increase over time, the various communications technologies described in Section 7 will continuously increase in capacity to meet the increased demand.

It is finally worth noting that because the data loading analysis requires so many thousands of assumptions, it is difficult to perform sensitivity studies within the constraints of the National ITS Architecture development effort. The variables that are the most critical to the final result are the penetration assumptions, because they are factors applied across groups of messages. Again, the penetration values were taken directly from the evaluatory design, using the “high” estimate for the worst-case analysis. Since the purpose of the data loading analysis is to prove the validity of the communications systems sizing, the worst case is studied. Because the effect of changing the penetration is linear across entire user service groups, estimates of the sensitivity of penetration on the average link loads are trivial to prepare from the data loading results, which were determined by user service group. The effect of penetration on the instantaneous link performance can only be determined by simulations. Unfortunately, a series of simulations would be required, which would be quite costly.

The per-user data loading models are very detailed and show the link data load resulting from each message. The sensitivity of the link data load to any of the message sizes and frequencies of use can be readily determined.

6.1 Data Loading Models

Seven user service groups of distinct usage patterns were defined. Where groups of users within a user service group with differing usage patterns could be defined, the user service groupings were sub-divided. An example is the division of local CVO from long-haul CVO. The grouping results in seven user service groups: Travelers (PIAS users), CVO-Local, CVO-Long Haul, Private Vehicles, Transit, Emergency Management, and Probes.

The set of market packages of interest to each user service group were defined, which in turn determined the message set for that user service group. Frequencies of use were defined for each message for each user service group. Finally, the statistics on the transmission of messages on each link were calculated, and the average data rates on each link were calculated.

Data loading models were calculated for each service individually, for both a peak and off-peak period that has been defined for each service. The most important goal of the data loading analysis is to determine the peak-period average data rates for use in communications system sizing. A two-level (peak/off-peak) model for each service allows the number of users to be varied through the day, so that the resulting data rate can be included as a function of time, giving a more accurate total data rate profile over time. It is critical to note that the hour(s) with the highest total data rate from all services will be used in sizing the communications links.

6.2 Wireless Data Loads

The wireless interfaces consist of the two-way wide area (u1t) wireless interface, the broadcast wide area (u1b) interface, the short range, DSRC, (u_2) interface, and the vehicle-to-vehicle (u_3) interface. Data loads determined for these are shown in the next three sections, with the exception of the u_3 interface. The u_3 interface, intended for AHS applications, is for dedicated systems that are still in the early research phase and which are under study in another program.

6.2.1 Two-Way Wireless Data Loads

Per-user peak-period data loading models for the u1t interface by user service group for each of the scenarios were completed and are shown in Appendix F. There is a total of 24 data loading models.

These per-user peak-period results were then used to determine the off-peak loads, which are a fraction of the peak period loads, based on the usage profile by service (see Figure 4.6-1).

These results were then multiplied by the number of potential users in the scenario, and then divided by the total area of the scenario area to obtain the data loads per square mile for the charts. This step allows the calculation of the data load for each of the communications sites, regardless of the number used, given the area of coverage of each.

The results of the data loading analysis are shown graphically in Figures 6.2-1 through 6.2-24. The charts are ordered with the 1997 results first, then the 2002 results, followed by those for 2012. For each of the time frames there are 9 charts: Urbansville forward, reverse, and total data loads; Thruville forward, reverse, and total data loads; and Mountainville forward, reverse, and total data loads (Mountainville has no deployment in 1997).

The charts show the data loads in bits per second per square mile, by user service group, by hour of the day, for a weekday. The load for any wireless communications subsystem can then be calculated by multiplying these results by the area of coverage of the communications subsystem. It should be noted that whether during or outside the peak periods, these results are average loads; statistical variations are handled in the communications simulations.

The data loading analysis results charted in Figures 6.2-1 through 6.2-24 are summarized in Table 6.2-1.

Figure 6.2-1 Data Loading by Service - Forward, 1997, Urbansville

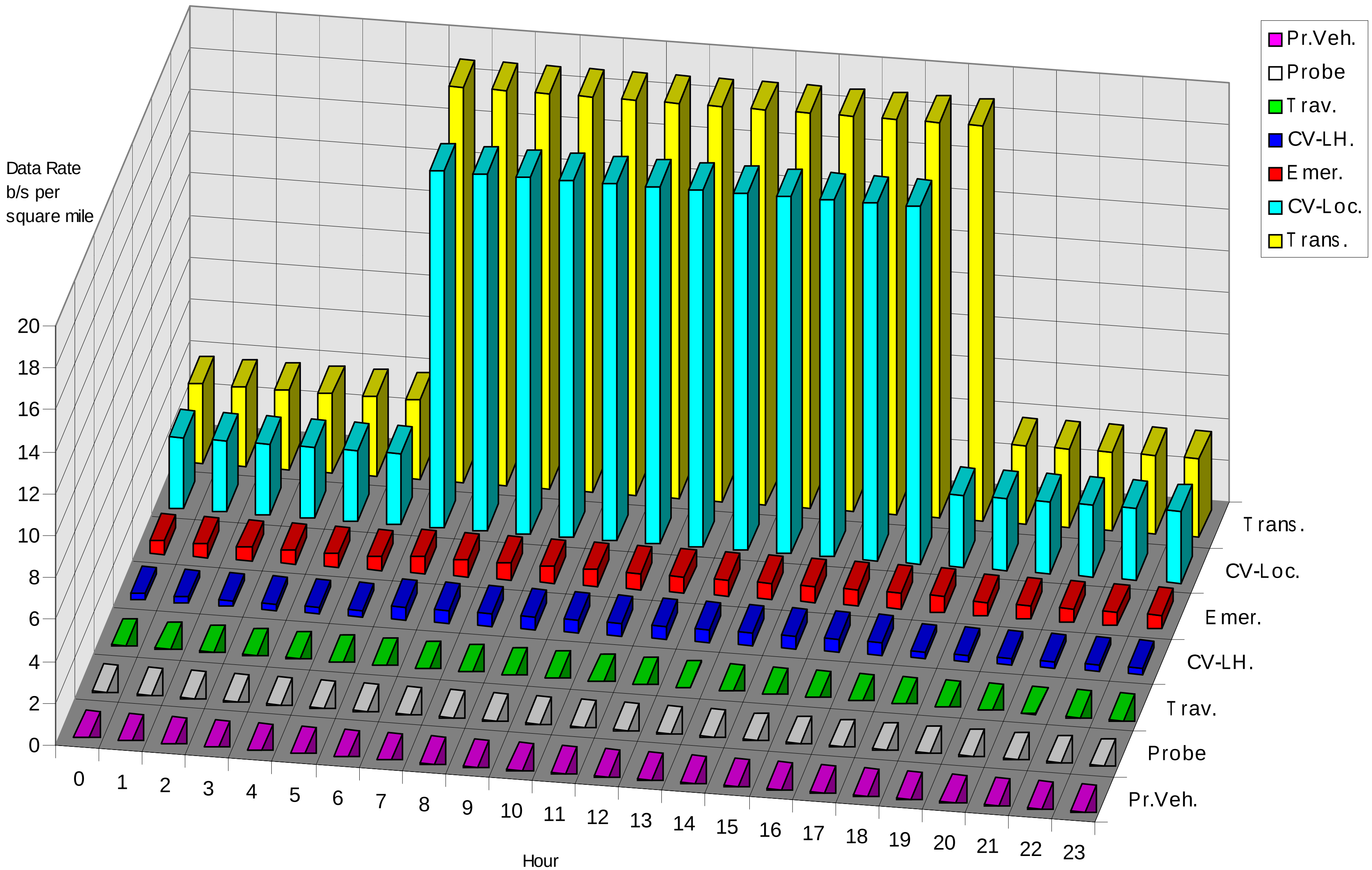


Figure 6.2-2 Data Loading by Service - Reverse, 1997, Urbansville

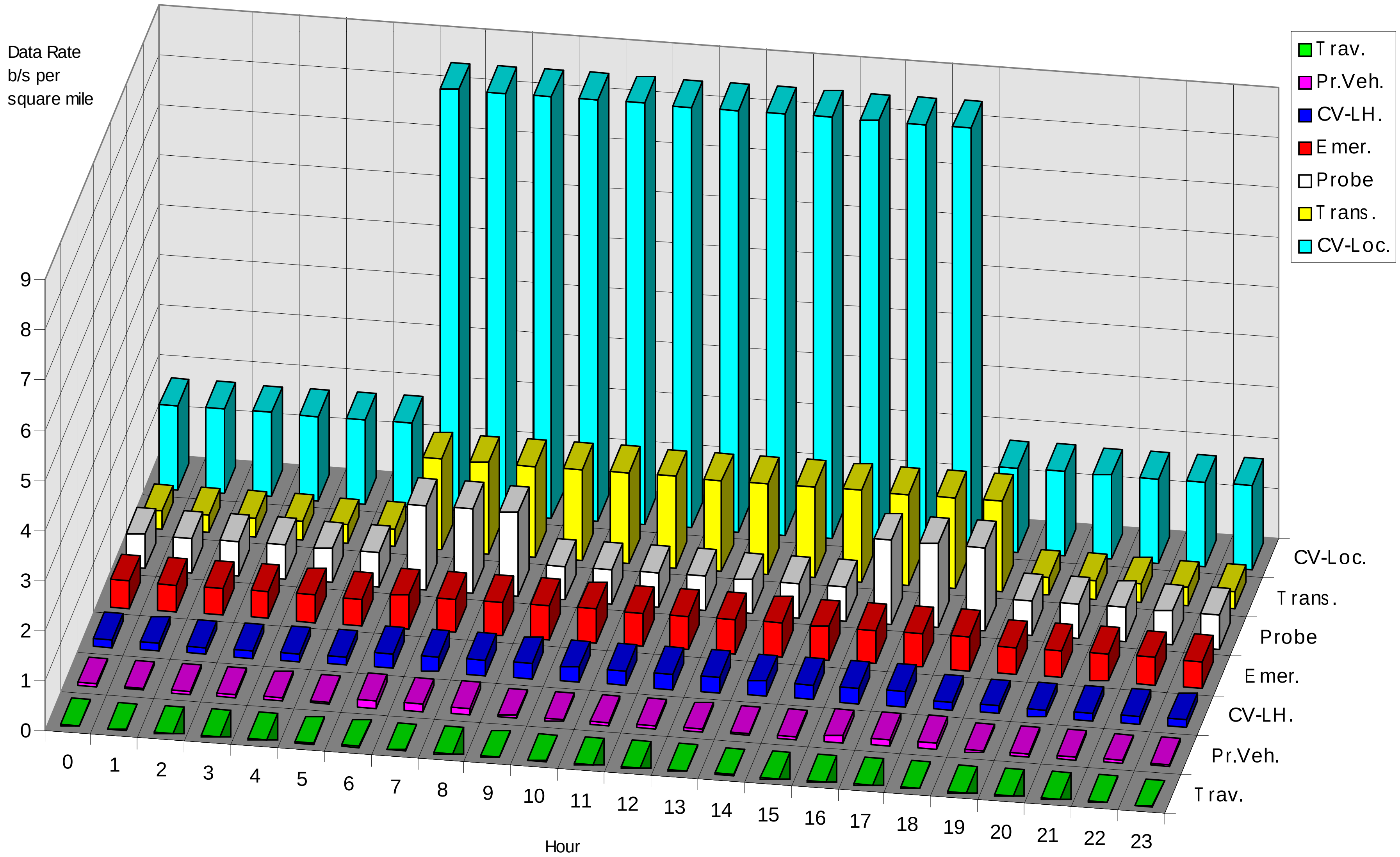


Figure 6.2-3 Total Data Loading, 1997, Urbansville.

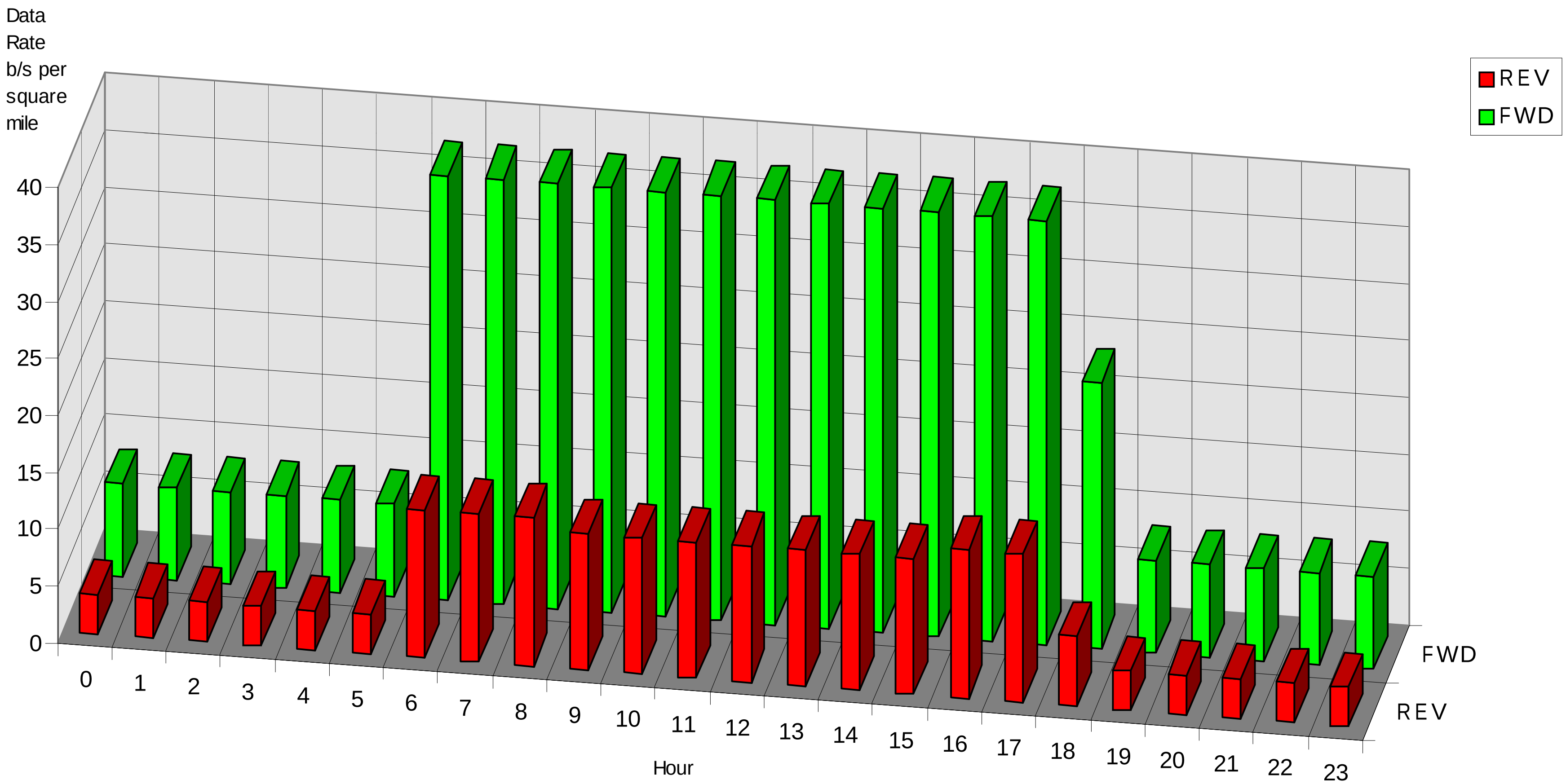


Figure 6.2-4 Data Loading by Service - Forward, 1997, Thruville.

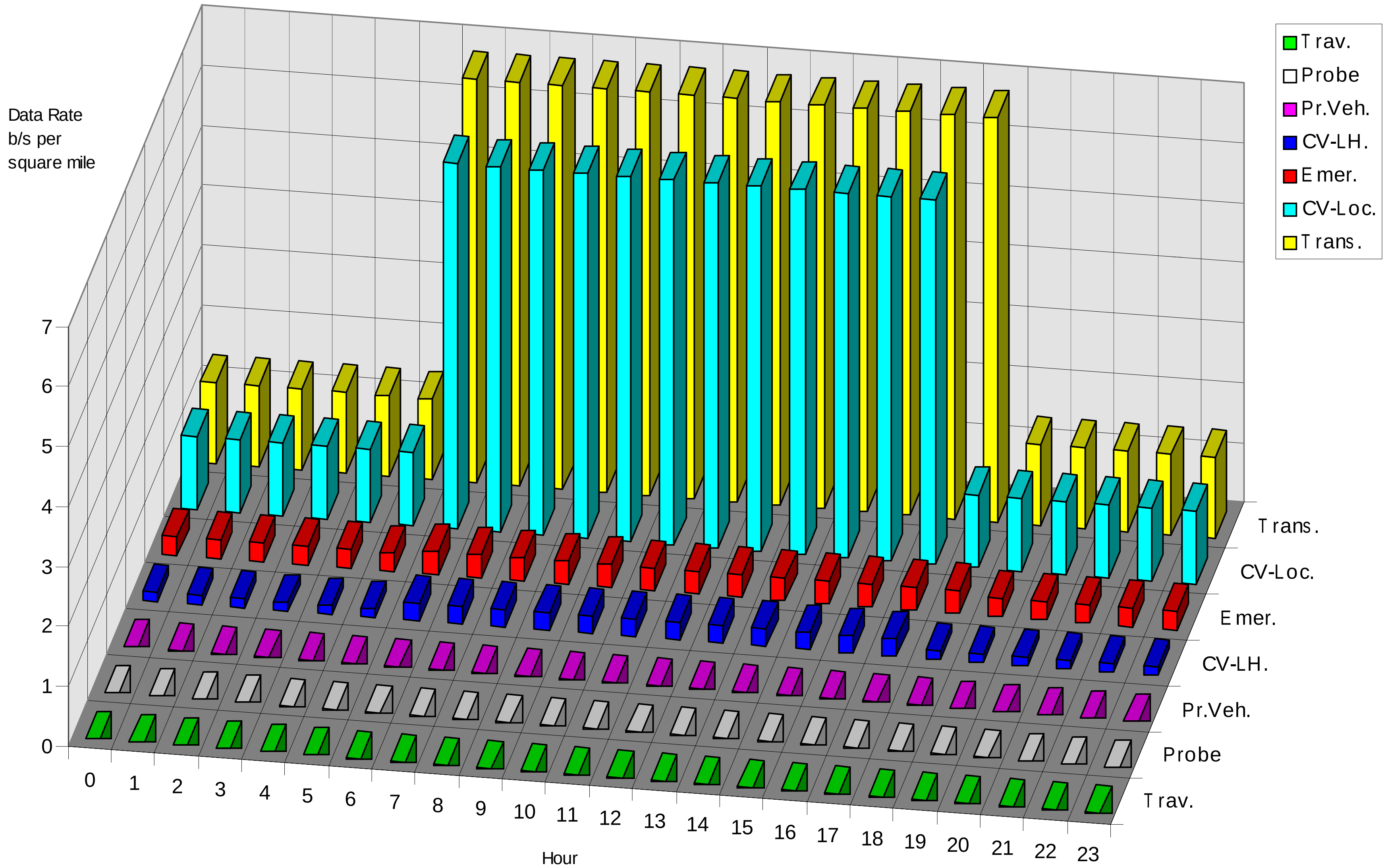


Figure 6.2-5 Data Loading by Service - Reverse, 1997, Thruville

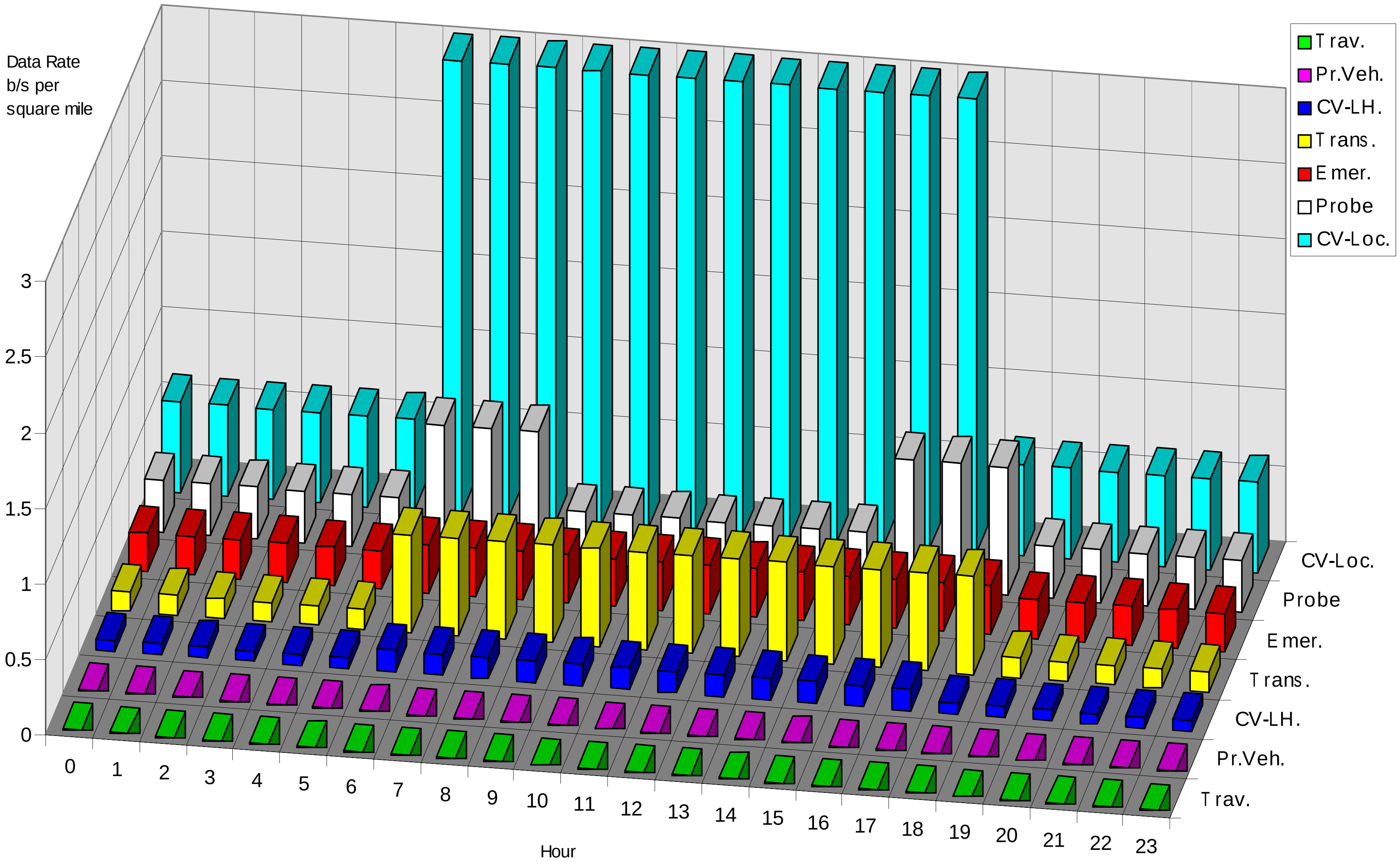


Figure 6.2-6 Total Data Loading, 1997, Thruville

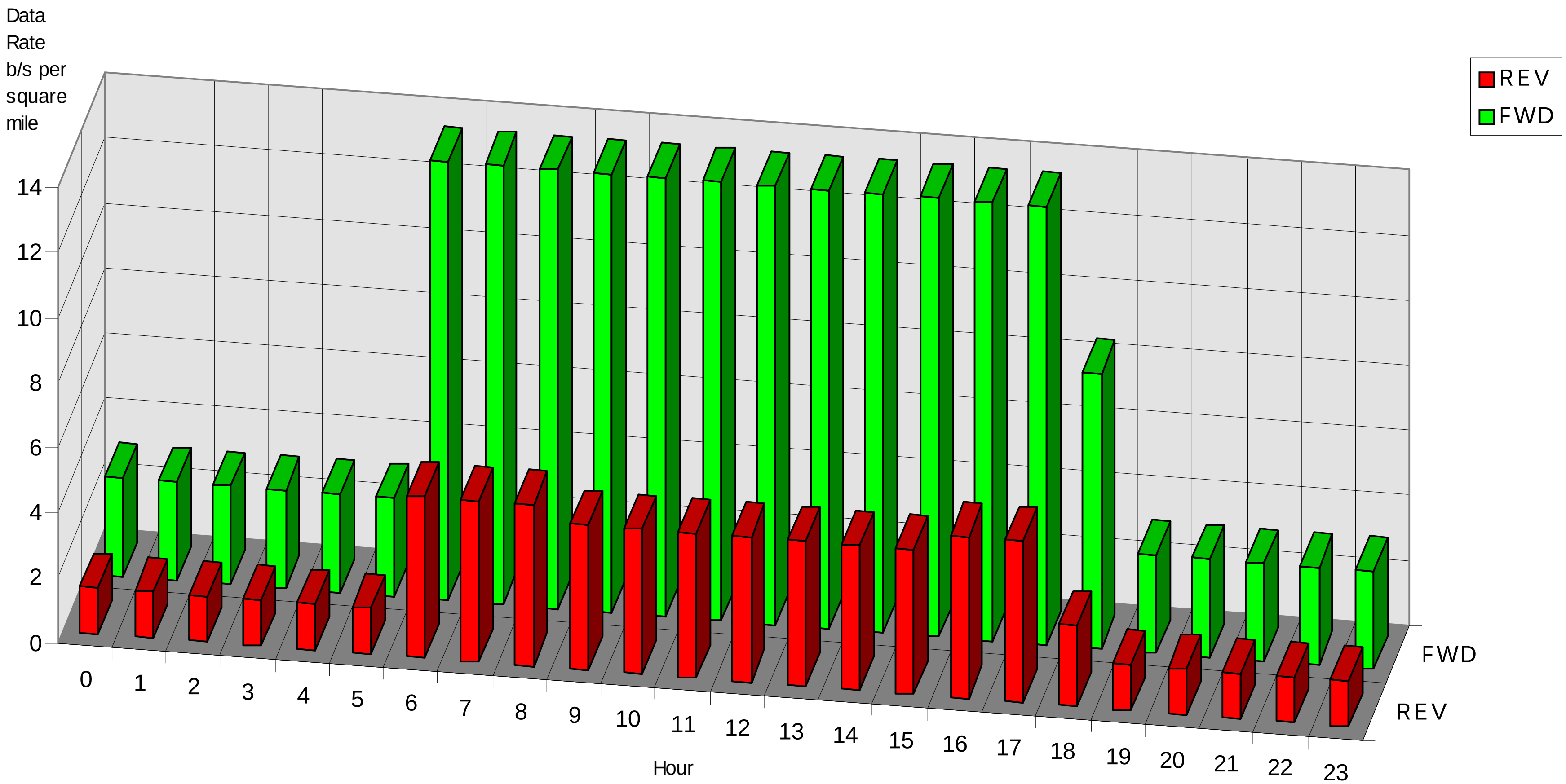


Figure 6.2-7 Data Loading by Service - Forward, 2002, Urbansville.

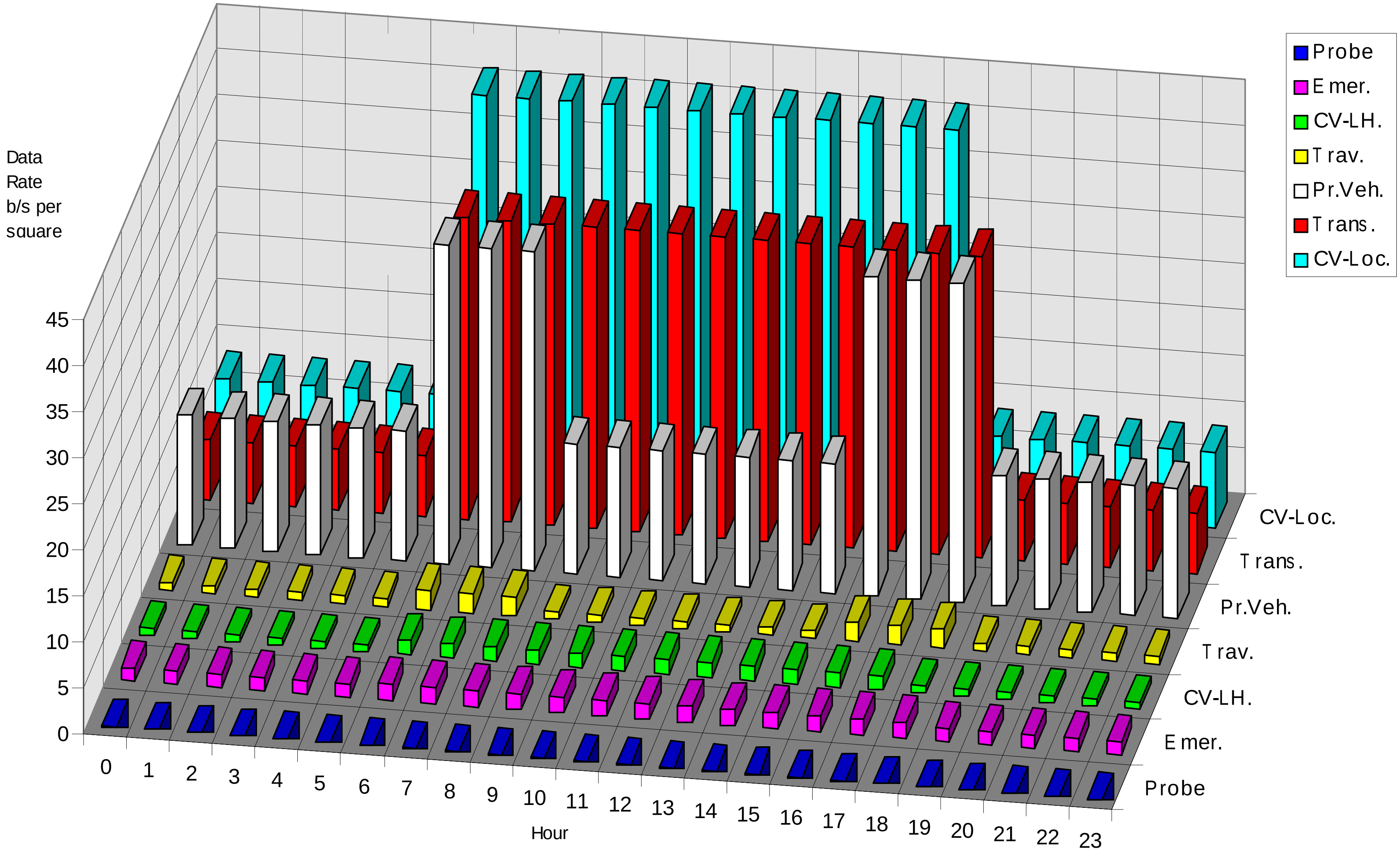


Figure 6.2-8 Data Loading by Service - Reverse, 2002, Urbansville.

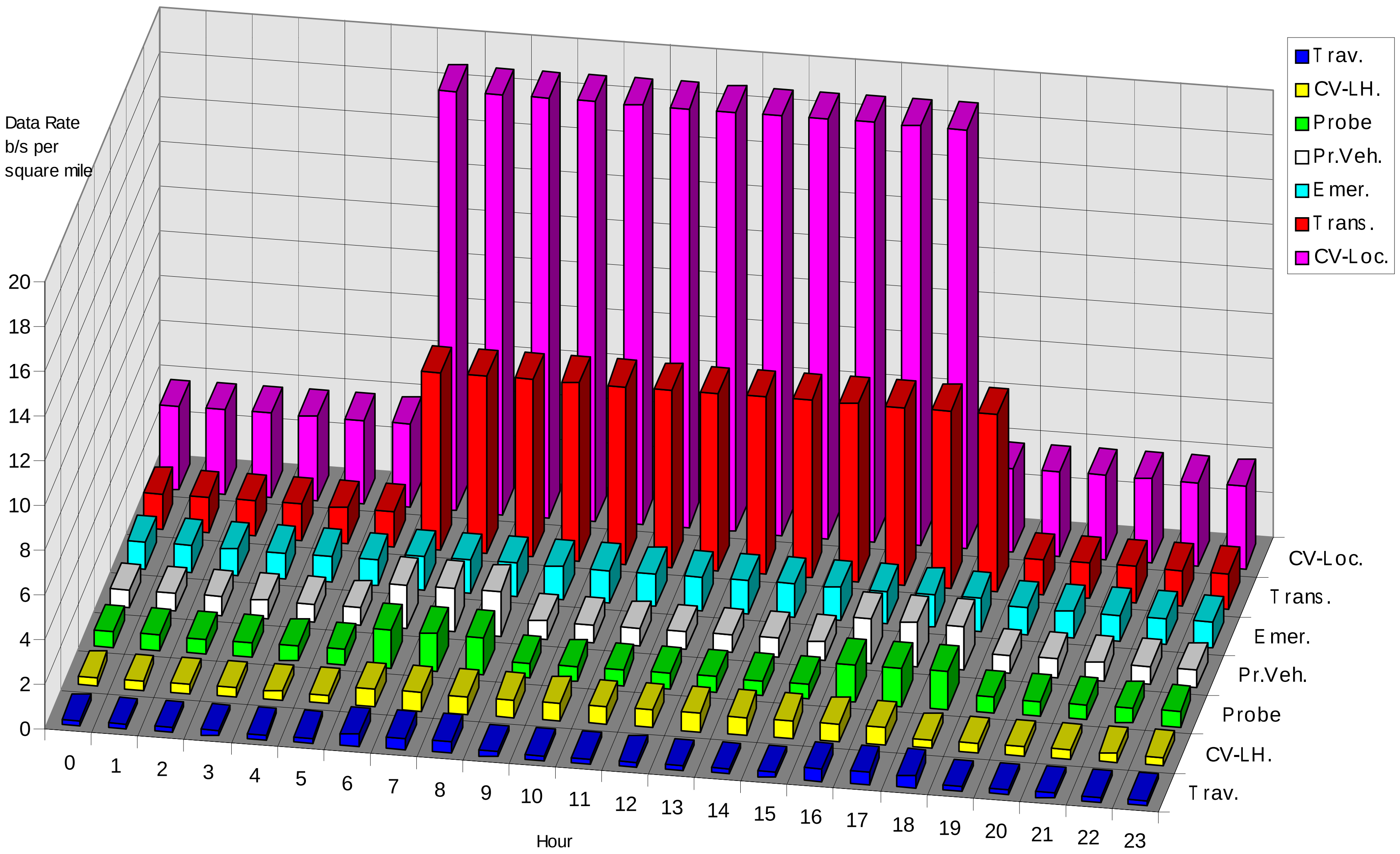


Figure 6.2-9 Total Data Loading, 2002, Urbansville.

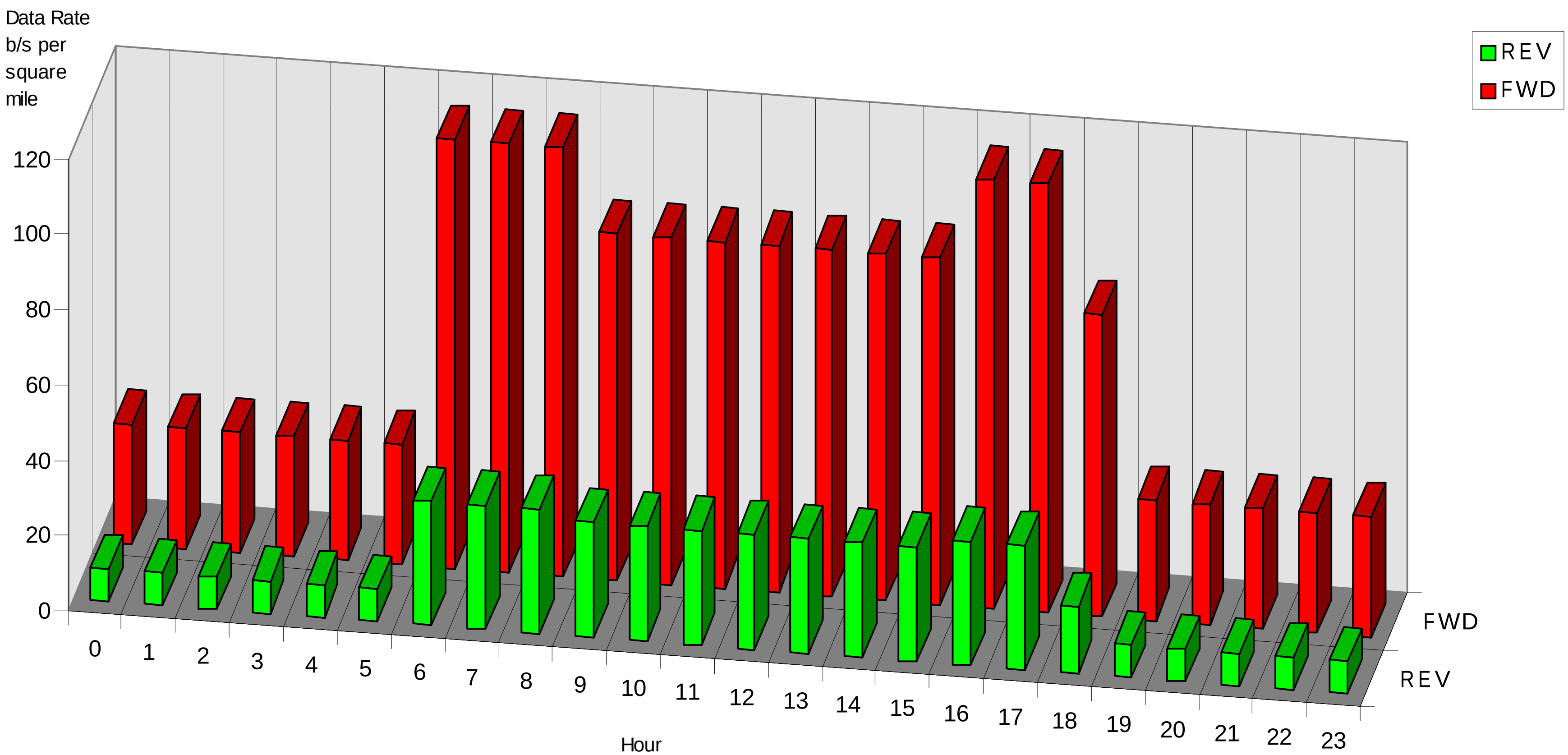


Figure 6.2-10 Data Loading by Service - Forward, 2002, Thruville.

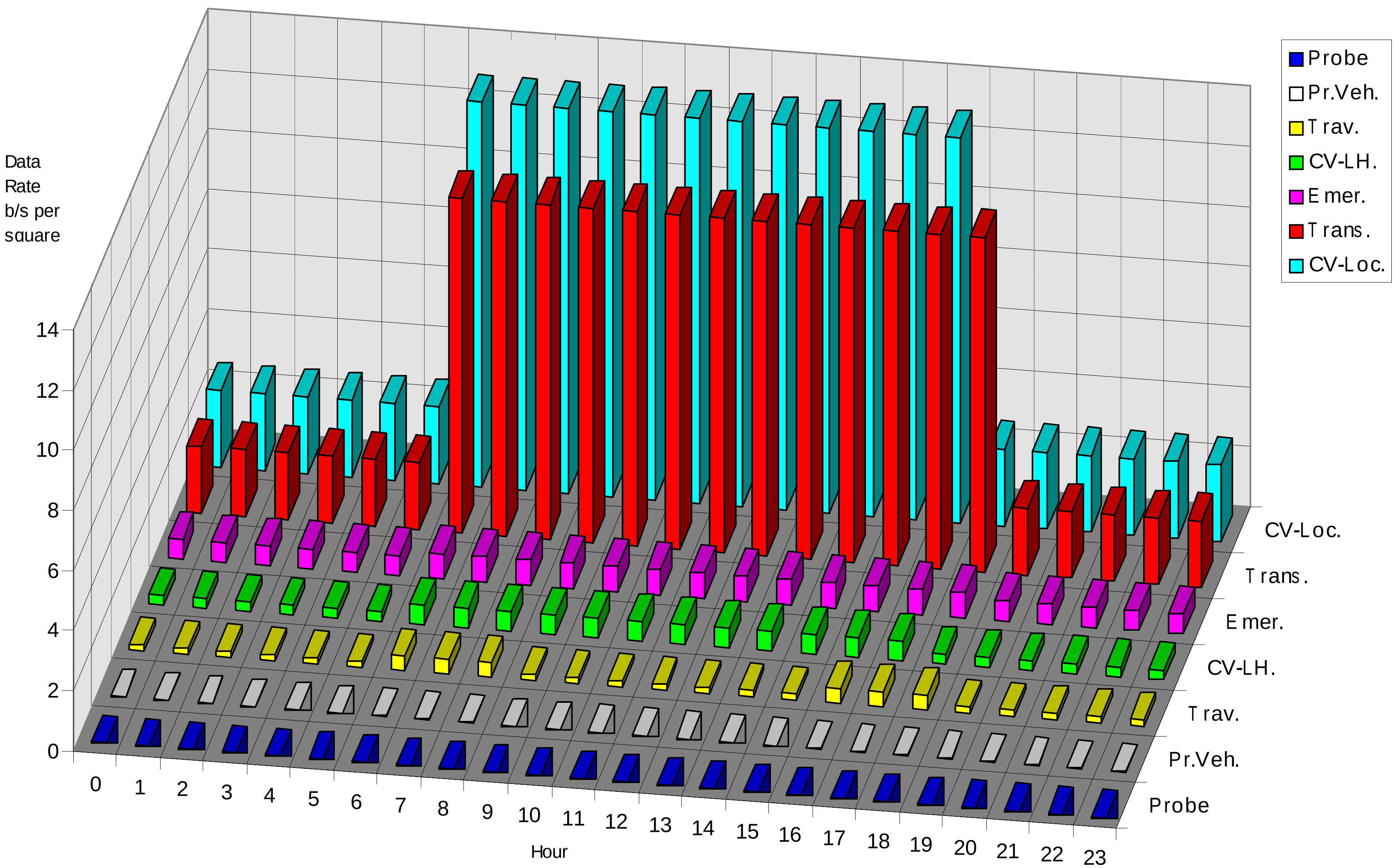


Figure 6.2-11 Data Loading by Service - Reverse, 2002, Thruville.

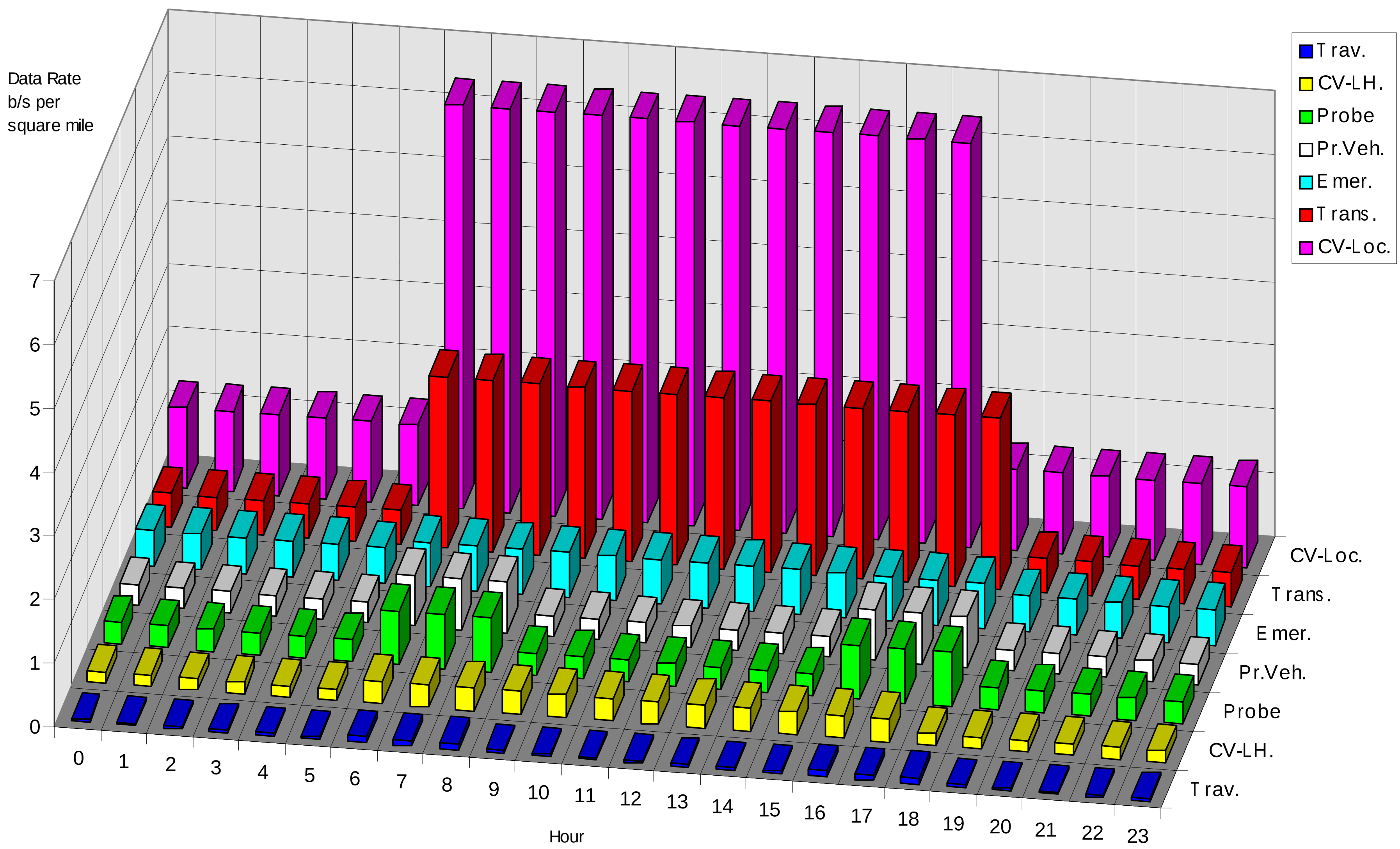


Figure 6.2-12 Total Data Loading, 2002, Thruville

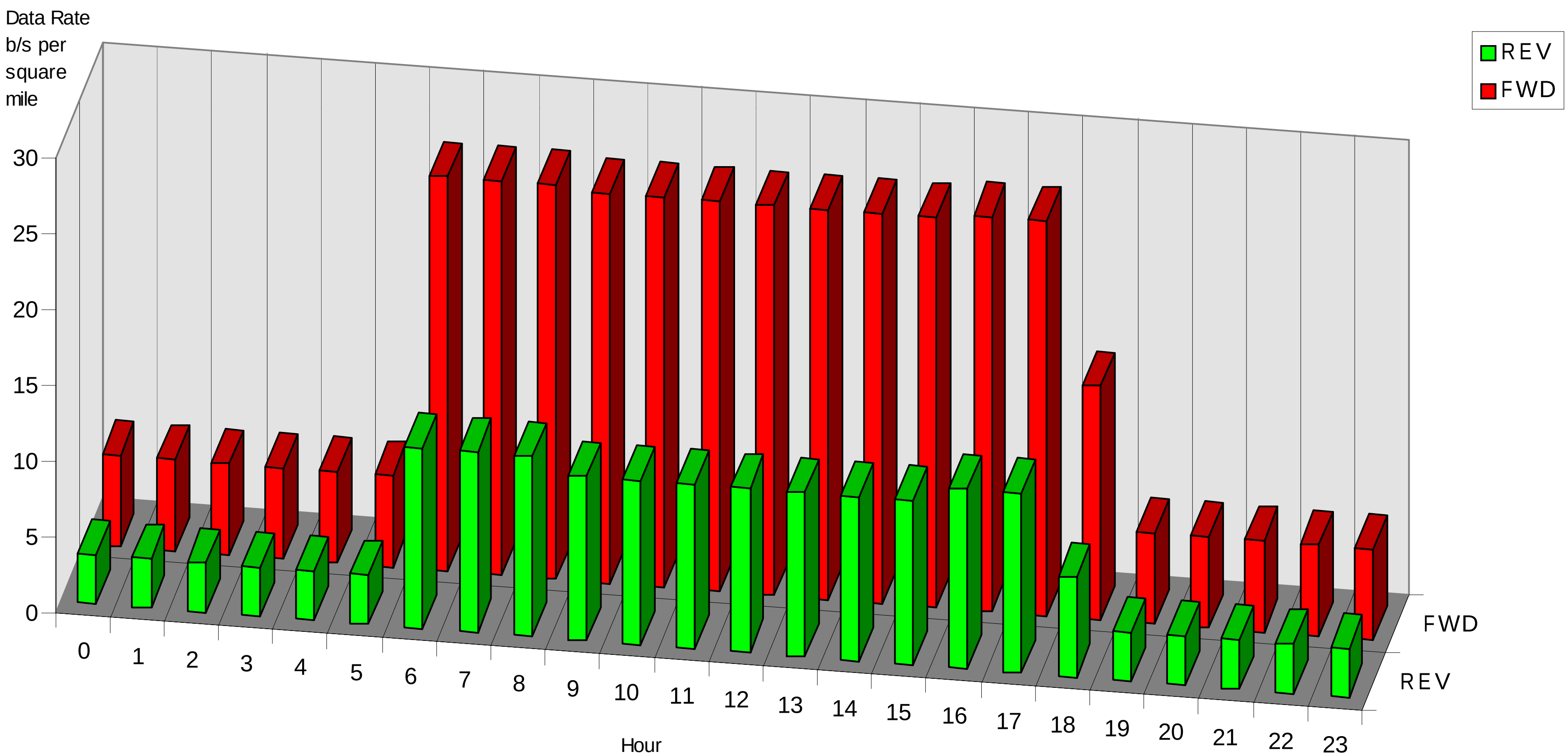


Figure 6.2-13 Data Loading by Service - Forward, 2002, Mountainville.

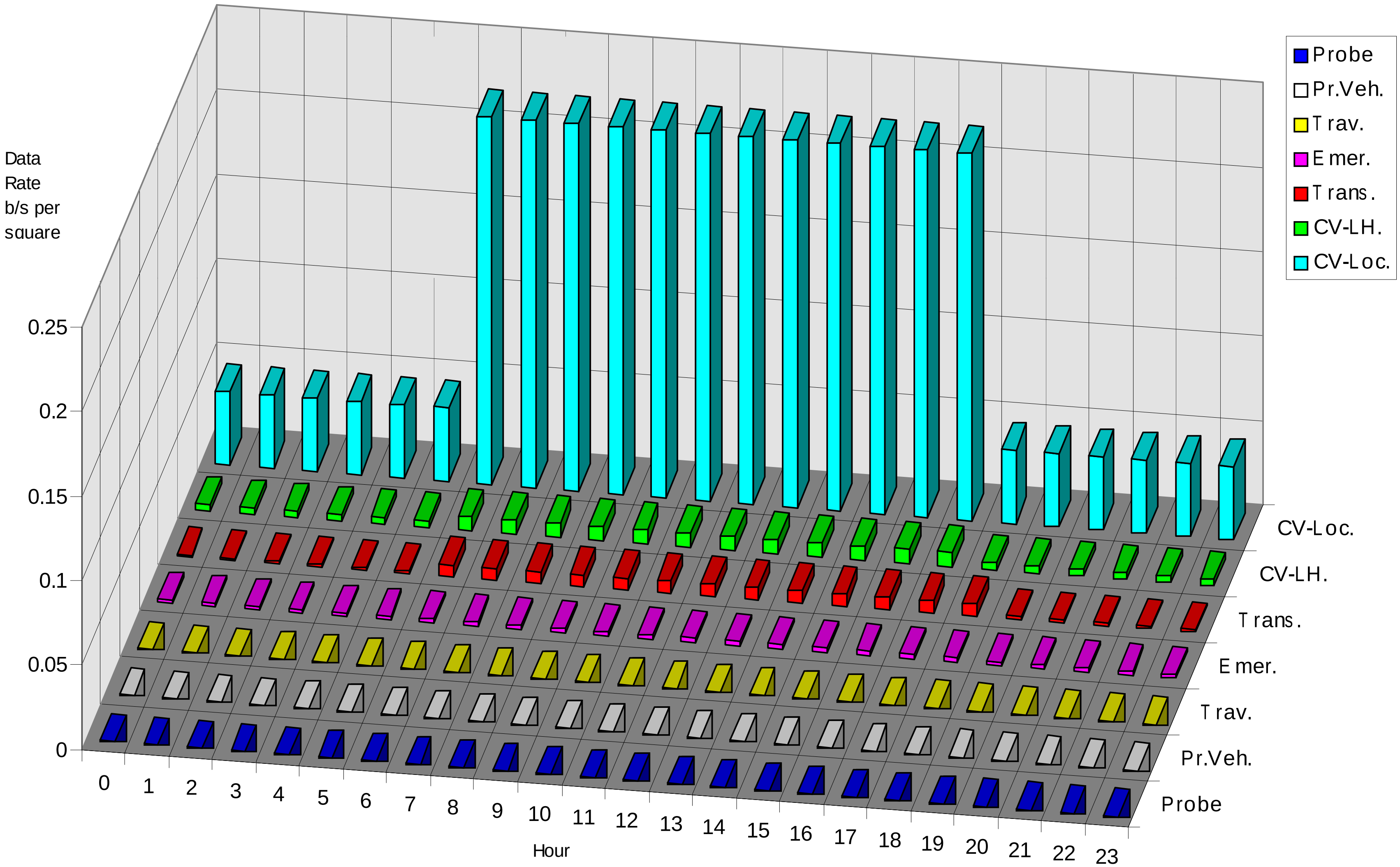


Figure 6.2-14 Data Loading by Service - Reverse, 2002, Mountainville.

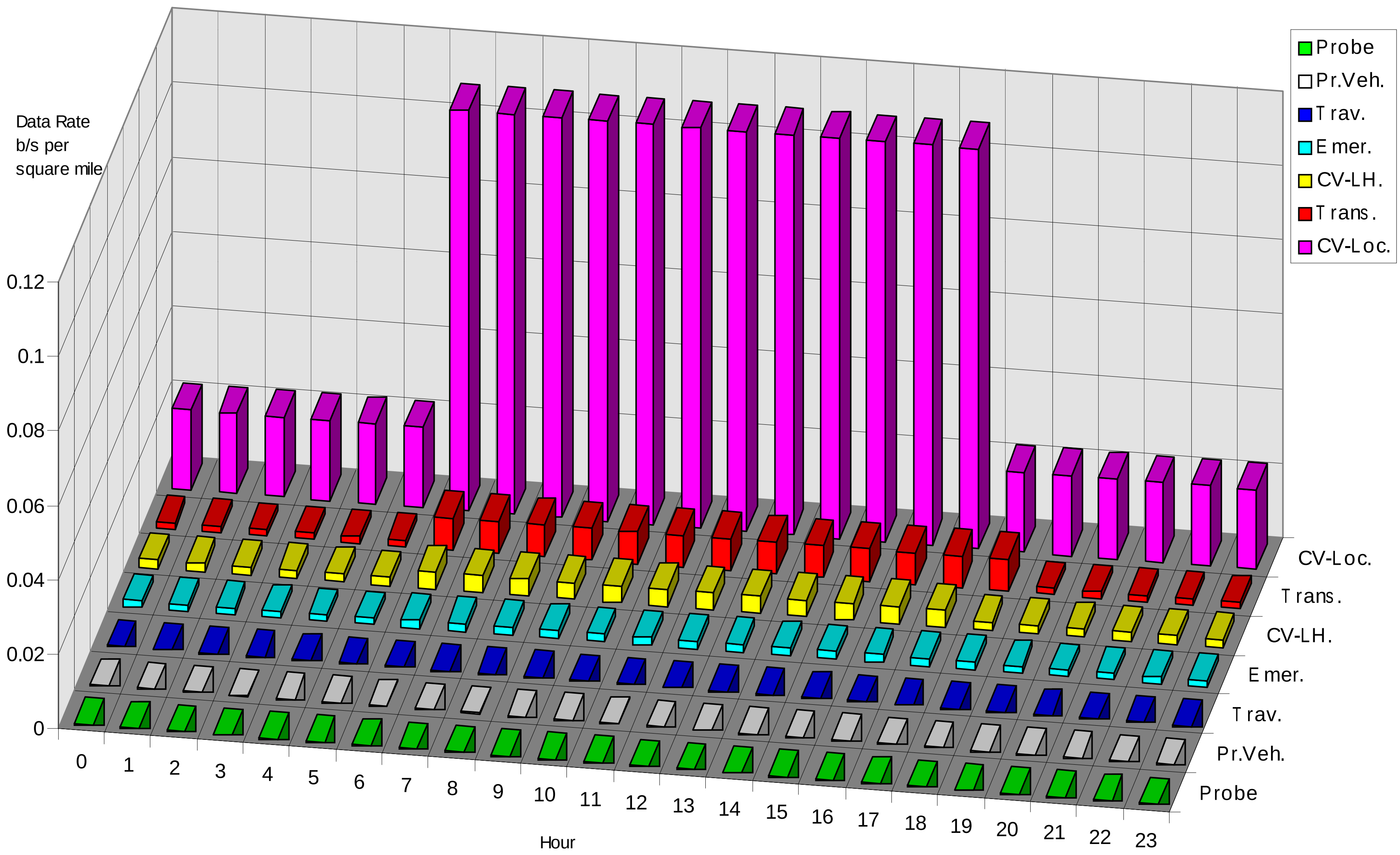


Figure 6.2-15 Total Data Loading, 2002, Mountainville.

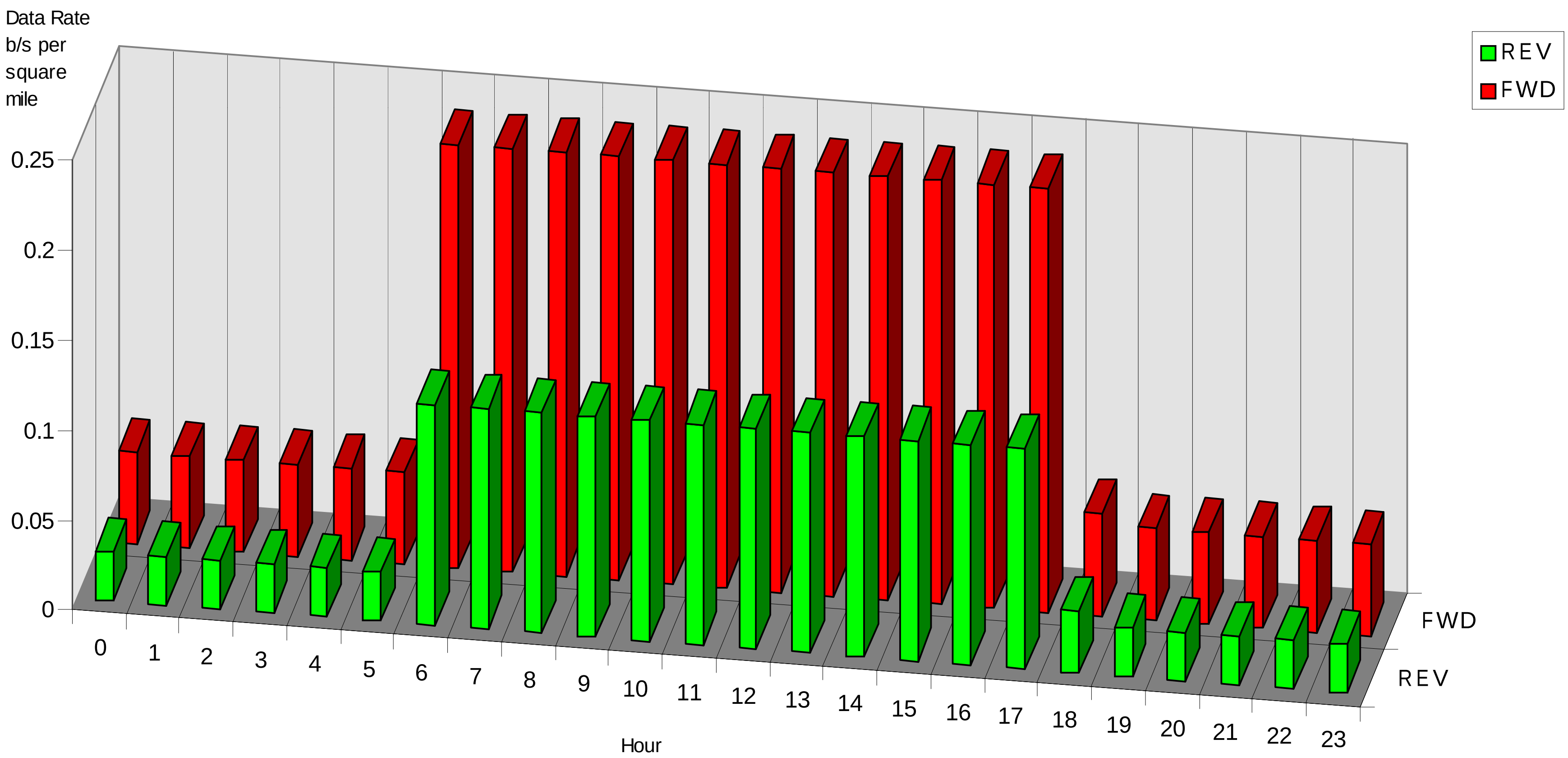


Figure 6.2-16 Data Loading by Service - Forward, 2012, Urbansville.

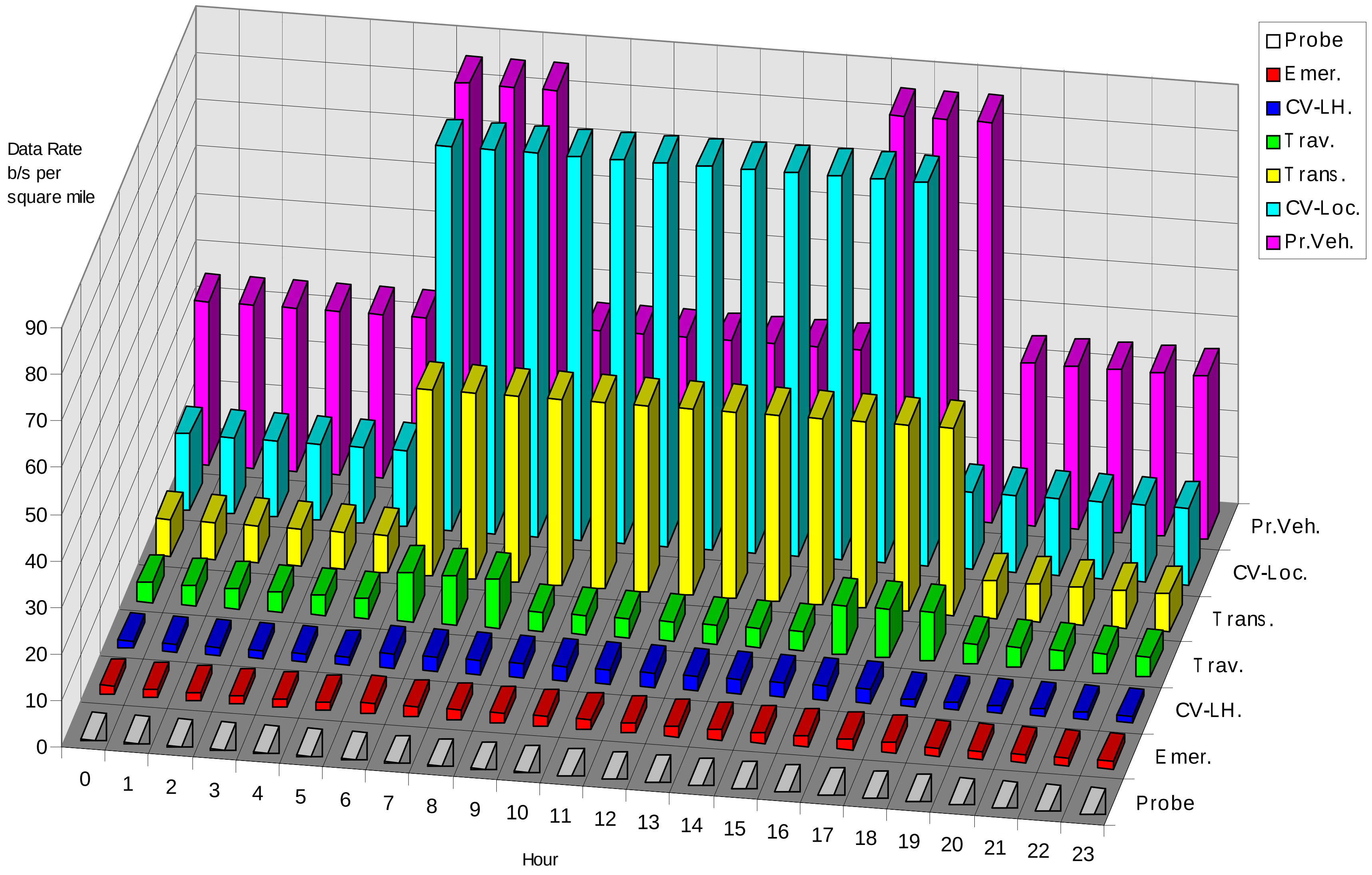


Figure 6.2-17 Data Loading by Service - Reverse, 2012, Urbansville

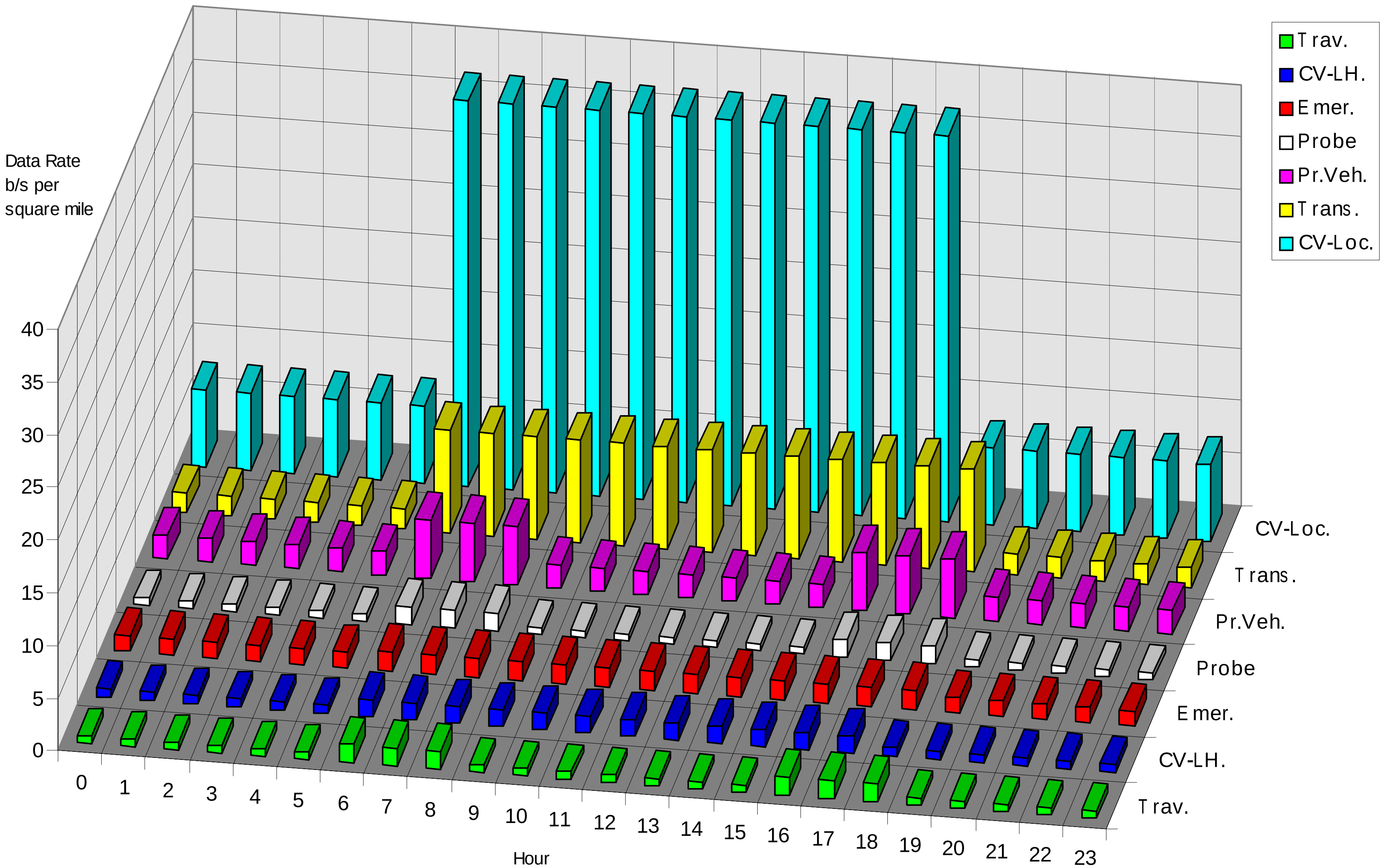


Figure 6.2.18 Total Data Loading, 2012, Urbansville.

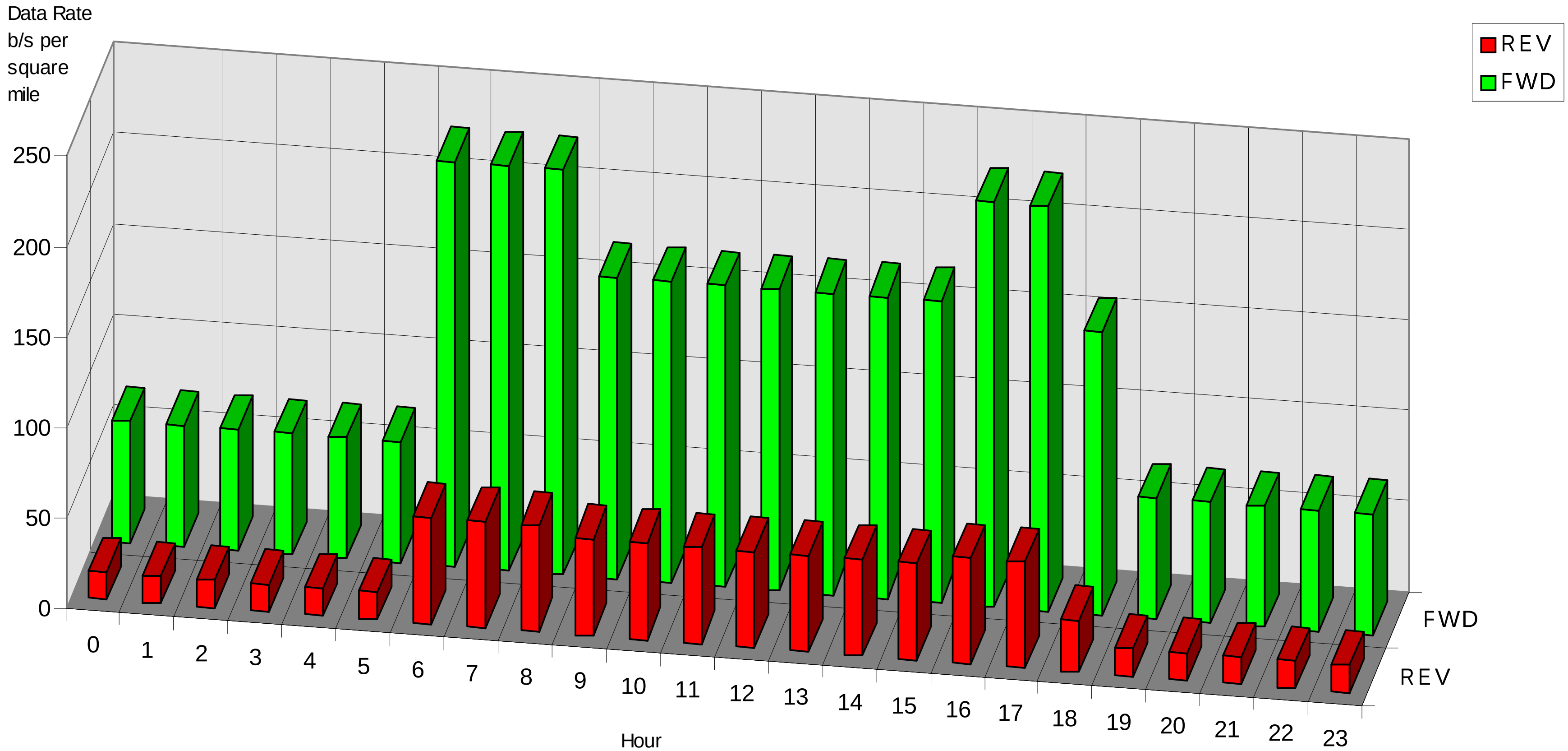


Figure 6.2-19 Data Loading by Service - Forward, 2012, Thruville.

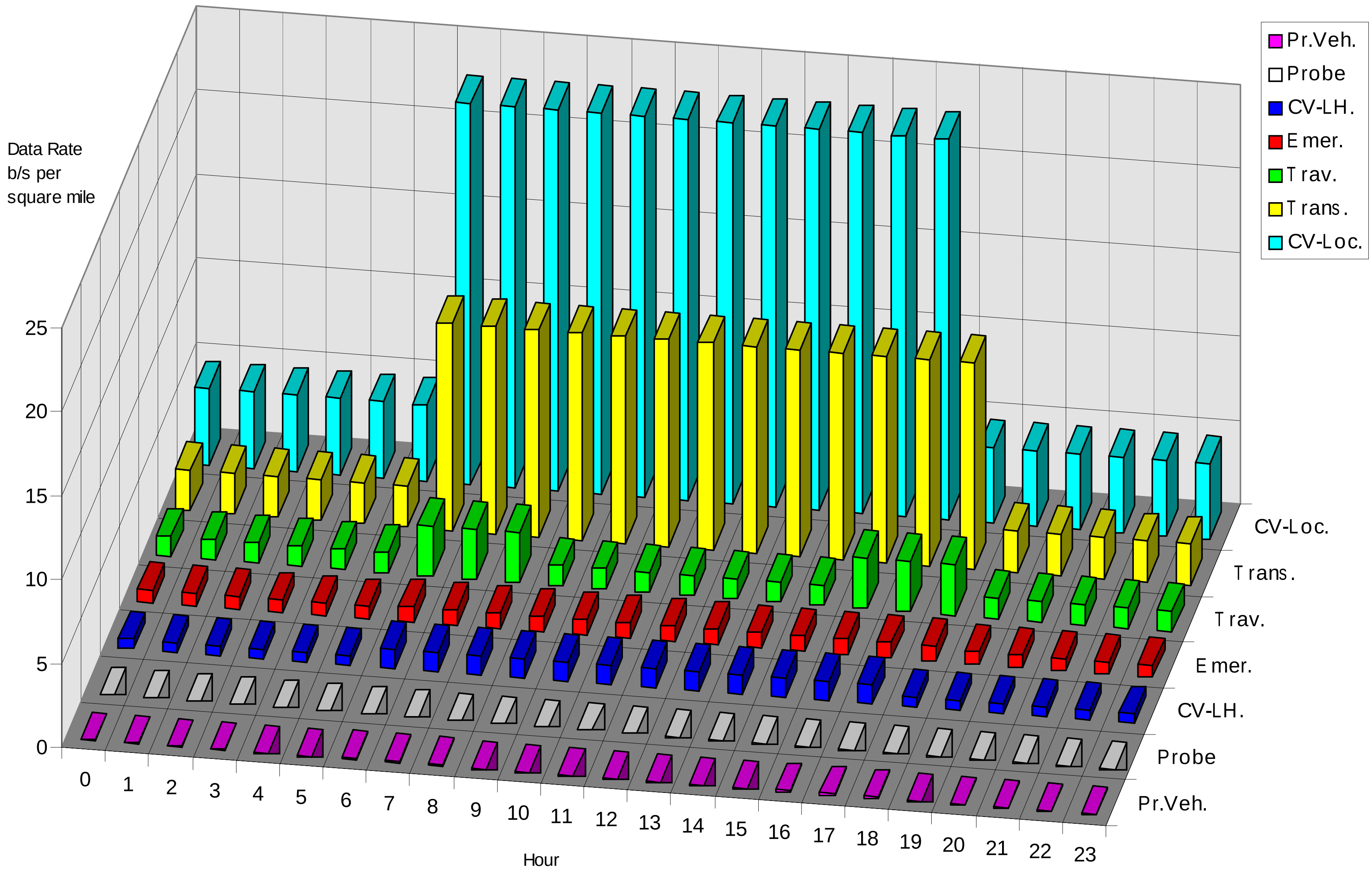


Figure 6.2-20 Data Loading by Service - Reverse, 2012, Thruville.

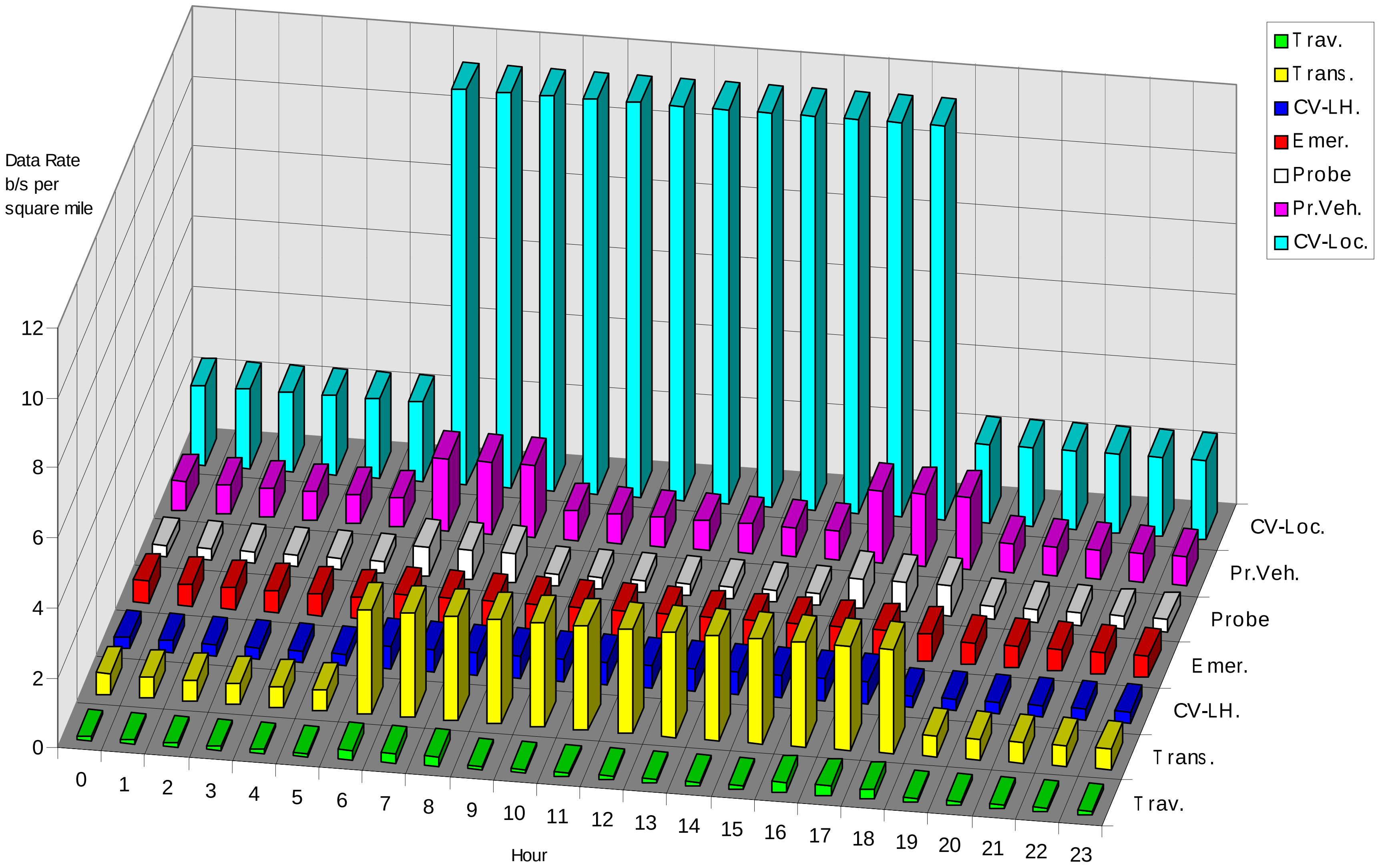


Figure 6.2-21 Total Data Loading, 2012, Thruville

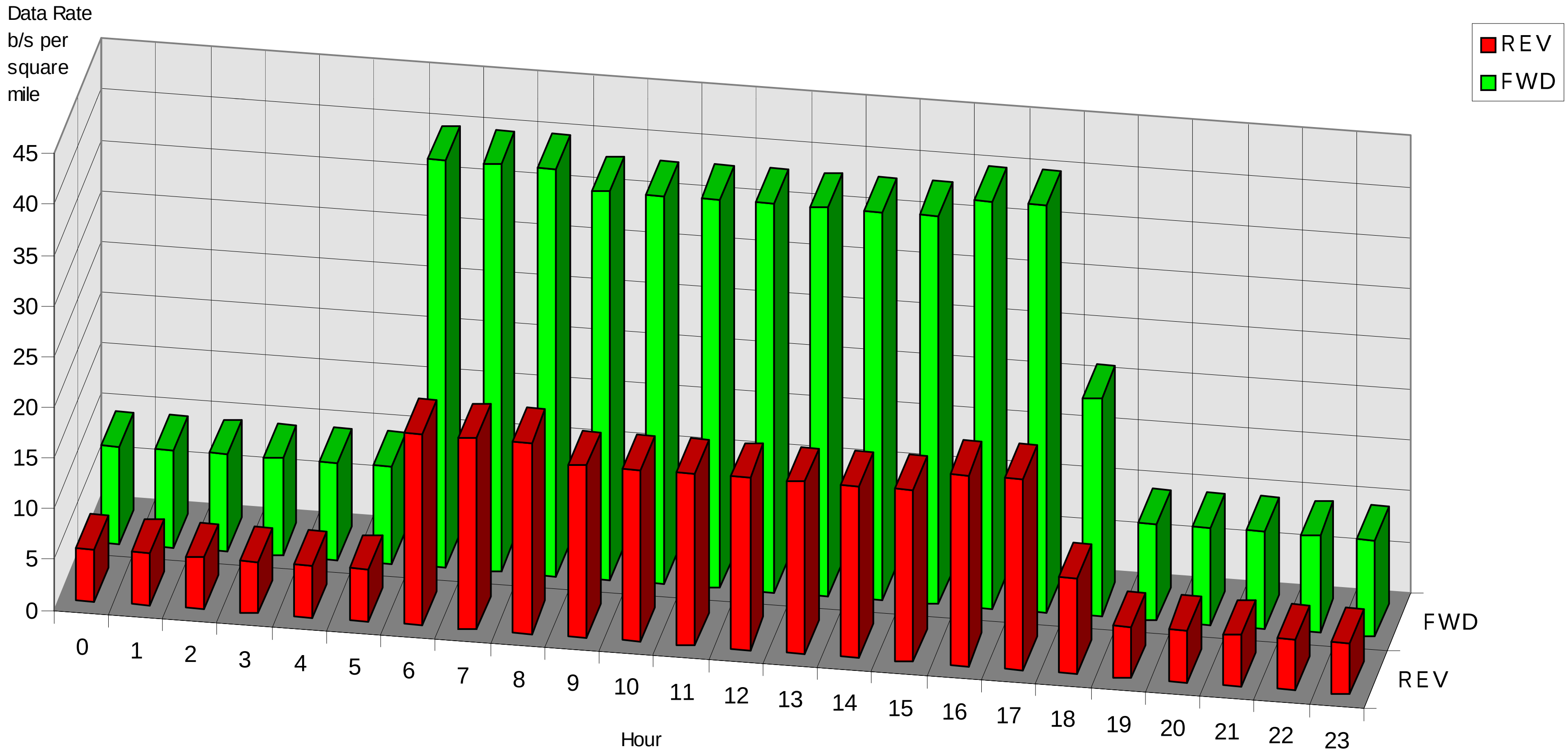


Figure 6.2-22 Data Loading by Service - Forward, 2012, Mountainville.

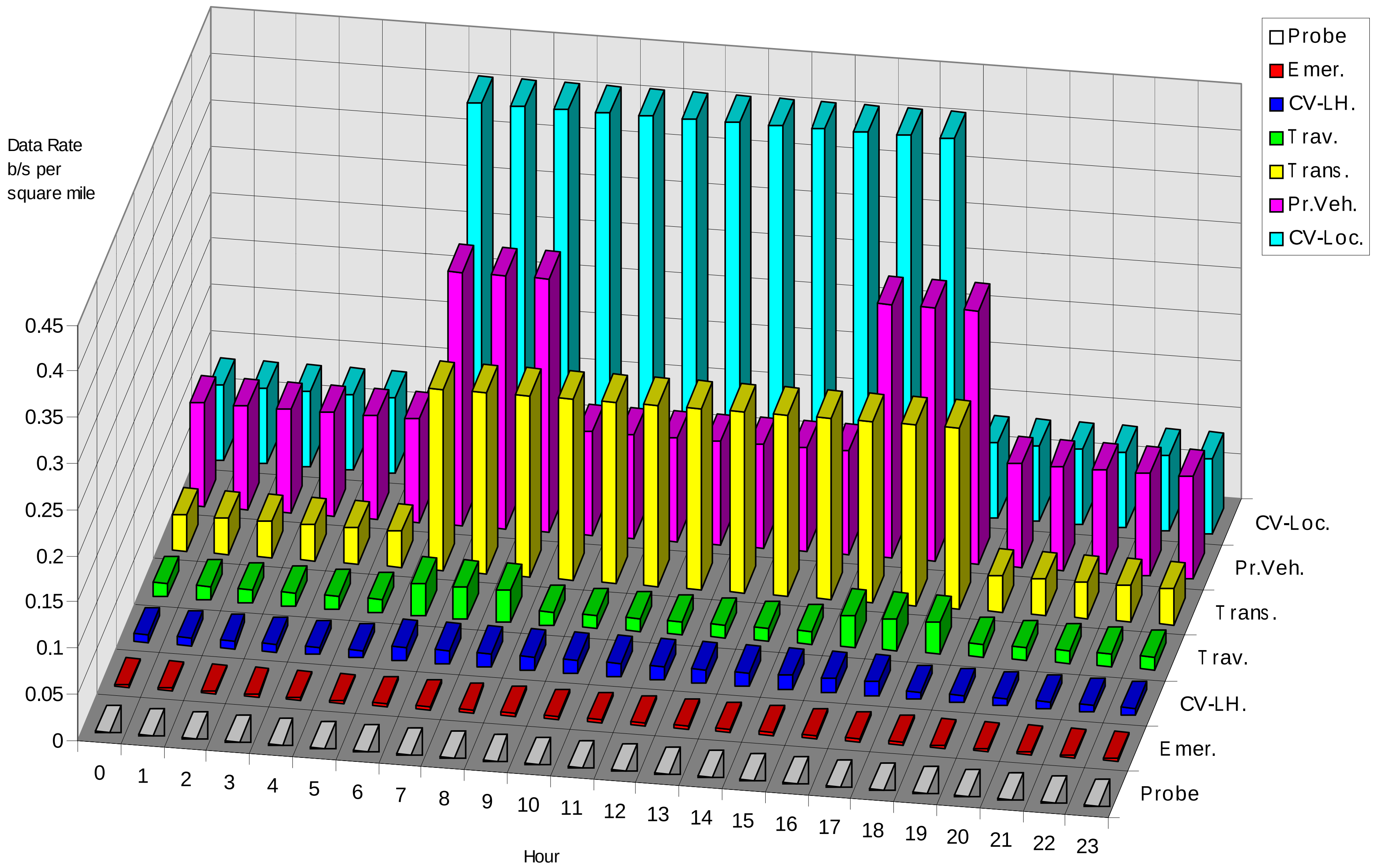


Figure 6.2-23 Data Loading by Service - Reverse, 2012, Mountainville.

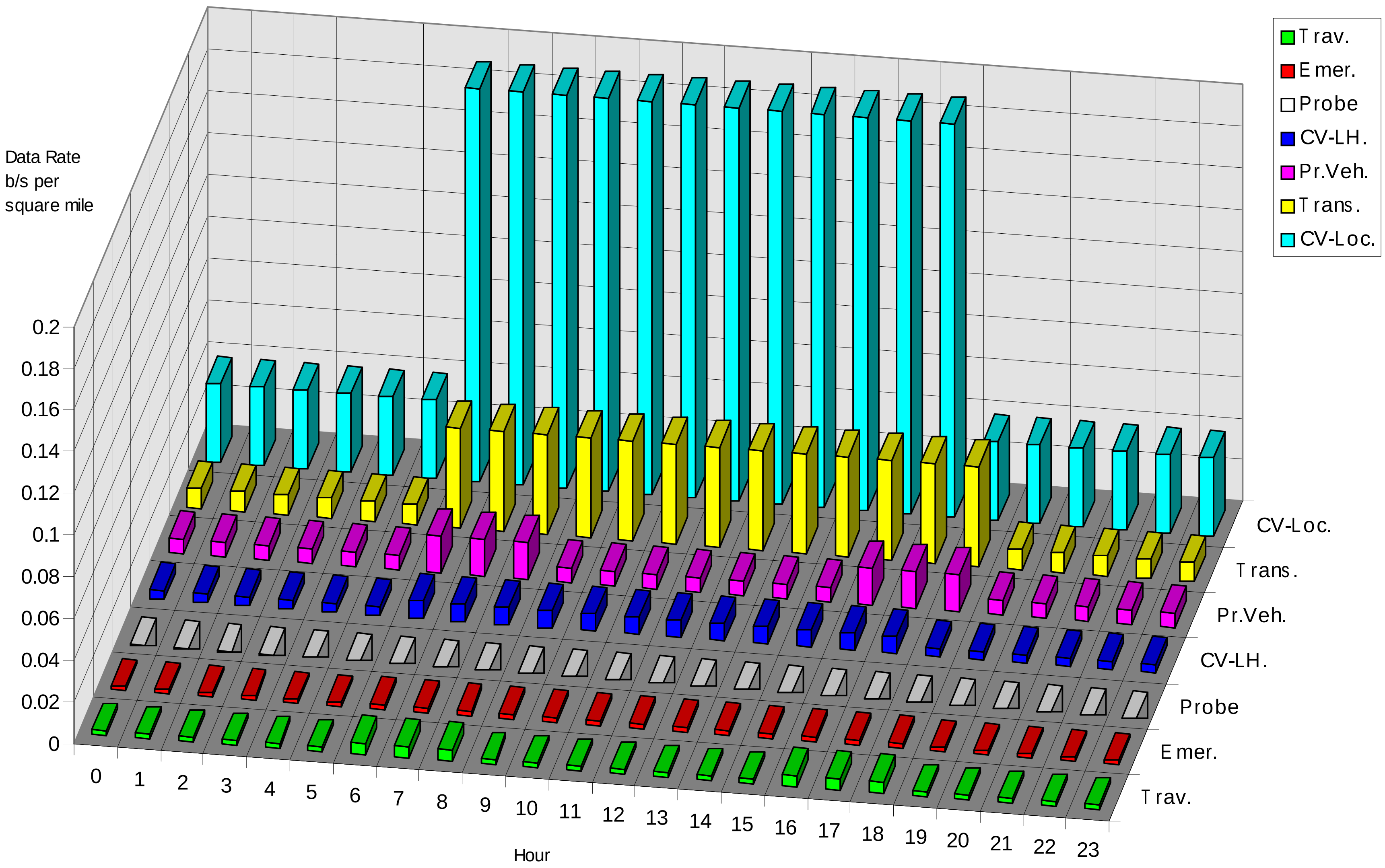


Figure 6.2-24 Total Data Loading, 2012, Mountainville.

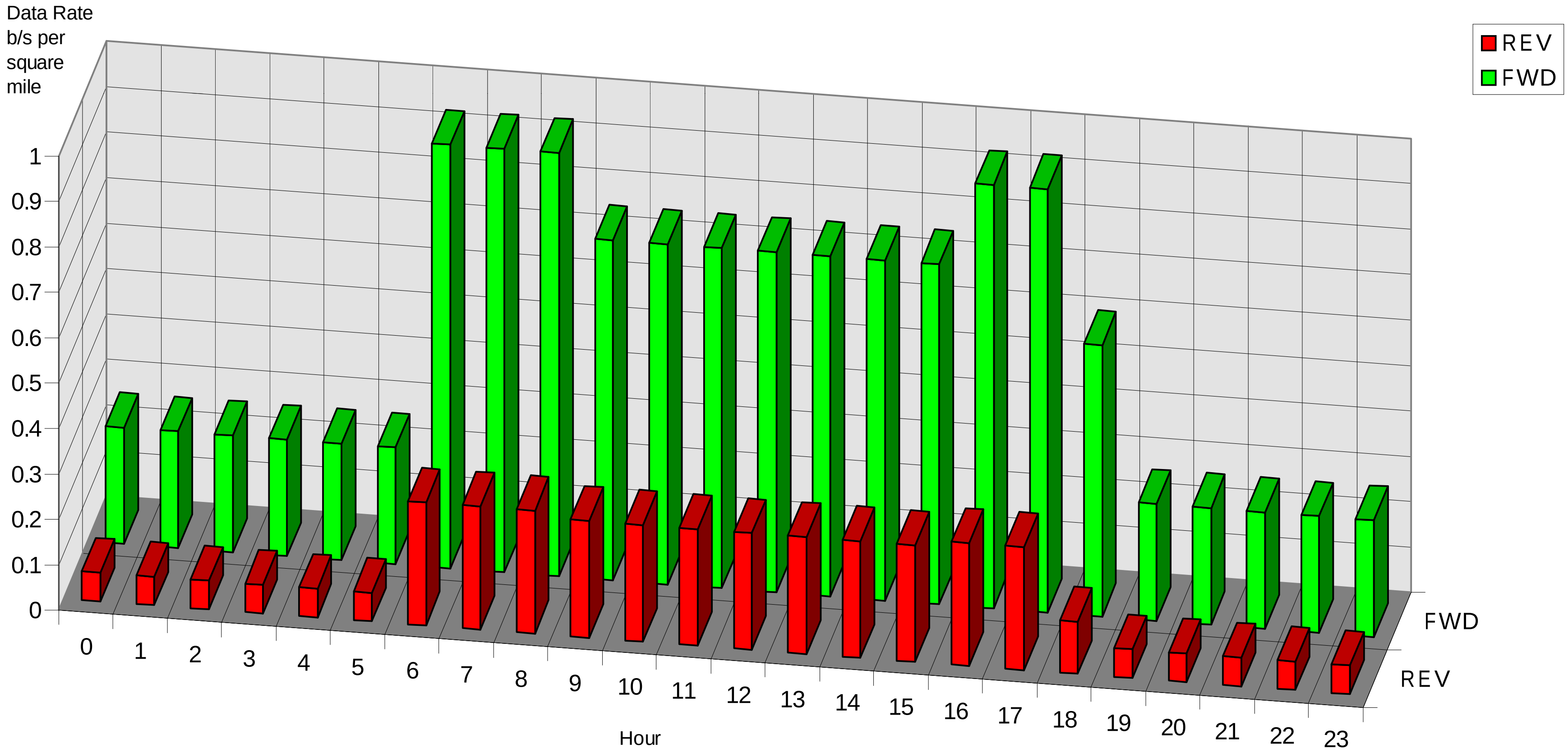


Table 6.2-1 Summary of Data Loading Results

Units are in bits per second per square mile.
No ITS deployment is assumed for Mountainville in 1997.

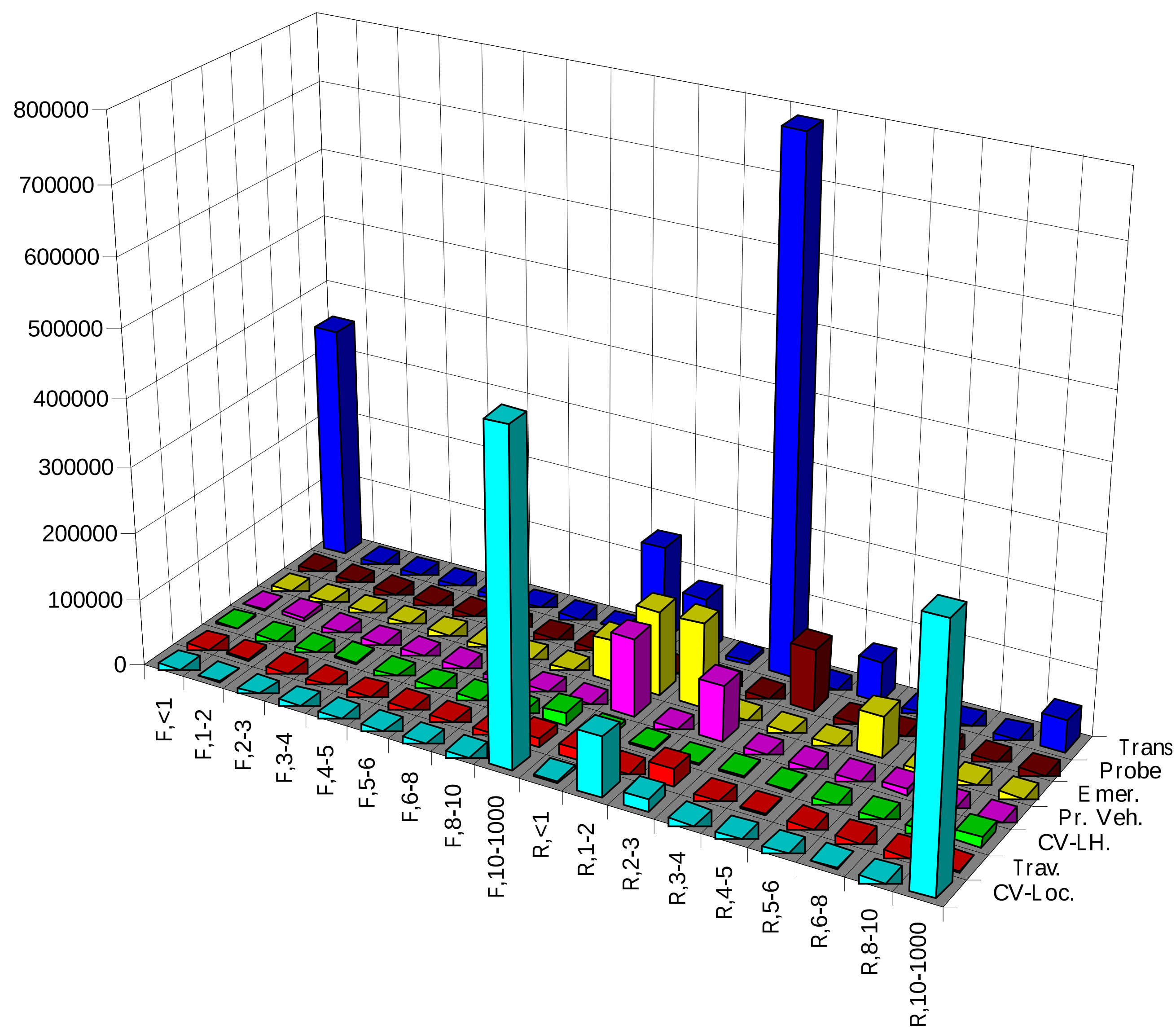
Year	Region	Direc.	Peak/Off-Peak	Pr.Veh.	Trav.	CV-Loc.	CV-LH.	Trans.	Emer.	Probe	TOTAL
1997	Urbansville	Fwd.	Peak per sq. mile:	0.00011	0.001	17.0426	0.61086	18.852	0.8055	0	37.312
1997	Urbansville	Fwd.	Off-Pk. per sq. mile:	4.6E-05	0.0004	3.40851	0.30543	3.7705	0.6444	0	8.1293
1997	Urbansville	Rev.	Peak per sq. mile:	0.13586	0.0153	8.40969	0.30144	1.8146	0.6722	1.676	13.025
1997	Urbansville	Rev.	Off-Pk. per sq. mile:	0.05529	0.0062	1.68194	0.15072	0.3629	0.5377	0.682	3.4768
1997	Thruville	Fwd.	Peak per sq. mile:	0	0	6.08559	0.2901	6.7306	0.3857	0	13.492
1997	Thruville	Fwd.	Off-Pk. per sq. mile:	0	0	1.21712	0.14505	1.3461	0.3086	0	3.0168
1997	Thruville	Rev.	Peak per sq. mile:	0	0	2.99933	0.14247	0.6479	0.3219	0.848	4.9598
1997	Thruville	Rev.	Off-Pk. per sq. mile:	0	0	0.59987	0.07123	0.1296	0.2575	0.345	1.4034
2002	Urbansville	Fwd.	Peak per sq. mile:	34.7122	2.0606	41.1999	1.55927	32.765	1.7521	0	114.05
2002	Urbansville	Fwd.	Off-Pk. per sq. mile:	14.1278	0.8387	8.23998	0.77963	6.553	1.4017	0	31.941
2002	Urbansville	Rev.	Peak per sq. mile:	1.96875	0.5357	18.6967	0.79403	7.9048	1.4732	1.676	33.049
2002	Urbansville	Rev.	Off-Pk. per sq. mile:	0.80128	0.218	3.73934	0.39701	1.581	1.1786	0.682	8.5972
2002	Thruville	Fwd.	Peak per sq. mile:	0.02433	0.48	12.8178	0.64325	11.136	0.8377	0	25.939
2002	Thruville	Fwd.	Off-Pk. per sq. mile:	0.0099	0.1954	2.56356	0.32162	2.2272	0.6702	0	5.9879
2002	Thruville	Rev.	Peak per sq. mile:	0.7944	0.0954	6.35185	0.35812	2.6867	0.7044	0.848	11.839
2002	Thruville	Rev.	Off-Pk. per sq. mile:	0.32332	0.0388	1.27037	0.17906	0.5373	0.5635	0.345	3.2577
2002	Mountainville	Fwd.	Peak per sq. mile:	4.1E-06	4E-08	0.21779	0.00823	0.0071	0.0025	0	0.2356
2002	Mountainville	Fwd.	Off-Pk. per sq. mile:	1.7E-06	2E-08	0.04356	0.00412	0.0014	0.002	0	0.0511
2002	Mountainville	Rev.	Peak per sq. mile:	6.5E-05	5E-07	0.10728	0.00452	0.0086	0.0021	0	0.1226
2002	Mountainville	Rev.	Off-Pk. per sq. mile:	2.7E-05	2E-07	0.02146	0.00226	0.0017	0.0017	0	0.0272
2012	Urbansville	Fwd.	Peak per sq. mile:	85.7982	10.484	82.056	3.1208	39.951	2.1606	0	223.57
2012	Urbansville	Fwd.	Off-Pk. per sq. mile:	34.9199	4.2668	16.4112	1.5604	7.9901	1.7285	0	66.877
2012	Urbansville	Rev.	Peak per sq. mile:	5.52382	1.7617	36.5907	1.57015	9.6664	1.8167	1.676	58.605
2012	Urbansville	Rev.	Off-Pk. per sq. mile:	2.24819	0.717	7.31814	0.78508	1.9333	1.4534	0.682	15.137
2012	Thruville	Fwd.	Peak per sq. mile:	0.11331	3.0041	22.6488	1.14186	12.298	0.9255	0	40.132
2012	Thruville	Fwd.	Off-Pk. per sq. mile:	0.04612	1.2227	4.52976	0.57093	2.4596	0.7404	0	9.5695
2012	Thruville	Rev.	Peak per sq. mile:	2.04407	0.2819	11.2614	0.64279	2.9756	0.7782	0.848	18.832
2012	Thruville	Rev.	Off-Pk. per sq. mile:	0.83194	0.1147	2.25227	0.3214	0.5951	0.6226	0.345	5.0833
2012	Mountainville	Fwd.	Peak per sq. mile:	0.27402	0.0344	0.40793	0.0156	0.1966	0.0029	0	0.9315
2012	Mountainville	Fwd.	Off-Pk. per sq. mile:	0.11153	0.014	0.08159	0.0078	0.0393	0.0023	0	0.2566
2012	Mountainville	Rev.	Peak per sq. mile:	0.01764	0.0058	0.18869	0.00834	0.0476	0.0024	0	0.2705
2012	Mountainville	Rev.	Off-Pk. per sq. mile:	0.00718	0.0024	0.03774	0.00417	0.0095	0.0019	0	0.0629

6.2.1.1 Histogram of Message Size Distribution

A histogram of the message size distribution for two-way wide area wirless links was prepared for the peak period for Urbansville for the 2002 time frame. The histogram is shown in Figure 6.2-25. The messages were sorted by size into bins of generally 100 bits wide, for the forward and reverse directions. The X axis shows the message size bins in units of hundreds of bits, where the “F” prefix is for the forward direction, and the “R” prefix is for the reverse direction. The Y axis shows the number of messages in that message size bin for the Urbansville region in the 2002 time frame.

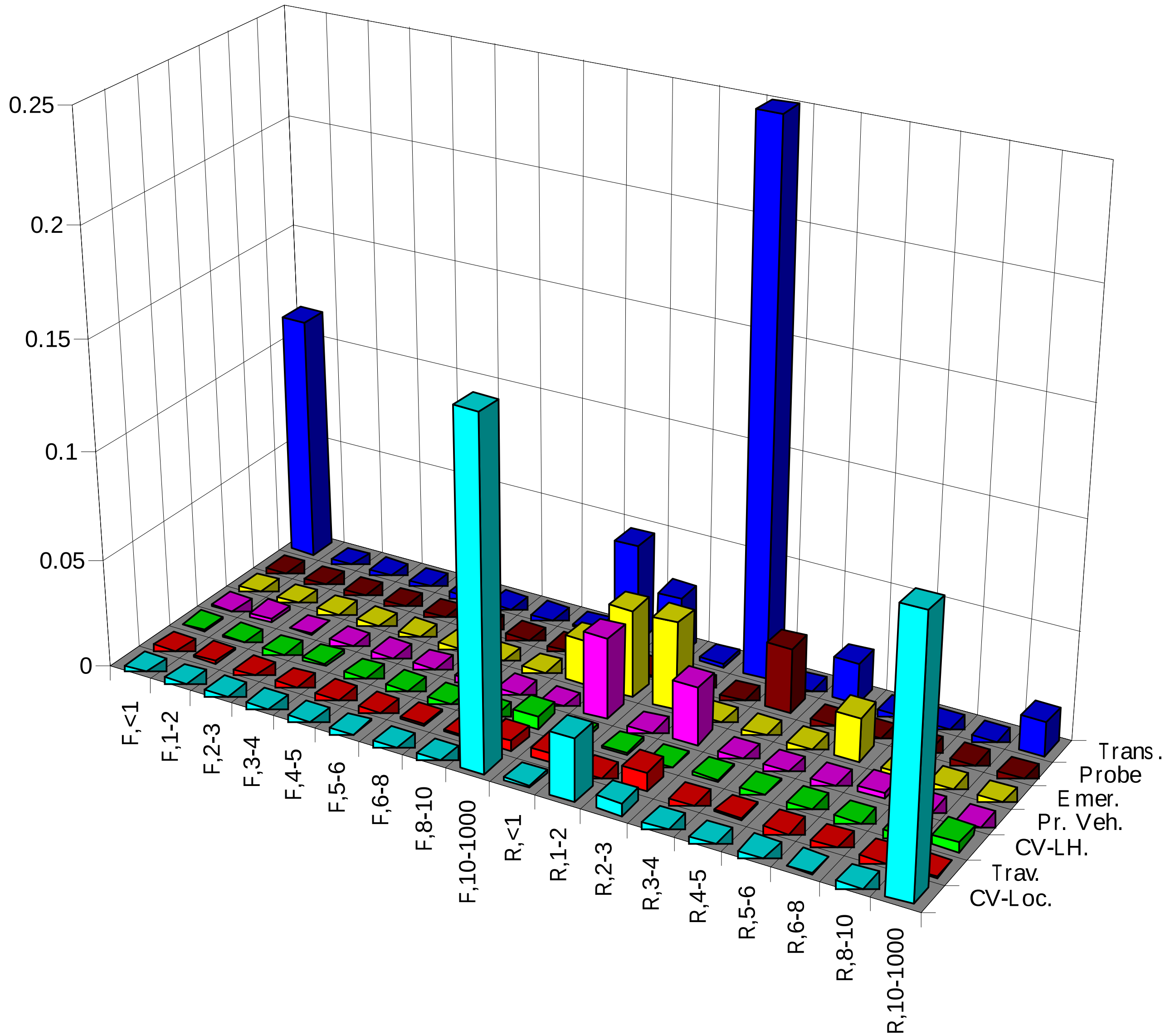
In order to provide a generalized result that can be applied to any urban region for the 2002 time frame, the histogram was calculated on a per-population basis. This histogram can then be used to calculate the distribution of messages for another urban region by multiplying the results by the population of the region to be studied. Figure 6.2-26 shows the per-population histogram.

Figure 6.2-25 Distribution of Messages for Urbansville, 2002, Peak Period



Note:
Y-Axis = Number of messages in peak period;
X-Axis = Message (in hundreds of bits);
F=Forward Direction;
R=Reverse Direction

Figure 6.2-26 Distribution of Messages per Population, Urban Area, 2002, Peak Period



6.2.2 Broadcast Data Loads

Table 6.2-2 lists a set of typical ITS services that are candidates for one-way wireless communication. These include: traffic information, traveler information, and transit services. For each service, the table presents: (1) message name, (2) message length in bits, (3) typical number of required links per geographical area, (4) average update frequency (e.g. traffic data every 10 minutes), (5) the effective information rate, which is calculated using the following expression:

Information rate (bits/sec) = [Message length (bits/message)]
* [num of traffic links (applicable to the message)]
* [update rate (messages/sec)]

Each message consists of a number of sub-flows. For example, the traffic_data_for_portables is composed of:

- tmc_identity
- traffic_data_for_media
- traveler_identity, current_data_for_media
- long_term_data_for_media
- predictive_model_data_for_media
- long_term_data_for_media
- wide_area_pollution_data
- pollution_state_area_collection
- current_ozone_pollution

Table 6.2-2 presents the size of the messages for a complete set of flows. The update frequency can be designed so that a full set of data flows for a message is broadcast at a low frequency (e.g., once every 10 minutes) and partial changes are broadcast at a higher frequency (e.g., once every minute).

Table 6.2-2 also presents the aggregate information rate. This is the effective information rate that the communication system must handle to provide these services in a geographical area. For these services the aggregate information rate is about 5651 bps.

Table 6.2-2 Candidate Messages for One Way Wireless Communication

Message Name	Size (bits)	No. of Links	Update Freq. (min.)	Data Rate (bps)
Traffic Information Services				
traffic_data_for_portables	819314	1	10	1,366
Aggregate Information Rate (bps)				**1,366**
Transit Services				
transit_deviations_for_portables	3560	1	15	4
traffic_data_for_kiosks	83874939	1	1500	932
transit_deviations_for_kiosks	357648	1	10	596
transit_services_for_portables	2512	1	10	4
Aggregate Information Rate (bps)				**1,536**
Traveler Information Services				
traveler_yellow_pages_data	970	50	10	81
advisory_data	6128	50	5	1,021
broadcast_data	10992	64	10	1,172
link_and_queue_data	400616	4	60	445
yellow_pages_advisory_data	10784	10	60	30
Aggregate Information Rate (bps)				**2,750**
Total Broadcast Information Rate (bps)				**5,651**

6.2.3 Short Range DSRC Data Loads

An analysis for DSRC systems when applied to a wide area setting, including data loads, is contained in Appendix G. The conclusion from there (and elsewhere) is that beacon systems are not appropriate as a substitute for wide area commercial services for wide area ITS applications (e.g., route guidance). DSRC is only recommended for those specifc applications that require an intimate physical interaction between the vehicle and the roadside infrastructure, such as in toll collection, commercial vehicle check, roadside safety inspection and the like (see Chapter 3). In all of these cases, because of the limited coverage of a beacon system and its fairly high data rate, data loading from a capacity standpoint is not an issue.

6.3 Wireline Data Loads

Wireline data loads are less critical than wireless because the current capabilities of the wireline infrastructure are simply enormous. Typically, the choice of medium (fiber, coaxial, etc.) is dictated by the desires and budgetary constraints of the jurisdictions. In any event, for completeness, wireline data loads based on the subsystem, data flow, and market package definitions have been calculated.

Data loads were calculated for all of the links between subsystems for the wireline (w) interface. Since the frequency of message use on these links is not directly related to usage by individual vehicle end users (for instance, a dataflow performing a database update that is transferring data on intersection traffic has a size or frequency of use related directly to the number of intersections in the region), the numerous parameters that enter into this analysis came from those used in the teamwork model of the logical architecture and used in sizing there as well. These parameters are all for the 2012 Urbansville scenario, proving a worst-case analysis.

Table 6.3-1 lists the independent parameters assumed in the analysis; Table 6.3-2 shows the derivation of the dependent parameters that are based on the independent parameters.

Table 6.3-1 Independent Parameters Used in the Wireline Data Loading

Name	Description	Urban 20 Year
ADJACENT_TMS	The average number of adjacent or cooperating Traffic management centers that a TMS within the ITS area under study will communicate with on a regular basis	5
AHS_MILES	The total number of ITS roadway miles being operated under some form of AHS system.	10
AHS_SEGMENT_LENGTH	The average length on an AHS segment.	3
AHS_TRIPS_per_DAY	The assumed average number of trips each AHS capable vehicle will make each day.	2
AHS_VEH_per_PLATOON	The average size of an AHS platoon, in vehicles.	6
AIR_RATE	The proportion of ITS traveler interactions that involve AIR as an alternative transportation mode..	0.1
AUTOINFRA	The assumed which all ITS users prefer autonomous versus infrastructure based route guidance.	0.25
BROADCAST_ITEMS	The number of broadcast data items typically contained in a specific ITS advisory broadcast.	6
COM_VEHS	The total number of commercial vehicles operable within the ITS area under study.	7802
CONTROLLERS_PER_HIGHWAY_CORRIDOR	The average number of traffic controllers per highway corridor within the jurisdiction being studied.	2
CONTROLLERS_PER_ROAD_CORRIDOR	The average number of traffic controllers per road corridor within the jurisdiction being studied.	2
CVI_RATE	The rate at which an average Commercial Vehicle Inspector actually performs inspections, expressed as Inspections per second. The numbers shown represent an average inspection time of approximately 30 minutes, to include preparation, rest periods.	0.0006
CVO_FAC	The total number of Commercial Vehicle Roadside facilities that are operating in the ITS area under study.	1
CVO_FAULT_RATE	The assumed rate at which commercial vehicles fail roadside inspections for all reasons to include safety, permits, driver credentials etc.	0.01
CVO_MAN	The total number of Commercial Vehicle Fleet Managers who can have simultaneous direct access to ITS at any one time. This will be less than the actual number of such Managers employed within the ITS area if they are working shifts.	20
CVO_VEHS	The total number of commercial vehicles operable within the ITS area under study.	7802
EP_MONITOR_DENSITY	The expected number of environmental pollution monitoring points (i.e. roadside transponders) normalized to intersections.	2

Table 6.3-1 Independent Parameters Used in the Wireline Data Loading

Name	Description	Urban 20 Year
ERMS_CALL_RATE	The daily rate at which EMS departments receive calls as a function of total population. The numbers for the Urban environment are based on a study of fire department EMS calls in 1994, reported by the Journal of Emergency Medical Services.	0.00034
ERMS_ROUTE_LENGTH	The average length of an emergency vehicle route, in miles.	5
ERMS_VEHS	The total number of emergency services vehicles available for operation in the ITS area under study. This takes no account of whether the vehicles are active or not.	5981
EVENT_RATE	The daily rate at which special events are scheduled which require ITS notifications.	4
FERRY_RATE	The proportion of ITS traveler interactions that involve FERRY operations as an alternative transportation mode..	0.001
HIGHWAY_CORRIDORS	The total number of primary highway traffic corridors under ITS strategic planning and control within the jurisdiction being studied.	18
HIGHWAY_CROSSINGS	The total number of controlled or monitored multi-modal crossings of roads within the ITS environment under study. Based on data available for "typical" urban, interurban and rural areas.	2000
HIGHWAY_MILES	Total freeway (limited access) mileage in the ITS area under study.	225
HIGHWAY_PLAN_SEQUENCES	The number of distinct planned sequences used for highway sign activation..	30
HIGHWAY_SIGN_PLANS	The number of distinct plans used for highway sign activation..	30
HIGHWAY_SIGN_SEQUENCES	The number of distinct sequences used for highway sign activation..	30
IMAGE_LARGE	A large (or high resolution) image, typically used for automated surveillance (as opposed to human visual) processes. Roughly equivalent to a 256 color (or gray scale) image of 1024 X 1024 picture elements (pels).	1048576
IMAGE_SMALL	A small (or low resolution) image, typically used for visual identification (as opposed to automatic) purposes. Roughly equivalent to a 256 color (or gray scale) image of 640 X 480 picture elements (pels).	307200
INCIDENT_RATE	An assumed average incidents per vehicle in a day, normalized to general vehicle population (VEHS).	0.0001
INTERSECTIONS	The total number of controlled or monitored intersections within the ITS environment under study. Based on data available for "typical" urban, interurban and rural areas.	2560
INTERSECTIONS_PER_CORRIDOR	The average number of roadway intersections per corridor within the jurisdiction being studied.	200
JPEG	Images are assumed to be compressed for the purposes of estimating data flow sizes. Still images are assumed to be compressed using the Joint Photographic Experts Group (JPEG) methodology.	0.03
KIOSKS_PER_TRANSIT_STOP	An assumed density of kiosk facilities based on the number of transit stops in the ITS area under study.	0.5
LANE_FLOW_RATE	Average traffic flow rate (Vehicles/second) on a single traffic lane. Based on a 24 hour period, this value should be adjusted as required to quantify time-of-day and incident specifics.	0.04
LANES_PER_DIRECTION	The average number of lanes, in each direction, at an average intersection.	3
LINK_LENGTH	The average length, in miles, of a navigable route link, for the ITS area under study. This parameter is quantified for roadway links. Pedestrian travelers may require shorter links.	1
LINK_STOPS	The average number of stops in an average link.	1

Table 6.3-1 Independent Parameters Used in the Wireline Data Loading

Name	Description	Urban 20 Year
LINKS_PER_INCIDENT	The average number of roadway links affected by an incident.	10
LOCAL_DATA	The typical number of data items containing advisory data that will be relevant to the local area surrounding a particular vehicle. This parameter is used to "filter" the advisory data list for data loading analysis..	3
MAX_AHS_SEGS	The maximum allowable number of segments into which a valid ahs route may be divided. This is an arbitrary assumption and is highly dependent on system design constraints.	10
MAX_ENF_AGENCIES	The maximum number of enforcement agencies with which an ITS communicates.	5
MAX_HIGHWAY_SEGS	The maximum allowable number of segments into which a valid freeway route may be divided. This is an arbitrary assumption and is highly dependent on system design constraints.	10
MAX_ROAD_SEGS	The maximum allowable number of segments into which a valid route over surface streets may be divided. This is an arbitrary assumption and is highly dependent on system design constraints.	100
MAX_SEG_WPS	The maximum allowable number of waypoints which a valid segment may utilize. This is an arbitrary assumption and is highly dependent on system design constraints.	10
MAX_STRATEGIES	The maximum number of traffic management strategies that can be specified for use in a single day.	400
MEDIA_OPS	The number of Media Operators who can have simultaneous direct access to the TMC at any one time. This will be less that the actual number of Media Operators who actually access the ITS if they are working shifts.	5
MODE_CHANGES	The average number of mode changes in an average traveler route.	1
MOV_BRIDGES	The total number of movable bridges within the ITS area under study. Based on available data for typical urban, interurban and rural areas.	4
MP	Market penetration assumption for ITS capabilities. It is used where a specific market penetration (e.g. MP_CVO) is not available or appropriate.	0.5
MP_CVO	Market penetration assumption for CVO operations. Expressed as a percentage of the total commercial fleet that will invest in equipment and/or services to utilize ITS functions.	0.75
MPAHS	The assumed AHS Market Penetration, i.e. the percentage of vehicles that are equipped to operate on AHS lanes.	0.001
MPCV	The assumed Commercial Vehicle Market Penetration, i.e. the percentage of commercial vehicles that are equipped to utilize ITS functions.	0.75
MPEG	Images are assumed to be compressed for the purposes of estimating data flow sizes. Full motion images are assumed to be compressed using the Motion Pictures Experts Group (MPEG) methodology. This parameter establishes the ratio assumed in this analysis.	0.01
MPKIOSK	The market penetration of ITS Travelers using Kiosks.	0.75
MPPDA	The market penetration of ITS Travelers using PDA devices.	0.1
MPPTT	The assumed Paratransit Traveler Market Penetration, i.e. the percentage of travelers that utilize paratransit operations.	0.03
MPPTV	The assumed Paratransit Vehicle Market Penetration, i.e. the percentage of vehicles providing flexible transit services that are equipped to utilize ITS functions.	1
MPPV	The assumed Private Vehicle Market Penetration, i.e. the percentage of private vehicles that are equipped to utilize ITS functions.	0.1

Table 6.3-1 Independent Parameters Used in the Wireline Data Loading

Name	Description	Urban 20 Year
MPTR	The assumed Traveler Market Penetration, i.e. the percentage of travelers that will utilize ITS functions.	0.1
MPTU	The assumed Transit User Market Penetration, i.e. the percentage of transit users that utilize ITS functions.	0.15
MPTV	The assumed Transit Vehicle Market Penetration, i.e. the percentage of transit vehicles that are equipped to utilize ITS functions.	1
NUM_ROUTES	The number of individual routes included in an average trip plan.	6
NUM_SEGS	The number of individual route segments included in an average route.	10
NUM_TRANSIT_ROUTES	The average total number of transit routes included within the ITS environment being analyzed. Does not include transit routes of "other TMS" environments. This is a assumption of a "typical" value derived from demographic data of U.S.	20
PARATRANS_MP	Market penetration for paratransit operations. Expressed as a percentage of the total population that will use para-transit facilities.	0.03
PARKING_LANES	The maximum number of parking lot payment lanes that are operating at a single parking lot in the ITS area under study. It is assumed that these lanes will only be used by vehicles that are equipped to utilize ITS functions.	2
PARKING_LOTS_PER_PROVIDER	The average total number of parking lots that are being operated by a single parking lot service provider in the ITS area under study.	4
PARKING_PROVIDER_RATE	Number of independent parking providers, normalized to general vehicle population (VEHS).	0.0002
PARKING_SPACE_RATE	Number of independent parking spaces, normalized to general vehicle population (VEHS).	0.01
PEDESTRIANS	The total number of controlled or monitored pedestrian crossings that are not also intersections within the ITS environment under study. Based on data available for "typical" urban, interurban and rural areas.	100
POPULATION	The total population of the ITS environment under study.	3788627
PTRANSIT_VEHS	The total number of Paratransit vehicles operating within the ITS area under study. A Paratransit vehicle is one that is used to carry one or passengers on a non-scheduled transit service that may not follow a fixed route.	100
PVT_MP	The assumed Private Vehicle Market Penetration, i.e. the percentage of private vehicles that are equipped to utilize ITS functions.	0.1
PVT_VEHS	The total number of vehicles excluding commercial and transit vehicles, operable within the ITS area under study.	2273176
RAIL_RATE	The proportion of ITS traveler interactions that involve heavy or light RAIL as an alternative transportation mode..	0.01
RAMPS	The total number of controlled or monitored highway access ramps within the ITS environment under study. Based on data available for "typical" urban, interurban and rural areas.	400
ROAD_ADAPTIVE_PLANS	The maximum number of indicator adaptive data (adaptive plans) that are available from the Manage Traffic Function.	10
ROAD_CORRIDORS	The total number of primary road traffic corridors under ITS strategic planning and control within the jurisdiction being studied.	18
ROAD_CROSSINGS	The total number of controlled or monitored multi-modal crossings of roads within the ITS environment under study. Based on data available for "typical" urban, interurban and rural areas.	2000
ROAD_FIXED_PLANS	The maximum number of fixed time indicator control sequences (fixed time plans) that are available from the Manage Traffic Function.	30

Table 6.3-1 Independent Parameters Used in the Wireline Data Loading

Name	Description	Urban 20 Year
ROAD_MILES	The total mileage of ITS usable roads and streets (as distinct from highways) within the area under analysis.	1701
ROUTE_LENGTH	The average length (in miles) of the average route requested of, or provided by the ITS system under study.	15
TAG_DEFECT_RATE	The assumed average rate at which tags will be rejected by ITS equipment INCLUDING bad credit, stolen tags and system failures.	0.0001
TOLL_LANES	The maximum number of toll lanes that are operating at an average toll plaza in the ITS area under study. It is assumed that these lanes will only be used by vehicles that are equipped to utilize ITS functions.	2
TOLL_MILES	The total number of ITS roadway miles being operated under some form of toll system. Based on available data for typical urban, interurban and rural areas.	50
TOLL_PLAZAS	The total number of toll collection points within the ITS area under study. Based on available data for typical urban, interurban and rural areas.	10
TRAFFIC_COORDINATION_RULES	The number of road-freeway coordination rules that are available from the Manage Traffic Function.	10
TRAFFIC_OPS	The number of Traffic Operations Personnel who can have simultaneous direct access to the TMC at any one time. This will be less than the actual number of Traffic Operations Personnel employed at the TMC if they are working shifts.	10
TRANSIT_DRIVERS	The total number of transit drivers available to operate the transit vehicles within the ITS area under study.	200
TRANSIT_FLEETS	The total number of transit fleets operating in the ITS area under study. The fleets may be operating the same type of service, e.g. buses, or differing types, e.g. one for buses, another for light rail (trams).	3
TRANSIT_STOPS	The total number of transit stops on all transit routes within the ITS area under study. It is assumed that as a minimum, they are all capable of receiving and displaying data about the next services due to arrive at the stop.	400
TRANSIT_TECH_WR	The average number of transit vehicles that one transit maintenance technician can service in an hour.	1
TRANSIT_USAGE_RATE	Number of transit users, normalized to total population (POPULATION).	0.01527
TRANSIT_VEHS	The total number of transit vehicles available for operation within the ITS area under study. A transit vehicle is a special type of vehicle that is designed and equipped to carry a number of passengers on a scheduled route.	1788
TRANSIT_WAIT_TIME	The average waiting time between regularly scheduled transit vehicles.	5
TUNNELS	An arbitrary assumption about the number of tunnel segments being managed by the ITS system under study..	1
VEHICLE_SIGN_OUTPUT_DENSITY	The expected number of in-vehicle signage transmission points (i.e. roadside transponders) per intersection.	2
VIDEO_CAMS	The total number of video sources in operation within the ITS area under study. Video sources are assumed to represent a significant data communications load.	850
YP_GLOBAL_ITEMS	The typical number of items of "yellow pages" type of information that will be available from throughout the geographic and/or jurisdictional area served by the ITS under study.	15

Table 6.3-1 Independent Parameters Used in the Wireline Data Loading

Name	Description	Urban 20 Year
YP_LOCAL_ITEMS	The typical number of items of "yellow pages" type of information that will be available in the local area of a particular vehicle.	15

Table 6.3-2 Dependent Parameters Used in the Wireline Data Loading Analysis

Name	Description	Basis
ACT_ERMS_VEHS	The total number of emergency services vehicles that are active for any particular emergency call. This will be a proportion of the total number of emergency services vehicles (ERMS_VEHS).	= 0.1 * ERMS_VEHS
AHS_SAMPLE_RATE	An arbitrary sample rate constant used to facilitate data loading estimates for AHS operations.	= 1 / DAY
AHS_VEHS	The total number of vehicles that are utilizing AHS functions to obtain dynamic in-vehicle route guidance. Based on an assumed market penetration (MPAHS) and the general vehicle population.	= MPAHS * VEHS
AUTONOMOUS_TRAVS	The total number of travelers that are utilizing autonomous route guidance. Based on an assumed ratio (AUTOINFRA) and the number of guided travelers (ITS_GUIDED_TRAVS).	= AUTOINFRA * ITS_GUIDED_TRAVS
CONTROLLERS	The total number of intermodal crossing controllers in traffic corridors.	= HIGHWAY_CROSSING_CONTROLLERS + ROAD_CROSSING_CONTROLLERS
CORRIDORS	The total number of traffic corridors.	= HIGHWAY_CORRIDORS + ROAD_CORRIDORS
CROSSING_CONTROLLERS	The total number of intermodal crossing controllers in traffic corridors.	= HIGHWAY_CROSSING_CONTROLLERS + ROAD_CROSSING_CONTROLLERS
CROSSINGS	The total number of intermodal HIGHWAY_CROSSINGS and ROAD_CROSSINGS	= HIGHWAY_CROSSINGS + ROAD_CROSSINGS
CVC_SAMPLE_RATE	An arbitrary sample rate constant used to facilitate data loading estimates for CVC operations.	= 1 / DAY
CVO_DVR	The total number of Commercial Vehicle Drivers who also act as their own Fleet Managers. This will be a proportion of the number of Commercial Vehicles (CVO_VEHS). It is assumed that all of the vehicles belonging to these owner drivers will be equipped.	=0.5 * CVO_VEHS
CVO_FAC_PER_ROUTE	The average number of CVO facilities on a typical CVO route. Dependent on the assumed total number of facilities (CVO_FAC) and the relative number of segments in a typical route (NUM_SEGS/ROADWAY_SEGS).	= (NUM_SEGS / ROADWAY_SEGS) * CVO_FAC
CVO_INSP	The total number of Commercial Vehicle Inspectors who can have simultaneous direct access to ITS at any one time in the ITS area under study. This will be dependent on the number of Commercial Vehicle Roadside facilities (CVO_FAC).	=2.5 * CVO_FAC

Table 6.3-2 Dependent Parameters Used in the Wireline Data Loading Analysis

Name	Description	Basis
DAY	Constant used in rate calculations, 24 hours	=24 * HOUR
DYNAMIC_TRAVS	The total number of travelers that are utilizing autonomous route guidance. Based on an assumed ratio (AUTOINFRA) and the number of guided travelers (ITS_GUIDED_TRAVS)	= (1 - AUTOINFRA) * ITS_GUIDED_TRAVS
ERMS_CALLS	The rate, in calls per second, at which EMS calls are received over an average 24 hour period.	= ERMS_CALL_RATE * (POPULATION) / DAY
GW_SIZE	Size of a green wave expressed as a number of route segments.	= ERMS_ROUTE_LENGTH / LINK_LENGTH
HIGHWAY_CROSSING_CONTROLLERS	The total number of intermodal highway crossing controllers in traffic corridors.	= HIGHWAY_CORRIDORS * CONTROLLERS_PER_HIGHWAY_CORRIDOR
HIGHWAY_INDICATORS	Total number of indicators (variable message signs and multimodal crossing signals) along freeways controlled/monitored within the ITS area under study. Assumed to be proportional to the total freeway mileage.	= HIGHWAY_MILES / 10
HIGHWAY_LINKS	The total number of navigable freeway links within the ITS area under study.	= HIGHWAY_MILES/LINK_LENGTH
HIGHWAY_SIGN_CONTROLLERS	The total number of highway sign controllers, assumed to be proportional to the number of highway signs.	= 6 * HIGHWAY_SIGNS
HIGHWAY_SIGNS	Total number of variable message signs along freeways controlled/monitored within the ITS area under study. Assumed to be proportional to the total number of freeway ramps.	= RAMPS / 4
HOUR	Constant used in rate calculations, 60 minutes	=60 * MINUTE
HOV_LANES	The total number of high-occupancy links being controlled/monitored within the ITS area under study. Based on the total number of its freeway links.	= .05 * HIGHWAY_LINKS
INCIDENTS	The average number of incidents in a 24 hour period, based on the incident rate (INCIDENT_RATE) and general vehicle population (VEHS).	= INCIDENT_RATE * VEHS
INDICATORS	Total number of indicators (intersection controllers, pedestrian controllers, variable message signs and multimodal crossings) controlled/monitored within the ITS area under study. Assumed to be proportional to the number of intersections.	= HIGHWAY_INDICATORS + ROAD_INDICATORS
INT_CONTROLLERS	The total number of roadway intersection controllers in traffic corridors.	= CORRIDORS * INTERSECTIONS_PER_CORRIDOR
ITS_CVO_VEHS	The total number of commercial vehicles within the ITS area under study that are equipped to utilize ITS functions.	= MPCV * COM_VEHS
ITS_GUIDED_TRAVS	The total number of travelers who can utilize ITS personal traveler guidance functions. This will be a proportion of the number of travelers who can simultaneously utilize ITS functions (ITS_TRAVS).	= 0.3 * ITS_TRAVS
ITS_GUIDED_VEHS	The total number of vehicles that are utilizing ITS functions to obtain dynamic in-vehicle route guidance. This is a subset of the subset of all types of vehicles equipped to utilize ITS functions (ACT_ERMS_VEHS, ITS_CVO_VEHS, ITS_PVT_VEHS, ITS_PTRANSIT	= ACT_ERMS_VEHS + 0.9 * ITS_CVO_VEHS + 0.25 * ITS_PVT_VEHS + 0.8 * ITS_PTRANSIT_VEHS + 0.2 * ITS_TRANSIT_VEHS

Table 6.3-2 Dependent Parameters Used in the Wireline Data Loading Analysis

Name	Description	Basis
ITS_PARATRANSIT_VEHS	The total number of flexible transit vehicles operating within the ITS area under study that are equipped to utilize ITS functions. This will be a proportion of the total number of paratransit vehicles (PARATRANSIT_VEHS).	=MPPTV*PARATRANSIT_VEHS
ITS_PTRANSIT_TRAVS	The total number of travelers who are utilizing ITS functions to obtain information on flexible transit services and (possibly) make reservation for one of those services. This is a proportion of the total number of travelers who can utilize ITS functions.	= MPPTT*ITS_TRAVS
ITS_PTRANSIT_VEHS	The total number of Paratransit vehicles operating within the ITS area under study that are equipped to utilize ITS functions. This will be a proportion of the total number of Paratransit vehicles (PTRANSIT_VEHS).	=0.9 * PTRANSIT_VEHS
ITS_PVT_VEHS	The total number of private vehicles within the ITS area under study that are equipped to utilize ITS functions.	= MPPV * PVT_VEHS
ITS_RS_TRAVS	The total number of travelers who are utilizing ITS functions to obtain Ridematching information and (possibly) make Ridematching reservations. This is a proportion of the total number of travelers who can utilize ITS functions (ITS_TRAVS).	= 0.1 * ITS_TRAVS
ITS_TRANSIT_USERS	The total number of transit users operating within the ITS area under study that utilize ITS functions. This will be a proportion of the total number of transit users (TRANSIT_USERS).	=MPTU * TRANSIT_USERS
ITS_TRANSIT_VEHS	The total number of transit vehicles operating within the ITS area under study that are equipped to utilize ITS functions. This will be a proportion of the total number of transit vehicles (TRANSIT_VEHS).	=MPTV * TRANSIT_VEHS
ITS_TRAVS	The total number of travelers who can simultaneously utilize ITS functions. This is a proportion of the total population (POPULATION).	= MPTR * POPULATION
ITS_VEHICLES	The total number of vehicles within the ITS area under study that are equipped to utilize ITS functions.	= ACT_ERMS_VEHS + ITS_CVO_VEHS + ITS_PVT_VEHS + ITS_PTRANSIT_VEHS + ITS_TRANSIT_VEHS
KIOSK_EMERGENCIES	Number of emergency calls per second being transmitted from ITS Kiosks. This assumed to be proportional to the number of ITS travelers (ITS_TRAVS), the expected rate of emergency calls within the general population (ERMS_CALL_RATE) and the market penetration.	= MPKIOSK * ERMS_CALL_RATE * ITS_TRAVS
LAST_PMODEL_UPDATE	This parameter is defined to provide a record of when the last time this table was updated. It is the Excel time serial corresponding to the last time this table was updated by PMODEL.XLS	= NOW()
LINKS	The total number of navigable links within the ITS area under study.	= ROAD_LINKS + HIGHWAY_LINKS
MAX_ADJ_CUR_INCIDENTS	The subset of maximum number of predicted incidents for a 24 hour period that will impact traffic conditions in another area.	= .2 * MAX_CUR_INCIDENTS
MAX_ADJ_PRED_INCIDENTS	The subset of maximum number of predicted incidents for a 24 hour period that will impact traffic conditions in another area.	= .2 * MAX_PRED_INCIDENTS

Table 6.3-2 Dependent Parameters Used in the Wireline Data Loading Analysis

Name	Description	Basis
MAX_ADV_CHARGES	The maximum number of advanced charges, Assumed to be 1% of the general ITS population, i.e. it is proportional to the general market penetration of ITS (MP).	= .01 * MP * POPULATION
MAX_ADV_FARES	The maximum number of advanced fares, Assumed to be 1% of the general ITS population, i.e. it is proportional to the general market penetration of ITS (MP).	= .01 * MP * POPULATION
MAX_ADV_TOLLS	The maximum number of advanced tolls, Assumed to be 1% of the general ITS population, i.e. it is proportional to the general market penetration of ITS (MP).	= .01 * MP * POPULATION
MAX_AHS_CHECKS	The maximum number of AHS check-in/check-out facilities.	= AHS_MILES / AHS_SEGMENT_LENGTH
MAX_BAD_PAYERS	The expected number of travelers who are known to the ITS system as bad credit risks, assumed to be a percentage of all ITS_TRAVELERS.	= .0001 * ITS_TRAVS
MAX_CUR_INCIDENTS	The maximum number of predicted incidents for a 24 hour period.	= INCIDENTS
MAX_LINKS	The maximum allowable number of segments into which a valid route may be divided.	= MAX_SEGS
MAX_PARKING_SENSORS	The maximum number of parking lot sensors, Assumed to be proportional to the number of PARKING_LOTS.	= 10 * PARKING_LOTS
MAX_PARKING_VMS	The maximum number of parking variable message signs, Assumed to be proportional to the number of PARKING_LOTS.	= 4 * PARKING_LOTS
MAX_PRED_INCIDENTS	The maximum number of predicted incidents for a 24 hour period,	= INCIDENTS
MAX_SEGS	The total number of navigable links within the ITS area under study.	= LINKS
MAX_SENSORS	The maximum number of ITS sensors, Assumed to be proportional to the number of intersections in the ITS area under study.	= 10 * INTERSECTIONS
MILES	The total number of miles in the area under study.	= HIGHWAY_MILES + ROAD_MILES
MINUTE	Constant used in rate calculations, 60 seconds	=60
MONTH	Constant used in rate calculations, 1/12 of a year	=YEAR / 12
NUM_CVO_RECORDS	The estimated number of records in the average CVO roadside database. It is based on an estimate of the total number of vehicles legally enrolled to operate in the ITS area under study. This will include all enrolled vehicles registered in the jurisdiction.	=MPCV*CVO_VEHS
NUM_PREDICTED_INCIDENTS	The predicted number of incidents in a 24 hour period.	= INCIDENTS
NUM_TRANSIT_SERVICES	The maximum number of vehicle schedules for a typical transit route. This is determined the TRANSIT_WAIT_TIME, i.e. an average wait time of 60 minutes requires 24 TRANSIT_SERVICES per 24 hour period.	= 24 * 60 / TRANSIT_WAIT_TIME
OTHER_SEGS	The total number of navigable non-vehicular segments within the ITS area under study.	= .1 * ROAD_LINKS
PARATRANSIT_VEHS	The total number of paratransit vehicles operating within the ITS area under study. A paratransit vehicle is one that is used to carry one or passengers on a non-scheduled transit service that may not follow a fixed route.	= .25 * TRANSIT_VEHS

Table 6.3-2 Dependent Parameters Used in the Wireline Data Loading Analysis

Name	Description	Basis
PARKING_LOT_PROVIDERS	The average number of independent parking service providers in the ITS area under study.	= PARKING_PROVIDER_RATE * POPULATION
PARKING_LOTS	The average total number of parking lots that are being operated by a single parking lot service provider in the ITS area under study.	= PARKING_LOTS_PER_PROVIDER * PARKING_LOT_PROVIDERS
PARKING_SAMPLE_RATE	An arbitrary sample rate constant used to facilitate data loading estimates for parking lot operations.	= 1 / DAY
PARKING_SPACES	The total average number of parking spaces available in the ITS area under study.	= PARKING_SPACE_RATE * VEHS
PED_CONTROLLERS	The total number of pedestrian activated signal controllers within the ITS area under study. This is dependent on the total number of intersections.	= .1 * INTERSECTIONS
PEDESTRIAN_SIGNAL_CONTROLLERS	The total number of pedestrian activated signal controllers within the ITS area under study. This is dependent on the total number of intersections.	= .1 * INTERSECTIONS
PERSONAL_EMERGENCIES	Number of emergency calls per second being transmitted from Personal Data Assistant (PDA) type devices. This assumed to be proportional to the number of ITS travelers (ITS_TRAVS), the expected rate of emergency calls within the general population.	= MPPDA * ERMS_CALL_RATE * ITS_TRAVS
POLLUTION_POINTS	The expected number of environmental pollution monitoring points (i.e. roadside transponders) . This number is assumed to be proportional to the number of intersections (INTERSECTIONS) in the area under study, and to a installed rate (EP_MONITOR_DENSITY)	= EP_MONITOR_DENSITY * INTERSECTIONS
RAMP_CONTROLLERS	The total number of ramp controllers, based on the number of ramps, within the ITS area under study.	= 2 * RAMPS
ROAD_CROSSING_CONTROLLERS	The total number of intermodal road crossing controllers in traffic corridors.	= ROAD_CORRIDORS * CONTROLLERS_PER_ROAD_CORRIDOR
ROAD_INDICATORS	Total number of indicators (intersection controllers, pedestrian controllers, variable message signs and multimodal crossings) along roads controlled/monitored within the ITS area under study. Assumed to be proportional to the number of intersections.	= 4 * INTERSECTIONS
ROAD_LINKS	The total number of navigable surface street links within the ITS area under study.	= ROAD_MILES/LINK_LENGTH
ROAD_SIGN_CONTROLLERS	The total number of road sign controllers, assumed to be proportional to the number of road signs.	= 6 * ROAD_SIGNS
ROAD_SIGNS	Total number of variable message signs along roads controlled/monitored within the ITS area under study. Assumed to be proportional to the number of intersections.	= INTERSECTIONS / 10
ROADWAY_SEGS	The total number of navigable route segments within the ITS area under study.	= LINKS
ROUTES	The average number of routes requested during an average 24 hour period, based on the total number of ITS vehicles and travelers within the ITS area under study.	=2* (ITS_GUIDED_VEHS+ITS_GUIDED_TRAVS)

Table 6.3-2 Dependent Parameters Used in the Wireline Data Loading Analysis

Name	Description	Basis
SAMPLE_RATE	An arbitrary sample rate constant used to facilitate data loading estimates.	= 1/(5*MINUTE)
SIGN_CONTROLLERS	The total number of roadway sign controllers, assumed to be proportional to the number of signs.	= HIGHWAY_SIGN_CONTROLLERS+ROAD_SIGN_CONTROLLERS
SIGNS	The total number of HIGHWAY_SIGNS and ROAD_SIGNS	= HIGHWAY_SIGNS+ROAD_SIGNS
TOLL_SAMPLE_RATE	An arbitray sample rate constant used to facilitate data loading estimates for toll road operations.	= 1/DAY
TOLL_SEGS	Total number of Toll Segments within the ITS area under study. This is a percentage of the number of toll miles.	= .10 * TOLL_MILES
TOTAL_SEGS	The total number of navigable links within the ITS area under study.	= LINKS
TRANSIT_DEVS	The total number of transit vehicles that are running late, i.e. deviating from their routes and/or schedules at any particular moment within the ITS area under study. This will be proportional to the total number of transit vehicles currently running.	= .5 * TRANSIT_VEH_DEVS * TRANSIT_STOPS
TRANSIT_KIOSKS	The total number of transit stops within the ITS area under study that are also equipped as kiosks and able to support inquiries from transit users for information on transit services. This sill be dependent on the number of transit stops (TRANSIT_STOPS)	= KIOSKS_PER_TRANSIT_STOP * TRANSIT_STOPS
TRANSIT_ROUTE_SEGS	The average (typical) number of route segments in a typical (average) transit route.	= TRANSIT_STOPS / NUM_TRANSIT_ROUTES
TRANSIT_SAMPLE_RATE	An arbitrary sample rate constant used to facilitate data loading estimates for transit operations.	= 1 / DAY
TRANSIT_SEGS	The average (typical) number of route segments in a typical (average) transit route.	= TRANSIT_STOPS / NUM_TRANSIT_ROUTES
TRANSIT_TECH_ACTS	Transit Technician Activities, assumed to be proportional to the number of TRANSIT_VEHS.	= 2 * TRANSIT_VEHS
TRANSIT_TECHS	The total number of transit service technicians available to maintain the transit fleet within the ITS area under study. This number is assumed to be proportional to the size of the transit system as measured by the number of TRANSIT_VEHS	= TRANSIT_VEHS / 50
TRANSIT_USERS	The average number of travelers in the general population (POPULATION) using transit facilities on a daily basis.	= TRANSIT_USAGE_RATE * POPULATION
TRANSIT_VEH_DEVS	The total number of transit vehicles that are running late, i.e. deviating from their routes and/or schedules at any particular moment within the ITS area under study. This will be proportional to the total number of transit vehicles (TRANSIT_VEHS).	= 0.1 * TRANSIT_VEHS
TRANSIT_VIDEO_CAMS	The total number of video sources within the ITS area under study that are dedicated to the surveillance of transit operations. This number is based on the total number of TRANSIT_STOPS in the transit system.	= TRANSIT_STOPS / 8
VEHICLE_SIGN_OUTPUTS	The expected number of in-vehicle signage transmission points (i.e. roadside transponders). This number is assumed to be proportional to the number of intersections (INTERSECTIONS) and to the rate of implementation (VEHICLE_SIGN_OUTPUT_DENSITY)	= VEHICLE_SIGN_OUTPUT_DENSITY * INTERSECTIONS

Table 6.3-2 Dependent Parameters Used in the Wireline Data Loading Analysis

Name	Description	Basis
VEHS	The assumed total number of vehicles in the ITS area under study, based on the general population of the same area.	= .63 * POPULATION
WEEK	Constant used in rate calculations, 7 days	= 7 * DAY
YEAR	Constant used in rate calculations, 365.24 days	= 365.24 * DAY

The data loads calculated from these parameters can be considered the average data load. When determining the link data load, in addition to this average data load, the latency-driven peak link loads must be calculated. The maximum of these two (average load and peak link load) was used to determine the link data rate due to that particular message. The data loads resulting from all of the messages that flow over a particular link were summed.

The latencies were all set initially to 0.1 seconds. Where this decision caused a link data rate to be mainly driven by the latency requirement for a particular large message, the latency requirement was adjusted where it was not required to be so low. An example is the transmission of semi-annual reports where latency is not an issue.

The wireline data loading analysis is shown in Table 6.3-3. The table lists the wireline link in the left column, the message name, the frequency, the message size, the average link load based on the frequency and size, the latency requirement assumed, the peak link load based on size and latency, the maximum of the two load calculations, and finally the type of wireline leased digital link required to carry this load. As in the wireless analysis section in this document, no recommendation as to the specific link selection has been made. Private fiber networks can be deployed to carry all or part of this traffic. The selection of a leased digital link type is for illustration only. There are three digital link types assigned in this table: DS0 for up to 56 Kbps, DS1 for up to 1.544 Mbps, and DS3 for over 1.544 Mbps. The largest rate link shown is DS3 (46 Mbps), multiple links may be required in some cases. Additionally, it may be less costly to use multiple lower-rate links and not jump up to the next higher rate link when a threshold is reached. The summary for each link is in bold within a box for each link.

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
Construction and Maintenance to TMS	fcm_fault_clearance	0.002762541	82	0.226528323	0.1	820	820	
Construction and Maintenance to TMS	fcm_incident_information	0.002762541	146	0.403330916	0.1	1460	1460	
Construction and Maintenance to TMS Total				0.629859239		2280	2280	DS0
CVAS to CVCS	cv_credentials_database_update	1.15741E-05	482	0.005578704	0.1	4820	4820	
CVAS to CVCS	cv_credentials_information_response	0.00015	410	0.0615	0.1	4100	4100	
CVAS to CVCS	cv_safety_database_update	1.15741E-05	410	0.00474537	0.1	4100	4100	
CVAS to CVCS	cv_safety_information_response	0.0015	410	0.615	0.1	4100	4100	
CVAS to CVCS Total				0.686824074		17120	17120	DS0
CVAS to DMV	tdmv_cv_violation_identity_code	1.15741E-05	34	0.000393519	0.1	340	340	
CVAS to DMV	tdmv_cv_violation_vehicle_license	1.15741E-05	146	0.001689815	0.1	1460	1460	
CVAS to DMV Total				0.002083333		1800	1800	DS0
CVAS to Enforcement Agency	tea_cv_violation_data	1.15741E-05	274	0.003171296	0.1	2740	2740	
CVAS to Enforcement Agency Total				0.003171296		2740	2740	DS0
CVAS to Financial Institution	tfi_cv_payment_request	0.08385086	274	22.97513558	0.1	2740	2740	

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
CVAS to Financial Institution Total				22.97513558		2740	2740	DS0
CVAS to FMS	cf_clearance_enrollment_confirm	1.15741E-05	26	0.000300926	0.1	260	260	
CVAS to FMS	cf_enrollment_information	0.090300926	3818	344.7689352	0.1	38180	38180	
CVAS to FMS	cf_enrollment_payment_confirmation	0.051600529	170	8.772089947	0.1	1700	1700	
CVAS to FMS	cv_enrollment_information	0.006450066	3818	24.62635251	0.1	38180	38180	
CVAS to FMS	cv_enrollment_payment_confirmation	0.025800265	346	8.926891534	0.1	3460	3460	
CVAS to FMS Total				387.0945701		81780	81780	DS1
CVAS to Government Administrators	tga_quarterly_reports	1.28601E-07	8000018	1.028808899	60	133333.6333	133333.6333	
CVAS to Government Administrators	tga_request_fees_updates	0.051600529	8000018	412805.1616	10	800001.8	800001.8	
CVAS to Government Administrators Total				412806.1904		933335.4333	933335.4333	DS1
CVAS to Other CVAS	tocvas_data_table	0.013545139	8210	111.2055903	1	8210	8210	
CVAS to Other CVAS	tocvas_enrollment_confirmation	0.013545139	82	1.110701389	0.1	820	820	
CVAS to Other CVAS	tocvas_enrollment_request	0.013545139	50	0.677256944	0.1	500	500	
CVAS to Other CVAS	tocvas_provide_data	0.013545139	50	0.677256944	0.1	500	500	

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
CVAS to Other CVAS Total				113.6708056		10030	10030	DS0
CVAS to PS	cv_operational_data	1.15741E-05	8192018	94.81502315	10	819201.8	819201.8	
CVAS to PS Total				94.81502315		819201.8	819201.8	DS1
CVCS to CVAS	cv_credentials_information_reques t	0.00015	554	0.0831	0.1	5540	5540	
CVCS to CVAS	cv_roadside_daily_log	1.15741E-05	3362	0.038912037	0.1	33620	33620	
CVCS to CVAS	cv_safety_information_request	0.0015	554	0.831	0.1	5540	5540	
CVCS to CVAS	cv_safety_information_request	0.162541667	554	90.04808333	0.1	5540	5540	
CVCS to CVAS	cv_update_safety_problems_list	0.000015	538	0.00807	0.1	5380	5380	
CVCS to CVAS Total				91.00916537		55620	55620	DS0
DMV to CVAS	fdmv_cv_violation_state_identity	1.15741E-05	26	0.000300926	0.1	260	260	
DMV to CVAS	fdmv_cv_violation_vehicle_registra tion	1.15741E-05	90	0.001041667	0.1	900	900	
DMV to CVAS Total				0.001342593		1160	1160	DS0
DMV to PMS	fdmv_parking_lot_violation_state_i dentity	0.000925926	26	0.024074074	0.1	260	260	
DMV to PMS	fdmv_parking_lot_violation_vehicle _registration	0.000925926	90	0.083333333	0.1	900	900	

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
DMV to PMS Total				0.107407407		1160	1160	DS0
DMV to TAS	fdmv_toll_violation_state_identity	0.000925926	26	0.024074074	0.1	260	260	
DMV to TAS	fdmv_toll_violation_vehicle_registration	0.000925926	90	0.083333333	0.1	900	900	
DMV to TAS Total				0.107407407		1160	1160	DS0
DMV to TMS	fdmv_traffic_violation_state_identity	75.93147035	26	1974.218229	0.1	260	1974.218229	
DMV to TMS	fdmv_traffic_violation_vehicle_registration	75.93147035	90	6833.832332	0.1	900	6833.832332	
DMV to TMS Total				8808.050561		1160	8808.050561	DS0
E911 or ETS to EM	fets_emergency_telephone_service_identity	0.014908949	146	2.176706531	0.1	1460	1460	
E911 or ETS to EM	fets_incident_details	0.002762541	202	0.558033185	0.1	2020	2020	
E911 or ETS to EM Total				2.734739716		3480	3480	DS0
EM to E911 or ETS	tets_incident_acknowledge	0.014908949	26	0.38763267	0.1	260	260	
EM to E911 or ETS Total				0.38763267		260	260	DS0
EM to FMS	cf_hazmat_request	5.78704E-05	146	0.008449074	0.1	1460	1460	
EM to FMS Total				0.008449074		1460	1460	DS0

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
EM to ISP	emergency_vehicle_route_request	8.917042303	1370	12216.34795	0.1	13700	13700	
EM to ISP	incident_information	0.001388889	858	1.191666667	0.1	8580	8580	
EM to ISP Total				12217.53962		22280	22280	DS0
EM to Other EM	toec_emergency_telephone_service_identity	0.014908949	146	2.176706531	0.1	1460	1460	
EM to Other EM	toec_incident_details	0.014908949	202	3.011607666	0.1	2020	2020	
EM to Other EM Total				5.188314197		3480	3480	DS0
EM to PS	emergency_vehicle_operational_data	1.15741E-05	819218	9.481689815	15	54614.53333	54614.53333	
EM to PS Total				9.481689815		54614.53333	54614.53333	DS0
EM to RTS	emergency_request_kiosk_traveler_acknowledge	96.6099885	26	2511.859701	0.1	260	2511.859701	
EM to RTS Total				2511.859701		260	2511.859701	DS0
EM to TMS	emergency_vehicle_green_wave	8.917042303	1098	9790.912448	0.1	10980	10980	
EM to TMS	incident_details	0.001388889	218	0.302777778	0.1	2180	2180	
EM to TMS	incident_response_status	0.003333333	826	2.753333333	0.1	8260	8260	
EM to TMS Total				9793.96856		21420	21420	DS0

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
EM to TRMS	transit_incident_coordination_data	4.62963E-06	41106	0.190305556	0.1	411060	411060	
EM to TRMS Total				0.190305556		411060	411060	DS1
EMMS to Map Update Provider	tmup_request_pollution_display_update	6.35938E-08	34	2.16219E-06	0.1	340	340	
EMMS to Map Update Provider Total				2.16219E-06		340	340	DS0
EMMS to PS	pollution_operational_data	1.15741E-05	1843458	21.33631944	100	18434.58	18434.58	
EMMS to PS Total				21.33631944		18434.58	18434.58	DS0
EMMS to RS	pollution_state_vehicle_acceptance_criteria	0.000277778	642	0.178333333	0.1	6420	6420	
EMMS to RS Total				0.178333333		6420	6420	DS0
EMMS to TMS	pollution_incident	0.001111111	202	0.224444444	0.1	2020	2020	
EMMS to TMS	pollution_state_data	0.003333333	282	0.94	0.1	2820	2820	
EMMS to TMS	wide_area_pollution_data	0.003333333	1024226	3414.086667	30	34140.86667	34140.86667	
EMMS to TMS Total				3415.251111		38980.86667	38980.86667	DS0
Event Promoters to TMS	fep_event_information	4	530	2120	0.1	5300	5300	
Event Promoters to TMS Total				2120		5300	5300	DS0

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
Financial Institution to CVAS	ffi_cv_payment_confirm	0.067725694	34	2.302673611	0.1	340	340	
Financial Institution to CVAS Total				2.302673611		340	340	DS0
Financial Institution to ISP	ffi_driver_map_payment_confirm	0.014406915	34	0.489835096	0.1	340	340	
Financial Institution to ISP	ffi_registration_payment_confirm	0.007203457	34	0.244917548	0.1	340	340	
Financial Institution to ISP	ffi_traveler_display_payment_confirm	4.384984954	34	149.0894884	0.1	340	340	
Financial Institution to ISP	ffi_traveler_map_payment_confirm	0.012005763	34	0.408195949	0.1	340	340	
Financial Institution to ISP	ffi_traveler_other_services_payments_confirm	0.006002882	34	0.204097975	0.1	340	340	
Financial Institution to ISP	ffi_traveler_rideshare_payment_confirm	0.004322075	34	0.146950542	0.1	340	340	
Financial Institution to ISP Total				150.5834855		2040	2040	DS0
Financial Institution to PMS	ffi_bad_charges_payment_updates	3.47222E-05	2066	0.071736111	0.1	20660	20660	
Financial Institution to PMS	ffi_confirm_charges_payment	0.128894326	26	3.351252463	0.1	260	260	
Financial Institution to PMS Total				3.422988574		20920	20920	DS0
Financial Institution to TAS	ffi_bad_toll_payment_updates	3.47222E-05	2066	0.071736111	0.1	20660	20660	
Financial Institution to TAS	ffi_confirm_toll_payment	0.128894326	34	4.382407067	0.1	340	340	

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
Financial Institution to TAS Total				4.454143178		21000	21000	DS0
Financial Institution to TRMS	ffi_bad_fare_payment_updates	3.47222E-05	2066	0.071736111	0.1	20660	20660	
Financial Institution to TRMS	ffi_confirm_fare_payment	0.128894326	26	3.351252463	0.1	260	260	
Financial Institution to TRMS	ffi_other_services_payment_confirm	0.007203457	34	0.244917548	0.1	340	340	
Financial Institution to TRMS Total				3.667906122		21260	21260	DS0
FMS to CVAS	cf_enroll_clearance_data	1.15741E-05	402	0.004652778	0.1	4020	4020	
FMS to CVAS	cf_enrollment_payment_request	0.051600529	414	21.36261905	0.1	4140	4140	
FMS to CVAS	cf_enrollment_request	0.090300926	3498	315.8726389	0.1	34980	34980	
FMS to CVAS	cv_enrollment_payment_request	0.045150463	414	18.69229167	0.1	4140	4140	
FMS to CVAS	cv_enrollment_request	0.006450066	3498	22.56233135	0.1	34980	34980	
FMS to CVAS Total				378.4945337		82260	82260	DS1
FMS to EM	cf_hazmat_route_information	0.090300926	3754	338.9896759	0.1	37540	37540	
FMS to EM	cf_hazmat_vehicle_information	1.65344E-06	242	0.000400132	0.1	2420	2420	
FMS to EM Total				338.9900761		39960	39960	DS0

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
FMS to Intermodal Freight Depot	To_Intermodal_Freight_Depot	0.010523964	530	5.577700861	0.1	5300	5300	
FMS to Intermodal Freight Depot Total				5.577700861		5300	5300	DS0
FMS to Intermodal Freight Shipper	To_Intermodal_Freight_Shipper	0.010523964	530	5.577700861	0.1	5300	5300	
FMS to Intermodal Freight Shipper Total				5.577700861		5300	5300	DS0
FMS to ISP	cf_route_request	0.090300926	1234	111.4313426	0.1	12340	12340	
FMS to ISP	cv_route_request	0.045150463	1354	61.13372685	0.1	13540	13540	
FMS to ISP Total				172.5650694		25880	25880	DS0
FMS to Payment Instrument	tpi_debited_commercial_manager_payment	0.090300926	50	4.515046296	0.1	500	500	
FMS to Payment Instrument Total				4.515046296		500	500	DS0
Government Administrators to CVAS	fga_carrier_safety_ratings	3.80267E-07	82	3.11819E-05	0.1	820	820	
Government Administrators to CVAS	fga_tax_and_credential_fees	3.80267E-07	530	0.000201542	0.1	5300	5300	
Government Administrators to CVAS Total				0.000232724		6120	6120	DS0
Intermodal Freight Depot to FMS	From_Intermodal_Freight_Depot	0.010523964	530	5.577700861	0.1	5300	5300	
Intermodal Freight Depot to FMS Total				5.577700861		5300	5300	DS0

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
Intermodal Freight Shipper to FMS	From_Intermodal_Freight_Shipper	0.010523964	530	5.577700861	0.1	5300	5300	
Intermodal Freight Shipper to FMS Total				5.577700861		5300	5300	DS0
Intermodal Transportation Service Provider to ISP	fitsp_air_services	37886.27	32768018	>10E+08	10	3276801.8	3276801.8	
Intermodal Transportation Service Provider to ISP	fitsp_ferry_services	378.8627	32768018	>10E+08	10	3276801.8	3276801.8	
Intermodal Transportation Service Provider to ISP	fitsp_intermodal_service_confirmation	0.48673333	338	164.5158655	10	33.8	164.5158655	
Intermodal Transportation Service Provider to ISP	fitsp_rail_services	3788.627	32768018	>10E+08	10	3276801.8	3276801.8	
Intermodal Transportation Service Provider to ISP Total				164.5158655		9830439.2	9830569.916	DS3
Intermodal Transportation Service Provider to TRMS	fitsp_transit_service_data	0.000277778	8192018	2275.560556	0.1	81920180	81920180	
Intermodal Transportation Service Provider to TRMS Total				2275.560556		81920180	81920180	DS3
ISP to EM	emergency_vehicle_route	0.08946	3890	347.9994	0.1	38900	38900	
ISP to EM	incident_information_request	0.001388889	170	0.236111111	0.1	1700	1700	
ISP to EM Total				348.2355111		40600	40600	DS0
ISP to Financial Institution	tfi_driver_map_payment_request	0.024003794	274	6.577039641	0.1	2740	2740	
ISP to Financial Institution	tfi_registration_payment_request	3.80267E-07	274	0.000104193	0.1	2740	2740	

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
ISP to Financial Institution	tfi_traveler_display_payment_request	2.192492477	274	600.7429387	0.1	2740	2740	
ISP to Financial Institution	tfi_traveler_map_payment_request	0.144069158	274	39.47494942	0.1	2740	2740	
ISP to Financial Institution	tfi_traveler_other_services_payments_request	0.438498495	274	120.1485877	0.1	2740	2740	
ISP to Financial Institution	tfi_traveler_rideshare_payment_request	10.52396389	274	2883.566106	0.1	2740	2883.566106	
ISP to Financial Institution Total				3650.509725		16440	16583.56611	DS0
ISP to FMS	cf_route	0.051600529	3034	156.5560053	0.1	30340	30340	
ISP to FMS	cv_route	0.045150463	3154	142.4045602	0.1	31540	31540	
ISP to FMS Total				298.9605655		61880	61880	DS1
ISP to Intermodal Transportation Service Provider	titsp_air_services_request	526.1981944	530	278885.0431	0.1	5300	278885.0431	
ISP to Intermodal Transportation Service Provider	titsp_confirm_intermodal_service	0.876996991	530	464.8084051	0.1	5300	5300	
ISP to Intermodal Transportation Service Provider	titsp_ferry_services_request	526.1981944	530	278885.0431	0.1	5300	278885.0431	
ISP to Intermodal Transportation Service Provider	titsp_rail_services_request	526.1981944	530	278885.0431	0.1	5300	278885.0431	
ISP to Intermodal Transportation Service Provider Total				837119.9376		21200	841955.1292	DS1
ISP to Map Update Provider	tmup_request_other_routes_map_update	0.016666667	34	0.566666667	0.1	340	340	

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
ISP to Map Update Provider	tmup_request_route_selection_map_update	0.016666667	34	0.566666667	0.1	340	340	
ISP to Map Update Provider Total				1.133333333		680	680	DS0
ISP to Media	tm_incident_information	0.0000694	819200	56.85248	10	81920	81920	
ISP to Media	tm_traffic_information	0.001388889	8192018	11377.80278	10	819201.8	819201.8	
ISP to Media	tm_transit_emergency_information	4.62963E-06	8192018	37.92600926	10	819201.8	819201.8	
ISP to Media	tm_transit_incident_information	0.60814766	8192018	4981956.575	10	819201.8	4981956.575	
ISP to Media	tm_transit_schedule_variations	596	2066	1231336	10	206.6	1231336	
ISP to Media	tm_traveler_information_request	0.001388889	82	0.113888889	10	8.2	8.2	
ISP to Media Total				6224765.27		2539740.2	7933624.375	DS3
ISP to Other ISP	toisp_data_supply	0.1753429	163840018	28728183.89	5	32768003.6	32768003.6	
ISP to Other ISP	toisp_request_data	17.53429167	34	596.1659167	0.1	340	596.1659167	
ISP to Other ISP Total				28728780.06		32768343.6	32768599.77	DS3
ISP to PMS	advanced_other_charges_request	301.3333333	514	154885.3333	0.1	5140	154885.3333	
ISP to PMS	advanced_traveler_charges_request	0.438498495	370	162.2444433	0.1	3700	3700	

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
ISP to PMS	parking_lot_data_request	52.61981944	34	1789.073861	0.1	340	1789.073861	
ISP to PMS	parking_lot_reservation_request	0.109624624	34	3.727237211	0.1	340	340	
ISP to PMS Total				156840.3789		9520	160714.4072	DS1
ISP to PS	current_other_routes_use	0.003333333	34054	113.5133333	1	34054	34054	
ISP to PS	current_other_routes_use	0.003333333	34054	113.5133333	1	34054	34054	
ISP to PS	current_road_network_use	0.003333333	385234	1284.113333	1	385234	385234	
ISP to PS Total				1511.14		453342	453342	DS1
ISP to RTS	advanced_tolls_and_charges_roadside_confirm	298	426	126948	0.1	4260	126948	
ISP to RTS	traffic_data_for_kiosks	2.192492477	83874957	183895211.5	1	83874956.68	183895211.5	
ISP to RTS	transit_deviations_for_kiosks	2.192492477	357666	784180.0142	0.1	3576660	3576660	
ISP to RTS	traveler_payment_confirmation	0.438498495	666	292.0399979	0.1	6660	6660	
ISP to RTS	traveler_transaction_confirmation	0.438498495	498	218.3722507	0.1	4980	4980	
ISP to RTS	traveler_trip_information	3.332	33314	111002.248	0.1	333140	333140	
ISP to RTS	traveler_yellow_pages_data	526.1981944	987.68	519715.4327	0.1	9876.8	519715.4327	

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
ISP to RTS Total				185437567.6		87810533.48	188463315	DS3
ISP to TAS	advanced_other_tolls_request	702.1202133	530	372123.7131	0.1	5300	372123.7131	
ISP to TAS	advanced_traveler_tolls_request	0.93889	530	497.6117	0.1	5300	5300	
ISP to TAS Total				372621.3248		10600	377423.7131	DS1
ISP to TMS	confirm_incident_data_output	0.003333333	26	0.086666667	1	26	26	
ISP to TMS	current_other_routes_use	0.003333333	34054	113.5133333	1	34054	34054	
ISP to TMS	current_road_network_use	0.003333333	385234	1284.113333	1	385234	385234	
ISP to TMS	current_transit_routes_use	0.003333333	50	0.166666667	1	50	50	
ISP to TMS	low_traffic_route	0.001666667	3874	6.456666667	1	3874	3874	
ISP to TMS	media_incident_data_updates	0.000555556	1666	0.925555556	1	1666	1666	
ISP to TMS	request_incident_media_data	0.027777778	50	1.388888889	1	50	50	
ISP to TMS	traffic_data_media_request	0.083333333	34	2.833333333	1	34	34	
ISP to TMS Total				1409.484444		424988	424988	DS1
ISP to TRMS	advanced_other_fares_request	407.4535467	738	300700.7174	0.1	7380	300700.7174	

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
ISP to TRMS	advanced_tolls_and_charges_vehicle_confirm	298	426	126948	0.1	4260	126948	
ISP to TRMS	advanced_traveler_fares_request	0.438498495	738	323.6118896	0.1	7380	7380	
ISP to TRMS	paratransit_service_confirmation	0.087699699	218	19.1185344	0.1	2180	2180	
ISP to TRMS	paratransit_trip_request	15.78594583	1418	22384.47119	0.1	14180	22384.47119	
ISP to TRMS	transit_services_advisories_request	0.003333333	274	0.913333333	0.1	2740	2740	
ISP to TRMS	transit_services_guidance_request	0.003333333	466	1.553333333	0.1	4660	4660	
ISP to TRMS	transit_vehicle_deviations_details_request	596	26	15496	0.1	260	15496	
ISP to TRMS Total				465874.3857		43040	482489.1886	DS1
ISP to Yellow Pages Service Providers	typsp_provider_registration_confirm	3.80267E-07	50	1.90134E-05	0.1	500	500	
ISP to Yellow Pages Service Providers	typsp_transaction_request	105.2396389	82	8629.650389	0.1	820	8629.650389	
ISP to Yellow Pages Service Providers	typsp_yellow_pages_info_request	0.003333333	274	0.913333333	0.1	2740	2740	
ISP to Yellow Pages Service Providers Total				8630.563741		4060	11869.65039	DS0
Map Update Provider to EMMS	fmup_pollution_display_update	0.000277778	16384018	4551.116111	15	1092267.867	1092267.867	
Map Update Provider to EMMS Total				4551.116111		1092267.867	1092267.867	DS1

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
Map Update Provider to ISP	fmup_other_routes_map_data	0.000277778	81920018	22755.56056	5	16384003.6	16384003.6	
Map Update Provider to ISP	fmup_route_selection_map_data	1.65344E-06	81920018	135.4497652	5	16384003.6	16384003.6	
Map Update Provider to ISP Total				22891.01032		32768007.2	32768007.2	DS3
Map Update Provider to PS	fmup_deployment_map_update	1.65344E-06	81920018	135.4497652	5	16384003.6	16384003.6	
Map Update Provider to PS Total				135.4497652		16384003.6	16384003.6	DS3
Map Update Provider to RTS	fmup_traveler_display_update	1.65344E-06	16384018	27.08997685	5	3276803.6	3276803.6	
Map Update Provider to RTS Total				27.08997685		3276803.6	3276803.6	DS3
Map Update Provider to TMS	fmup_demand_display_update	1.65344E-06	16384018	27.08997685	5	3276803.6	3276803.6	
Map Update Provider to TMS	fmup_incident_display_update	0.331504863	16384018	5431381.634	5	3276803.6	5431381.634	
Map Update Provider to TMS	fmup_traffic_display_update	0.001388889	16384018	22755.58056	5	3276803.6	3276803.6	
Map Update Provider to TMS Total				5454164.305		9830410.8	11984988.83	DS3
Media to ISP	fm_traveler_infirmation	0.000555556	8210	4.561111111	1	8210	8210	
Media to ISP Total				4.561111111		8210	8210	DS0
Multimodal Crossings to RS	fmmc_crossing_close_duration	1.15741E-05	50	0.000578704	0.1	500	500	

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
Multimodal Crossings to RS	fmmc_crossing_close_time	1.15741E-05	50	0.000578704	0.1	500	500	
Multimodal Crossings to RS Total				0.001157407		1000	1000	DS0
Other CVAS to CVAS	focvas_data_table	0.013545139	530	7.178923611	0.1	5300	5300	
Other CVAS to CVAS	focvas_enrollment_confirmation	0.013545139	26	0.352173611	0.1	260	260	
Other CVAS to CVAS	focvas_enrollment_request	0.013545139	274	3.711368056	0.1	2740	2740	
Other CVAS to CVAS	focvas_provide_data	0.013545139	66	0.893979167	0.1	660	660	
Other CVAS to CVAS Total				12.13644444		8960	8960	DS0
Other EM to EM	foec_emergency_telephone_service_identity	0.002762541	146	0.403330916	0.1	1460	1460	
Other EM to EM	foec_incident_details	0.002762541	202	0.558033185	0.1	2020	2020	
Other EM to EM Total				0.961364101		3480	3480	DS0
Other ISP to ISP	foisp_data_supply	1.15741E-05	163840018	1896.296505	5	32768003.6	32768003.6	
Other ISP to ISP	foisp_request_data	0.000277778	34	0.009444444	0.1	340	340	
Other ISP to ISP Total				1896.305949		32768343.6	32768343.6	DS3
Other TM to TMS	fotc_data_request	1.15741E-05	66	0.000763889	0.1	660	660	

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
Other TM to TMS	fotc_identity	1.15741E-05	50	0.000578704	0.1	500	500	
Other TM to TMS	fotc_transfer_data	1.15741E-05	4973504.1	57.56370465	5	994700.8164	994700.8164	
Other TM to TMS Total				57.56504724		995860.8164	995860.8164	DS1
Other TRM to TRMS	fotrm_transit_services	0.001111111	81920018	91022.24222	60	1365333.633	1365333.633	
Other TRM to TRMS Total				91022.24222		1365333.633	1365333.633	DS1
Parking Operator to PMS	fpo_current_lot_state	0.841917111	50	42.09585556	0.1	500	500	
Parking Operator to PMS	fpo_lot_occupancy	0.841917111	50	42.09585556	0.1	500	500	
Parking Operator to PMS Total				84.19171111		1000	1000	DS0
Parking Service Provider to PMS	fpsp_confirm_advanced_parking_payment	0.03507988	26	0.91207687	0.1	260	260	
Parking Service Provider to PMS	fpsp_current_lot_state	3.367668444	50	168.3834222	0.1	500	500	
Parking Service Provider to PMS	fpsp_lot_occupancy	3.367668444	50	168.3834222	0.1	500	500	
Parking Service Provider to PMS	fpsp_parking_lot_charge_change_response	0.03507988	66	2.315272056	0.1	660	660	
Parking Service Provider to PMS	fpsp_parking_lot_data	0.03507988	146	5.121662426	0.1	1460	1460	
Parking Service Provider to PMS	fpsp_transaction_reports_request	0.03507988	1042	36.55323457	0.1	10420	10420	

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
Parking Service Provider to PMS Total				381.6690904		13800	13800	DS0
Payment Instrument to FMS	fpi_commercial_manager_input_credit_identity	0.090300926	114	10.29430556	0.1	1140	1140	
Payment Instrument to FMS Total				10.29430556		1140	1140	DS0
Payment Instrument to PIAS	fpi_traveler_personal_input_credit_identity	2.192492477	178	390.2636609	0.1	1780	1780	
Payment Instrument to PIAS Total				390.2636609		1780	1780	DS0
Payment Instrument to RTS	fpi_confirm_fare_payment_at_roadside	0.10043808	26	2.611390089	0.1	260	260	
Payment Instrument to RTS	fpi_transit_roadside_tag_data	0.10043808	178	17.8779783	0.1	1780	1780	
Payment Instrument to RTS	fpi_transit_user_roadside_input_credit_identity	0.10043808	178	17.8779783	0.1	1780	1780	
Payment Instrument to RTS	fpi_traveler_roadside_input_credit_identity	4.384984954	178	780.5273218	0.1	1780	1780	
Payment Instrument to RTS Total				818.8946685		5600	5600	DS0
PMS to DMV	tdmv_parking_lot_violation_identity_code	0.000925926	34	0.031481481	0.1	340	340	
PMS to DMV	tdmv_parking_lot_violation_vehicle_license	0.000925926	146	0.135185185	0.1	1460	1460	
PMS to DMV Total				0.166666667		1800	1800	DS0
PMS to Enforcement Agency	tea_parking_violation_data	0.000925926	274	0.253703704	0.1	2740	2740	

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
PMS to Enforcement Agency Total				0.253703704		2740	2740	DS0
PMS to Financial Institution	tfi_parking_lot_payment_violator_data	0.000185185	2066	0.382592593	0.1	20660	20660	
PMS to Financial Institution	tfi_request_charges_payment	0.000115741	274	0.031712963	0.1	2740	2740	
PMS to Financial Institution Total				0.414305556		23400	23400	DS0
PMS to ISP	advanced_other_charges_confirm	108.5729722	346	37566.24839	0.1	3460	37566.24839	
PMS to ISP	advanced_traveler_charges_confirm	105.2396389	250	26309.90972	0.1	2500	26309.90972	
PMS to ISP	parking_lot_availability	52.61981944	370	19469.33319	0.1	3700	19469.33319	
PMS to ISP	parking_lot_reservation_confirm	0.109624624	34	3.727237211	0.1	340	340	
PMS to ISP Total				83349.21854		10000	83685.49131	DS1
PMS to Parking Operator	tpo_change_lot_state	0.003333333	50	0.166666667	0.1	500	500	
PMS to Parking Operator Total				0.166666667		500	500	DS0
PMS to Parking Service Provider	tpsp_change_lot_state	0.003333333	82	0.273333333	0.1	820	820	
PMS to Parking Service Provider	tpsp_parking_lot_charge_change_request	0.001111111	50	0.055555556	0.1	500	500	
PMS to Parking Service Provider	tpsp_request_advanced_parking_payment	0.2	82	16.4	0.1	820	820	

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
PMS to Parking Service Provider	tpsp_transaction_reports	0.000115741	81920018	9481.483565	100	819200.18	819200.18	
PMS to Parking Service Provider Total				9498.212454		821340.18	821340.18	DS1
PMS to TMS	parking_lot_charge_change_response	0.001111111	26	0.028888889	0.1	260	260	
PMS to TMS	parking_lot_current_occupancy	1	170	170	0.1	1700	1700	
PMS to TMS	parking_lot_current_state	1	178	178	0.1	1780	1780	
PMS to TMS	vms_parking_guidance_for_highways	1	1947881.4	1947881.405	10	194788.1405	1947881.405	
PMS to TMS	vms_parking_guidance_for_roads	1	1947881.4	1947881.405	10	194788.1405	1947881.405	
PMS to TMS Total				3896110.838		393316.281	3899502.81	DS3
PMS to TRMS	parking_lot_price_data	0.000192747	8192018	1578.983546	100	81920.18	81920.18	
PMS to TRMS	parking_lot_transaction_reports	0.000115741	8192018	948.1502315	100	81920.18	81920.18	
PMS to TRMS	parking_lot_transit_request	0.005555556	34	0.188888889	0.1	340	340	
PMS to TRMS Total				2527.322666		164180.36	164180.36	DS1
PS to Map Update Provider	tmup_deployment_map_update_request	1.15741E-05	34	0.000393519	0.1	340	340	
PS to Map Update Provider	tmup_map_static_data	1.15741E-05	81920018	948.1483565	100	819200.18	819200.18	

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
PS to Map Update Provider Total				948.14875		819540.18	819540.18	DS1
PS to Transportation Planners	ttp_evaluation_results	0.003333333	8192018	27306.72667	100	81920.18	81920.18	
PS to Transportation Planners	ttp_output_data_store	0.003333333	8192018	27306.72667	100	81920.18	81920.18	
PS to Transportation Planners	ttp_output_documentation	0.000277778	81920018	22755.56056	100	819200.18	819200.18	
PS to Transportation Planners	ttp_output_link_data	1.15741E-05	8192018	94.81502315	100	81920.18	81920.18	
PS to Transportation Planners	ttp_simulation_data	0.003333333	8192018	27306.72667	100	81920.18	81920.18	
PS to Transportation Planners Total				104770.5556		1146880.9	1146880.9	DS1
RS to EMMS	pollution_state_roadside_collection	1	218	218	0.1	2180	2180	
RS to EMMS	pollution_state_vehicle_collection	1	178	178	0.1	1780	1780	
RS to EMMS	pollution_state_vehicle_log_data	0.003333333	178	0.593333333	0.1	1780	1780	
RS to EMMS Total				396.5933333		5740	5740	DS0
RS to Multimodal Crossings	tmmc_crossing_clear_at_highways	1	50	50	0.1	500	500	
RS to Multimodal Crossings	tmmc_crossing_clear_at_roads	1	50	50	0.1	500	500	
RS to Multimodal Crossings	tmmc_stop_alternate_mode_at_highways	1	50	50	0.1	500	500	

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
RS to Multimodal Crossings	tmmc_stop_alternate_mode_at_roads	1	50	50	0.1	500	500	
RS to Multimodal Crossings	tmmc_stop_traffic_at_highways	1	50	50	0.1	500	500	
RS to Multimodal Crossings	tmmc_stop_traffic_at_roads	1	50	50	0.1	500	500	
RS to Multimodal Crossings Total				300		3000	3000	DS0
RS to TMS	ahs_checking_details	2.31481E-05	50	0.001157407	0.1	500	500	
RS to TMS	hov_lane_data_input	1	83928.08	83928.08	0.1	839280.8	839280.8	
RS to TMS	incident_analysis_data	1	2066	2066	0.1	20660	20660	
RS to TMS	indicator_input_data_from_highways	1	1802266	1802266	0.1	18022660	18022660	
RS to TMS	indicator_input_data_from_roads	1	3986	3986	0.1	39860	39860	
RS to TMS	roadside_fault_data	3.17969E-08	50	1.58985E-06	0.1	500	500	
RS to TMS	traffic_image_data	60	83904.08	5034244.8	0.1	839040.8	5034244.8	
RS to TMS	traffic_sensor_data	1	3929	3929	0.1	39290	39290	
RS to TMS	vehicle_pollution_alert	75.89397035	402	30509.37608	0.1	4020	30509.37608	
RS to TMS	vehicle_pollution_message_for_highways	75.89397035	362	27473.61727	0.1	3620	27473.61727	

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
RS to TMS	vehicle_pollution_message_for_roads	75.89397035	362	27473.61727	0.1	3620	27473.61727	
RS to TMS Total				7015876.492		19813051.6	24082452.21	DS3
RTS to EM	emergency_request_kiosk_traveler_details	96.6099885	370	35745.69575	0.1	3700	35745.69575	
RTS to EM Total				35745.69575		3700	35745.69575	DS0
RTS to ISP	advanced_tolls_and_charges_roadside_request	298	738	219924	0.1	7380	219924	
RTS to ISP	traffic_data_kiosk_request	2.192492477	98	214.8642627	0.1	980	980	
RTS to ISP	transit_deviation_kiosk_request	2.192492477	66	144.7045035	0.1	660	660	
RTS to ISP	traveler_current_condition_request	2.192492477	58	127.1645637	0.1	580	580	
RTS to ISP	traveler_payment_information	0.438498495	978	428.8515285	0.1	9780	9780	
RTS to ISP	traveler_transaction_request	0.438498495	402	176.2763951	0.1	4020	4020	
RTS to ISP	traveler_trip_confirmation	0.438498495	858	376.231709	0.1	8580	8580	
RTS to ISP	traveler_trip_request	2.192492477	1434	3144.034212	0.1	14340	14340	
RTS to ISP	traveler_yellow_pages_information_request	2.192492477	26	57.0048044	0.1	260	260	
RTS to ISP Total				224593.132		46580	259124	DS1

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
RTS to Map Update Provider	tmup_request_traveler_display_update	6.35938E-08	34	2.16219E-06	0.1	340	340	
RTS to Map Update Provider Total				2.16219E-06		340	340	DS0
RTS to Payment Instrument	tpi_debited_fare_payment_at_roadside	0.10043808	50	5.021904018	0.1	500	500	
RTS to Payment Instrument	tpi_debited_transit_user_payment_at_roadside	0.10043808	50	5.021904018	0.1	500	500	
RTS to Payment Instrument	tpi_debited_traveler_payment_at_roadside	4.384984954	50	219.2492477	0.1	500	500	
RTS to Payment Instrument	tpi_request_fare_payment_at_roadside	0.10043808	34	3.414894732	0.1	340	340	
RTS to Payment Instrument Total				232.7079505		1840	1840	DS0
RTS to TRMS	fare_collection_roadside_violation_information	0.11111	74154	8239.25094	0.1	741540	741540	
RTS to TRMS	other_services_roadside_request	5.96	2418	14411.28	0.1	24180	24180	
RTS to TRMS	request_roadside_fare_payment	1788	466	833208	0.1	4660	833208	
RTS to TRMS	transit_roadside_fare_payment_confirmation	0.10043808	26	2.611390089	0.1	260	260	
RTS to TRMS	transit_roadside_passenger_data	1.333	122	162.626	0.1	1220	1220	
RTS to TRMS	transit_services_kiosk_request	2.192492477	314	688.4426377	0.1	3140	3140	
RTS to TRMS	transit_services_travelers_request	0.13391744	466	62.40552727	0.1	4660	4660	

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
RTS to TRMS	transit_user_roadside_image	3.973788156	73746	293050.9814	0.1	737460	737460	
RTS to TRMS Total				1149825.598		1517120	2345668	DS3
Secure Area Environment to TRMS	fsa_transit_panic_button	4.62963E-06	50	0.000231481	0.1	500	500	
Secure Area Environment to TRMS	fsa_transit_video_image	30	8388626	251658780	0.1	83886260	251658780	
Secure Area Environment to TRMS Total				251658780		83886760	251659280	DS3
TAS to DMV	tdmv_toll_violation_identity_code	0.000925926	34	0.031481481	0.1	340	340	
TAS to DMV	tdmv_toll_violation_vehicle_license	0.000925926	146	0.135185185	0.1	1460	1460	
TAS to DMV Total				0.166666667		1800	1800	DS0
TAS to Enforcement Agency	tea_toll_violation_data	0.000925926	274	0.253703704	0.1	2740	2740	
TAS to Enforcement Agency Total				0.253703704		2740	2740	DS0
TAS to Financial Institution	tfi_request_toll_payment	0.000115741	274	0.031712963	0.1	2740	2740	
TAS to Financial Institution	tfi_toll_payment_violator_data	0.000185185	2066	0.382592593	0.1	20660	20660	
TAS to Financial Institution Total				0.414305556		23400	23400	DS0
TAS to ISP	advanced_other_tolls_confirm	509.3598522	346	176238.5089	0.1	3460	176238.5089	

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
TAS to ISP	advanced_traveler_tolls_confirm	105.2396389	250	26309.90972	0.1	2500	26309.90972	
TAS to ISP	vehicle_toll_probe_data	0.003333333	202	0.673333333	0.1	2020	2020	
TAS to ISP Total				202549.0919		7980	204568.4186	DS1
TAS to PS	toll_operational_data	1.15741E-05	58.004167	0.000671345	0.1	580.0416667	580.0416667	
TAS to PS Total				0.000671345		580.0416667	580.0416667	DS0
TAS to TCS	advanced_toll_needed	509.8598522	530	270225.7217	0.1	5300	270225.7217	
TAS to TCS	toll_bad_payment_check_response	0.666666667	314	209.3333333	0.1	3140	3140	
TAS to TCS Total				270435.055		8440	273365.7217	DS1
TAS to TMS	probe_data_for_traffic	0.003333333	8210	27.36666667	0.1	82100	82100	
TAS to TMS	toll_price_changes_response	0.001111111	26	0.028888889	0.1	260	260	
TAS to TMS Total				27.39555556		82360	82360	DS1
TAS to Toll Service Provider	ttsp_credit_identity	509.8598522	146	74439.53842	0.1	1460	74439.53842	
TAS to Toll Service Provider	ttsp_toll_price_changes_request	0.001111111	82	0.091111111	0.1	820	820	
TAS to Toll Service Provider	ttsp_toll_segments	509.8598522	530	270225.7217	0.1	5300	270225.7217	

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
TAS to Toll Service Provider	ttsp_transaction_reports	0.002777778	81920018	227555.6056	20	4096000.9	4096000.9	
TAS to Toll Service Provider	ttsp_vehicle_identity	509.8598522	274	139701.5995	0.1	2740	139701.5995	
TAS to Toll Service Provider Total				711922.5563		4106320.9	4581187.76	DS3
TAS to TRMS	toll_price_data	3.81563E-06	914	0.003487485	0.1	9140	9140	
TAS to TRMS	toll_transaction_reports	0.002777778	8192018	22755.60556	20	409600.9	409600.9	
TAS to TRMS Total				22755.60904		418740.9	418740.9	DS1
TCS to TAS	advanced_toll_transactions	0.833333333	338	281.6666667	0.1	3380	3380	
TCS to TAS	confirm_advanced_tolls_payment	0.5	410	205	0.1	4100	4100	
TCS to TAS	current_toll_transactions	0.666666667	786	524	0.1	7860	7860	
TCS to TAS	toll_bad_payment_check_request	0.666666667	306	204	0.1	3060	3060	
TCS to TAS	toll_payment_violator_data	0.000555556	322	0.178888889	0.1	3220	3220	
TCS to TAS	toll_violation_information	0.000925926	8192018	7585.201852	10	819201.8	819201.8	
TCS to TAS Total				8800.047407		840821.8	840821.8	DS1
TMS to Construction and Maintenance	tcm_fault_data	0.000235806	82	0.019336081	0.1	820	820	

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
TMS to Construction and Maintenance	tcm_incident_confirmation	0.002762541	26	0.071826054	0.1	260	260	
TMS to Construction and Maintenance	tcm_request_incident_change	0.002762541	274	0.756936103	0.1	2740	2740	
TMS to Construction and Maintenance Total				0.848098237		3820	3820	DS0
TMS to DMV	tdmv_traffic_violation_identity_code	75.93147035	34	2581.669992	0.1	340	2581.669992	
TMS to DMV	tdmv_traffic_violation_vehicle_license	75.93147035	146	11085.99467	0.1	1460	11085.99467	
TMS to DMV Total				13667.66466		1800	13667.66466	DS0
TMS to EM	incident_alert	0.000277778	842	0.233888889	0.1	8420	8420	
TMS to EM	incident_details_request	0.001388889	170	0.236111111	0.1	1700	1700	
TMS to EM	incident_response_clear	0.000277778	146	0.040555556	0.1	1460	1460	
TMS to EM Total				0.510555556		11580	11580	DS0
TMS to EMMS	pollution_state_data_request	0.003333333	50	0.166666667	0.1	500	500	
TMS to EMMS Total				0.166666667		500	500	DS0
TMS to Enforcement Agency	tea_traffic_violation_data	75.93147035	274	20805.22288	0.1	2740	20805.22288	
TMS to Enforcement Agency Total				20805.22288		2740	20805.22288	DS0

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
TMS to Event Promoters	tep_event_confirmation	0.000277778	26	0.007222222	0.1	260	260	
TMS to Event Promoters Total				0.007222222		260	260	DS0
TMS to ISP	current_highway_network_state	0.4	339034	135613.6	0.1	3390340	3390340	
TMS to ISP	current_road_network_state	0.4	339034	135613.6	0.1	3390340	3390340	
TMS to ISP	incident_data_output	0.003333333	530	1.766666667	0.1	5300	5300	
TMS to ISP	link_data_for_guidance	1.15741E-05	578	0.006689815	0.1	5780	5780	
TMS to ISP	predicted_incidents	0.003333333	194791.74	649.3057894	10	19479.17368	19479.17368	
TMS to ISP	prediction_data	0.001111111	400634	445.1488889	0.1	4006340	4006340	
TMS to ISP	retrieved_incident_media_data	0.0055556	90124442	500695.35	10	9012444.2	9012444.2	
TMS to ISP	traffic_data_for_media	0.083333333	8192018	682668.1667	5	1638403.6	1638403.6	
TMS to ISP	traffic_data_media_parameters	1.65344E-06	530	0.000876323	0.1	5300	5300	
TMS to ISP Total				1455686.946		21473726.97	21473726.97	DS3
TMS to Map Update Provider	tmup_request_demand_display_update	6.35938E-08	34	2.16219E-06	0.1	340	340	
TMS to Map Update Provider	tmup_request_incident_display_update	6.35938E-08	34	2.16219E-06	0.1	340	340	

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
TMS to Map Update Provider	tmup_request_traffic_display_update	1.27188E-07	34	4.32438E-06	0.1	340	340	
TMS to Map Update Provider Total				8.64876E-06		1020	1020	DS0
TMS to Other TM	totc_data_request	0.003333333	66	0.22	0.1	660	660	
TMS to Other TM	totc_identity	0.003333333	50	0.166666667	0.1	500	500	
TMS to Other TM	totc_transfer_data	1.15741E-05	87713260	1015.199769	5	17542652.02	17542652.02	
TMS to Other TM Total				1015.586436		17543812.02	17543812.02	DS3
TMS to PMS	parking_lot_charge_change_request	0.001111111	322	0.357777778	0.1	3220	3220	
TMS to PMS	parking_lot_input_data	1	509217.47	509217.4688	10	50921.74688	509217.4688	
TMS to PMS	selected_parking_lot_control_strategy	0.066666667	436507.83	29100.52203	10	43650.78304	43650.78304	
TMS to PMS	static_data_for_parking_lots	1.15741E-05	128048	1.482037037	10	12804.8	12804.8	
TMS to PMS Total				538319.8306		110597.3299	568893.0518	DS1
TMS to PS	ahs_operational_data	1.15741E-05	26.028642	0.000301257	0.1	260.2864198	260.2864198	
TMS to PS	current_incident_static_data	1.15741E-05	1317104	15.24425926	100	13171.04	13171.04	
TMS to PS	current_traffic_static_data	1.90781E-07	763847840	145.7279915	100	7638478.4	7638478.4	

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
TMS to PS	traffic_data_for_deployment	1.15741E-05	83874885	970.7741283	10	8387488.468	8387488.468	
TMS to PS Total				1131.74668		16039398.19	16039398.19	DS3
TMS to RS	ahs_control_data_changes	2.31481E-05	4114	0.095231481	0.1	41140	41140	
TMS to RS	indicator_control_data_for_highways	1	173674	173674	0.1	1736740	1736740	
TMS to RS	indicator_control_data_for_roads	1	3561234	3561234	0.1	35612340	35612340	
TMS to RS	indicator_control_monitoring_data_for_highways	1	173674	173674	0.1	1736740	1736740	
TMS to RS	indicator_control_monitoring_data_for_roads	1	3561234	3561234	0.1	35612340	35612340	
TMS to RS	vehicle_sign_data	2	901146	1802292	0.1	9011460	9011460	
TMS to RS Total				9272108.095		83750760	83750760	DS3
TMS to TAS	toll_price_changes_request	0.001111111	914	1.015555556	0.1	9140	9140	
TMS to TAS Total				1.015555556		9140	9140	DS0
TMS to TRMS	parking_lot_charge_request	0.003333333	26	0.086666667	0.1	260	260	
TMS to TRMS	prediction_data	0.001111111	400634	445.1488889	10	40063.4	40063.4	
TMS to TRMS	toll_price_request	0.003333333	26	0.086666667	0.1	260	260	

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
TMS to TRMS	transit_conditions_demand_request	0.003333333	34	0.113333333	0.1	340	340	
TMS to TRMS	transit_fare_request	0.003333333	26	0.086666667	0.1	260	260	
TMS to TRMS	transit_services_changes_request	0.001111111	8210	9.122222222	0.1	82100	82100	
TMS to TRMS	transit_services_demand_request	0.003333333	562	1.873333333	0.1	5620	5620	
TMS to TRMS Total				456.5177778		128903.4	128903.4	DS1
Toll Service Provider to TAS	ftsp_confirm_advanced_toll	0.036529774	34	1.242012326	0.1	340	340	
Toll Service Provider to TAS	ftsp_toll_price_changes_response	3.80267E-07	34	1.29291E-05	0.1	340	340	
Toll Service Provider to TAS	ftsp_toll_price_data	0.000115741	274	0.031712963	0.1	2740	2740	
Toll Service Provider to TAS Total				1.273738218		3420	3420	DS0
Traffic Operations Personnel to EMMS	ftop_pollution_data_information_request	0.000277778	50	0.013888889	0.1	500	500	
Traffic Operations Personnel to EMMS	ftop_pollution_parameter_updates	0.000277778	274	0.076111111	0.1	2740	2740	
Traffic Operations Personnel to EMMS Total				0.09		3240	3240	DS0
Transit Maintenance Personnel to TRMS	ftmp_transit_vehicle_maintenance_updates	1.15741E-05	530	0.006134259	0.1	5300	5300	
Transit Maintenance Personnel to TRMS Total				0.006134259		5300	5300	DS0

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
Transit System Operators to TRMS	ftso_emergency_request_acknowledge	0.60792	34	20.66928	0.1	340	340	
Transit System Operators to TRMS	ftso_fare_updates	3.80267E-07	274	0.000104193	0.1	2740	2740	
Transit System Operators to TRMS	ftso_media_parameter_request	1.15741E-05	34	0.000393519	0.1	340	340	
Transit System Operators to TRMS	ftso_media_parameter_updates	1.15741E-05	274	0.003171296	0.1	2740	2740	
Transit System Operators to TRMS	ftso_request_fare_output	3.47222E-05	34	0.001180556	0.1	340	340	
Transit System Operators to TRMS	ftso_security_action	4.63E-06	146	0.000675922	0.1	1460	1460	
Transit System Operators to TRMS Total				20.67480549		7960	7960	DS0
Transportation Planners to PS	ftp_evaluation_request	1.15741E-05	146	0.001689815	0.1	1460	1460	
Transportation Planners to PS	ftp_export_request	1.15741E-05	50	0.000578704	0.1	500	500	
Transportation Planners to PS	ftp_generation_request	1.15741E-05	2066	0.023912037	0.1	20660	20660	
Transportation Planners to PS	ftp_import_request	1.15741E-05	82	0.000949074	0.1	820	820	
Transportation Planners to PS	ftp_output_request	1.15741E-05	82	0.000949074	0.1	820	820	
Transportation Planners to PS	ftp_parameters	1.15741E-05	274	0.003171296	0.1	2740	2740	
Transportation Planners to PS	ftp_request_documentation	1.15741E-05	82	0.000949074	0.1	820	820	

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
Transportation Planners to PS	ftp_request_link_data	1.15741E-05	50	0.000578704	0.1	500	500	
Transportation Planners to PS	ftp_simulation_request	1.15741E-05	34	0.000393519	0.1	340	340	
Transportation Planners to PS	ftp_static_data	1.15741E-05	530	0.006134259	0.1	5300	5300	
Transportation Planners to PS	ftp_traffic_data_request	1.15741E-05	34	0.000393519	0.1	340	340	
Transportation Planners to PS	ftp_update_link_data	1.15741E-05	530	0.006134259	0.1	5300	5300	
Transportation Planners to PS Total				0.045833333		39600	39600	DS0
TRMS to EM	transit_coordination_data	0.000833333	40994	34.16166667	10	4099.4	4099.4	
TRMS to EM	transit_emergency_data	0.60814766	178	108.2502834	0.1	1780	1780	
TRMS to EM	transit_incident_details	4.62963E-06	178	0.000824074	0.1	1780	1780	
TRMS to EM Total				142.4127742		7659.4	7659.4	DS0
TRMS to Enforcement Agency	tea_fare_collection_roadside_violation_data	178.8	274	48991.2	0.1	2740	48991.2	
TRMS to Enforcement Agency	tea_fare_collection_vehicle_violation_data	178.8	274	48991.2	0.1	2740	48991.2	
TRMS to Enforcement Agency	tea_fare_payment_violation_data	3.973788156	274	1088.817955	0.1	2740	2740	
TRMS to Enforcement Agency Total				99071.21795		8220	100722.4	DS1

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
TRMS to Financial Institution	tfi_fare_payment_violator_data	0.496666667	2066	1026.113333	0.1	20660	20660	
TRMS to Financial Institution	tfi_other_services_payment_request	11.92	274	3266.08	0.1	2740	3266.08	
TRMS to Financial Institution	tfi_request_fare_payment	1.15741E-05	274	0.003171296	0.1	2740	2740	
TRMS to Financial Institution Total				4292.196505		26140	26666.08	DS0
TRMS to Intermodal Transportation Service Provider	titsp_transit_arrival_changes	596	4114	2451944	0.1	41140	2451944	
TRMS to Intermodal Transportation Service Provider	titsp_transit_arrival_deviations	596	4114	2451944	0.1	41140	2451944	
TRMS to Intermodal Transportation Service Provider	titsp_transit_service_data	0.000277778	8192018	2275.560556	1	8192018	8192018	
TRMS to Intermodal Transportation Service Provider Total				4906163.561		8274298	13095906	DS3
TRMS to ISP	advanced_other_fares_confirm	407.4535467	410	167055.9541	0.1	4100	167055.9541	
TRMS to ISP	advanced_tolls_and_charges_vehicle_request	298	738	219924	0.1	7380	219924	
TRMS to ISP	advanced_traveler_fares_confirm	105.2396389	250	26309.90972	0.1	2500	26309.90972	
TRMS to ISP	paratransit_personal_schedule	15.78594583	418	6598.525358	0.1	4180	6598.525358	
TRMS to ISP	transit_deviation_data_received	596	26	15496	0.1	260	15496	
TRMS to ISP	transit_media_emergency_information	0.60814766	2330	1416.984047	0.1	23300	23300	

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
TRMS to ISP	transit_media_incident_information	4.62963E-06	4378	0.020268519	0.1	43780	43780	
TRMS to ISP	transit_services_for_advisory_data	0.003333333	172354	574.5133333	0.1	1723540	1723540	
TRMS to ISP	transit_services_for_guidance	0.003333333	2530	8.433333333	0.1	25300	25300	
TRMS to ISP	transit_user_payments_transactions	11.92	1042	12420.64	0.1	10420	12420.64	
TRMS to ISP	transit_vehicle_deviations_details	1.49	398502.8	593769.172	0.1	3985028	3985028	
TRMS to ISP Total				1043574.152		5829788	6248753.029	DS3
TRMS to Other TRM	totrm_transit_services	0.000277778	81920018	22755.56056	60	1365333.633	1365333.633	
TRMS to Other TRM Total				22755.56056		1365333.633	1365333.633	DS1
TRMS to PIAS	transit_services_for_portables	2.192492477	2530	5547.005966	0.1	25300	25300	
TRMS to PIAS Total				5547.005966		25300	25300	DS0
TRMS to PMS	parking_lot_transit_response	0.005555556	34	0.188888889	0.1	340	340	
TRMS to PMS Total				0.188888889		340	340	DS0
TRMS to PS	financial_reports	1.65344E-06	24577818	40.63792659	60	409630.3	409630.3	
TRMS to PS	transit_passenger_operational_data	1.15741E-05	26.676481	0.000308756	0.1	266.7648148	266.7648148	

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
TRMS to PS	transit_services_for_deployment	1.15741E-05	172354	1.994837963	1	172354	172354	
TRMS to PS Total				42.63307331		582251.0648	582251.0648	DS1
TRMS to RTS	confirm_roadside_fare_payment	1788	26	46488	0.1	260	46488	
TRMS to RTS	other_services_roadside_respons e	5.96	2418	14411.28	0.1	24180	24180	
TRMS to RTS	request_transit_user_image	3.973788156	82	325.8506288	0.1	820	820	
TRMS to RTS	transit_roadside_fare_data	3.80267E-07	922	0.000350607	0.1	9220	9220	
TRMS to RTS	transit_roadside_fare_payment_de bited	1788	26	46488	0.1	260	46488	
TRMS to RTS	transit_roadside_fare_payment_re quest	1788	34	60792	0.1	340	60792	
TRMS to RTS	transit_services_for_kiosks	2.192492477	2378	5213.74711	0.1	23780	23780	
TRMS to RTS	transit_services_for_roadside_fare s	0.000289352	16826	4.868634259	0.1	168260	168260	
TRMS to RTS	transit_services_for_travelers	0.13391744	2530	338.8111244	0.1	25300	25300	
TRMS to RTS	transit_vehicle_arrival_time	0.111111111	66	7.333333333	0.1	660	660	
TRMS to RTS	transit_vehicle_user_data	13.33	106	1412.98	0.1	1060	1412.98	
TRMS to RTS Total				175482.8712		254140	407400.98	DS1

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
TRMS to Secure Area Environment	tsa_broadcast_message	4.62963E-06	402	0.001861111	0.1	4020	4020	
TRMS to Secure Area Environment	tsa_panuc_button_acknowledge	4.62963E-06	82	0.00037963	0.1	820	820	
TRMS to Secure Area Environment Total				0.002240741		4840	4840	DS0
TRMS to TMS	parking_lot_charge_details	0.003333333	322	1.073333333	0.1	3220	3220	
TRMS to TMS	toll_price_details	0.003333333	914	3.046666667	0.1	9140	9140	
TRMS to TMS	transit_fare_details	0.003333333	17306	57.68666667	0.1	173060	173060	
TRMS to TMS	transit_highway_overall_priority	596	26	15496	0.1	260	15496	
TRMS to TMS	transit_ramp_overall_priority	596	146	87016	0.1	1460	87016	
TRMS to TMS	transit_road_overall_priority	596	26	15496	0.1	260	15496	
TRMS to TMS	transit_running_data_for_demand	0.003333333	398270.8	1327.569333	1	398270.8	398270.8	
TRMS to TMS	transit_services_changes_response	0.001111111	34	0.037777778	0.1	340	340	
TRMS to TMS	transit_services_for_demand	0.003333333	172386	574.62	1	172386	172386	
TRMS to TMS Total				119972.0338		758396.8	874424.8	DS1
TRMS to Transit Maintenance Personnel	ttmp_work_schedule	0.001241667	8210	10.19408333	0.1	82100	82100	

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
TRMS to Transit Maintenance Personnel Total				10.19408333		82100	82100	DS1
TRMS to Transit System Operators	ttso_emergency_request	0.000833333	530	0.441666667	0.1	5300	5300	
TRMS to Transit System Operators	ttso_media_parameters	1.15741E-05	8210	0.095023148	0.1	82100	82100	
TRMS to Transit System Operators	ttso_potential_incidents_alarm	0.000833333	530	0.441666667	0.1	5300	5300	
TRMS to Transit System Operators	ttso_potential_security_problem	0.000833333	530	0.441666667	0.1	5300	5300	
TRMS to Transit System Operators	ttso_transaction_reports	1.15741E-05	81920018	948.1483565	100	819200.18	819200.18	
TRMS to Transit System Operators	ttso_transit_fare_output	3.47222E-05	8210	0.285069444	0.1	82100	82100	
TRMS to Transit System Operators Total				949.8534491		999300.18	999300.18	DS1
Weather Service to ISP	From_Weather_Service	0.001111111	1042	1.157777778	0.1	10420	10420	
Weather Service to ISP	fws_current_weather	0.000277778	530	0.147222222	0.1	5300	5300	
Weather Service to ISP	fws_predicted_weather	0.000277778	530	0.147222222	0.1	5300	5300	
Weather Service to ISP Total				1.452222222		21020	21020	DS0
Weather Service to TMS	From_Weather_Service	0.001111111	1042	1.157777778	0.1	10420	10420	
Weather Service to TMS	fws_current_weather	0.000277778	530	0.147222222	0.1	5300	5300	

Table 6.3-3 Wireline Data Loading Analysis, 2012, Urbansville

Wireline Link	Message	Frequency (/sec)	Message Size (bits)	Ave. Link Load (b/s)	Latency (sec)	Peak Link Load (b/s)	Max. Load (b/s)	Link Type
Weather Service to TMS	fws_predicted_weather	0.000277778	530	0.147222222	0.1	5300	5300	
Weather Service to TMS Total				1.452222222		21020	21020	DS0
Yellow Pages Service Providers to ISP	fypsp_request_provider_registration	3.80267E-07	50	1.90134E-05	0.1	500	500	
Yellow Pages Service Providers to ISP	fypsp_transaction_confirmation	105.2396389	26	2736.230611	0.1	260	2736.230611	
Yellow Pages Service Providers to ISP	fypsp_yellow_pages_data	0.003333333	8192018	27306.72667	10	819201.8	819201.8	
Yellow Pages Service Providers to ISP Total				30042.9573		819961.8	822438.0306	DS1

6.4 Analysis of the Data Loading Results

The general trends of the data loads are discussed in this section.

6.4.1 u1t Interface

In 1997 Urbansville, the transit and CVO-local user service groups are the largest users of data in the forward direction, with the other groups far below. In the reverse direction CVO-local is again the largest load, with smaller loads from transit and probes groups.

In 1997 Thruville, the transit and CVO-local groups provide the largest loads in the forward direction, with the others far below. In the reverse direction CVO-local is alone as the largest load, with probes, transit, and emergency having lower, but significant loads.

In 2002 Urbansville, CVO-local, transit, and private vehicles contribute the largest loads, with the others far below in the forward direction. In the reverse direction, CVO-local has the highest load with transit about one-half the load. The others are well down.

In 2002 Thruville, CVO-local and transit have the highest loads by a wide margin in the forward direction, with CVO-local contributing the largest load in the reverse direction.

In 2002 Mountainville, CVO-local is the largest load with all other users far below it in the forward direction. In the reverse direction CVO-local is alone the largest contributor, with all others well down.

In 2012 Urbansville, the private vehicles and CVO-local contribute the highest data loads, with transit at about one-half of their level. The others are well down. In the reverse direction, CVO-local is at the lead again, with transit at about one-third its level with private vehicle a bit lower.

In 2012 Thruville, CVO-local is largest in the forward direction, with transit at about one-half its level. In the reverse direction, CVO-local is the largest load with transit next at about one-third its level. Private vehicles, probes, and emergency all contribute significant loads.

In 2012 Mountainville, CVO-local has the highest load, with private vehicle and transit somewhat lower in the forward direction. In the reverse direction, CVO-local has the highest load with transit in second place at about one-fourth its level.

In each of the u1t scenarios and time frames studied, the forward direction data load is always higher than the reverse direction load, by a factor of two to three. The consistent users of the reverse direction are CVO and transit.

6.4.2 u1b Interface

The total aggregate data rate for a single broadcast transmitter sending the entire set of data from a region is 5,651 bps. This rate is easily achieved with any of the second generation broadcast subcarrier systems (see Section 7). If the data from the region is split between geographically-separated broadcast transmitters, the data rate on any individual transmitter would naturally be reduced.

6.4.3 u2 Interface

Due to the short propagation range of these systems, which enables fairly high data rates, their limited (by definition) coverage, and their layout to cover directly one or more lanes, communication capacity and performance are not issues. Any reasonably well designed multiple access scheme would handle the ultiple user within coverage of a given beacon. Various commercial solutions are currently available and are deployed in selected locales. There are, however, other issues of technical feasibility if these systems are considered for use to provide wide area wireless coverage, through wide spread deployment. These issues are discussed in Section 7 and Appendix G.

6.4.4 u3 Interface

The u3 interface, used for AHS applications, is still in the research stage and is covered in another program. Since this interface would use very-short-range communications over dedicated spectrum, there are no ITS communications system design issues that would not be addressed while conducting the AHS research independently.

6.4.5 Wireline Interface

There was a total of 140 wireline links studied, including links between subsystems, and to/from terminators. It was concluded that 60% of these links could be carried over 56 Kbps links. An additional 25% of the links could be carried over 1.5 Mbps links. The remaining links have aggregate data rates as high as 200 Mbps (i.e., for the ISP to RTS, and Secure Area Environment to TRMS links). In the case of a distributed subsystem, such as RS, the aggregate data load is the total load for all elements of the subsystem, where in a distribution network the total aggregate load is seen (such as near the TMS in the RS to TMS link case). Thus, the vast majority of these remaining links (particularly within a network) can be carried over 45 Mbps links. The wireline loads determined can easily be carried over numerous existing wireline communications options.

7. ASSESSMENT OF COMMUNICATION SYSTEMS AND TECHNOLOGIES

7.1 Introduction

In this section, a hot, contentious area is entered, that is, determining which communication systems are best suited for the ITS applications. It must be established at the outset that the intent of this section is **not** to recommend any "winning" systems or technologies – on the contrary, it can be stated *a priori* that all so-called winning solutions are at most temporarily such, heroes and victims of an unstoppable technology evolution that makes today's best into tomorrow's underdogs.

The intent of this section is solely to provide the reader with a characterization of today's candidate technologies that is as complete as possible, and also to offer a glimpse into the systems that loom on the horizon. Hopefully, this section will provide the implementors with a broad perspective of existing technologies. However, this section does not constitute in any way a technology study for any particular scenario. In particular, it does not account for any political, institutional, jurisdictional, budgetary or other similar constraints.

This section contains a broad analysis, review, and assessment of the various communication technologies that are applicable to the ITS architecture. The results of this assessment will lead to recommendations incorporated in the Physical Architecture definition that will be manifested, for example, in the Architecture Interconnect Specifications (AIS). The analyses herein lead naturally into the more detailed communication simulation issues addressed in Section 8 which is more focused on the simulation of a specific wireless system.[1]

This section begins with the review of the communication analysis objectives and methodology. It then discusses the assumptions underlying the systems and technologies selected for analysis – namely the use of shared infrastructure wherever and whenever possible.

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[1] For practical considerations, the wireless analysis/simulation effort has to be constrained to already standardized open systems. Since CDPD is the only fully standardized open-system for data communications over cellular (in the U.S. or abroad), with the added advantage of being already in the deployment stage, it will be analyzed in depth in Section 8 — this does not imply, however, any commitment to CDPD as the ITS wide-area delivery platform.

7.1.1 Objectives of the Technology Assessment

The main goal of the ITS communication systems technology assessment is to aid in selecting the best communication architecture (framework of system or systems, configurations, technologies, and techniques) that meet the objectives of the overall ITS system architecture. A secondary objective is to provide information for the implementors (local DOT's, etc.) to best match their needs to the capabilities of the available systems - subject to specific budgetary constraints.

Through communication systems analysis and a modicum of modeling and simulation, as appropriate, it will be ascertained how the communications element or "layer" of the system architecture satisfies the requirements at all stages of deployment, especially for the 1997, 2002, and 2012 time frames.

7.1.2 Underlying Assumptions

The strategy for assessing the communication layer of the ITS system architecture reflects both the Joint Team's architecture development philosophy and methodology. The communications layer provides the information transfer (data flow) that is required by the transportation layer to implement the desired user services. This communication component of the architecture must be technically and economically feasible as well as sensitive to the potential institutional and regulatory barriers. To fulfill this vision, the communication component has to emerge from current communications infrastructures, and progress in a manner consistent with the predicted evolution of telecommunication systems.

Two main principles will guide the evaluation efforts:

1. Extensive use of available technology whenever and wherever possible, and shared use of emerging infrastructures in order to minimize the costs directly attributable to ITS; and
2. Monitoring ongoing field trials and tests, as well as other FHWA/Government sponsored projects/studies (e.g., AHS Program).

Over the next twenty years, many new communications technologies, from multiple access to transport to switching, will be introduced at a rapid pace to support the demands of our information age. These technologies will offer extensive opportunities to handle the ITS user services and should be exploited fully. The technology projection displayed in Table 7.1-1 identifies the predicted availability of certain communication technologies and infrastructures to the year 2012.

In addition to the tremendous financial investment in the existing/emerging communication infrastructures (~$20 billion in the cellular infrastructure alone until 1995), an equally large amount of time and effort has been spent in developing standards to allow inter-operability and inter-connectivity among these systems. In the process, an extensive practical and theoretical knowledge base has been developed (reviewed in Section 7.5), that greatly expands upon the Phase I Technology Assessment in the Rockwell Team's *Physical Architecture* document. This broad assessment of communication technologies applicable to ITS includes in-depth, quantitative analyses. These analyses will be augmented in Section 8 with detailed simulations that examine a specific wide area technology deemed well suited for adoption as a service delivery medium within the National ITS Architecture.

7.1.3 Section Structure

Section 7.2 classifies the communication systems to be assessed into Wireless, both Wide-Area and Short-Range, and Wireline.

Section 7.3 analyzes the impact of non-ITS applications on the ITS service offerings assuming the use of shared media.

Section 7.4 analyzes the increasingly important role of protocols and inter-networking issues. It is important to understand that in a heterogeneous communications network (that at least encompasses both wireless and wireline components), it is the inter-networking functions (INF) that guarantee the system's throughput.

Section 7.5 presents the Technology Assessment arranged again into wireline and wireless systems, with substantially more emphasis on the wireless systems. The latter are classified and analyzed into wireless metropolitan area networks (MAN's), cell-based land-mobile systems, satellite-mobile systems, and broadcast systems.

Section 7.6 summarizes the Technology Assessment and presents an analysis of the systems side by side to facilitate comparison. The objective, once again, is not to recommend any specific solution, but to facilitate the implementors task of selecting the best solution for their identified problems and available budgets by having, in a single place, as complete a characterization of the systems as feasible at this time.

Table 7.1-1 Communications Technology Projections to the Year 2012

Technologies	1992	1997	2002	2012
Wireless Access	FDMA Analog	TDMA/CDMA Digital	CDMA/TDMA Digital	CDMA/TDMA Digital
Wireless Capacity	Moderate	High (3-5x AMPS)	High (5-10x AMPS)	High (10-15x AMPS)
Wireless Signal Coverage	All Urban, Most Inter-Urban, Some Rural	All Urban and Inter-Urban, Most Rural	All Urban and Inter-Urban All inhabited Rural	Ubiquitous
Wireless Media • Terrestrial: • Satellite:	 Most Macro Limited GEO	 Full Macro, Initial Micro Several GEO, Initial LEO	 Full Macro, Most Micro Full GEO, Partial LEO	Transparent, Hybrid Terrestrial Satellite Integrated Macro/Micro Full GEO/ Full LEO
Wireline Availability	Widespread Copper Limited Fiber for LAN's and Backbone	Fiber Backbone with Copper Drops Very Limited Hybrid Fiber-Coax	Very Limited Fiber to Curb Some Hybrid Fiber-Coax	Partial Fiber to Curb Limited Fiber to Home
Transfer Mode	Full Circuit-Switching Packet-Switching Initial Frame-Relaying	Partial Frame-Relaying Very Limited Asynchronous Transfer Mode (ATM)	Most Frame-Relaying Initial Fast-Packet Switching Partial ATM	Most Fast-Packet Switching Most ATM
Data Protocol	X.25, X.21	Frame-Relay ATM	Frame-Relay ATM	Mostly ATM
Transport Network Characteristics	Service Dependent Disconnected LAN's Slow Speed Interconnection	Initial Service-Independent Initial LAN Connectivity through Metropolitan Area Networks (MAN)	Partial Service-Independent Partial MAN's	Widespread Service Integrated Broadband Network—B-ISDN Most Service Independent
Intelligent Network Characteristics	Partial Wireline Support: • Number Translation	Most Wireline Support Partial Wireless Support • Mobility Services (Personal, Terminal)	Full Wireline Support Most Wireless Support	Fully Integrated Wireline/Wireless Support • Seamless Operation • Multi-Mode Terminal • Profile Portability • Dynamic Resource Allocation • Information Format Adaptation

7.2 Communication Systems Analysis and Assessment Approach

The communication systems/technologies assessment will be presented in two segments – wireless and wireline –reflecting the nature of the communication infrastructure. End-to-end performance, however, warrants looking at the ensemble behavior, not only of the wireless and wireline components of the communication layer, but also at the switching/routing elements. It should also be kept in mind, that as wireless systems become more prevalent, some distinctions in use will vanish.

7.2.1 Wireless Communication Systems Analysis

The wireless systems to be considered in an ITS context fall naturally into two different classes having to do with the intended range for information dissemination/collection: wide-area and short-range communication systems.

7.2.1.1 Wide-Area Communication Systems

Wireless communication is a broad and rapidly expanding field. The ITS architecture is most concerned with wireless *data* communication. Unfortunately, wireless data is a relatively new field, still with a number of proprietary systems. Moreover, some of the new wireless telecommunications standards that are being adopted for voice (e.g., CDMA and A-TDMA), have data service proposals that are in their infancy. The combination of breadth of communication system possibilities, new technology and proprietary systems, makes the analysis effort a rather daunting task. The analysis will therefore tackle different systems/technologies at different levels of depth and detail, ranging from very detailed, state-of-the-art simulation, to cursory quantitative examination of technical information available, even to the more risky anticipation of standards work results. Of course, the systems/technologies that are of most interest from a National ITS Architecture standpoint get the most detailed analytical treatment.

The systems to be analyzed are: wireless MAN (Metropolitan Area Network) systems targeting stationary users, land-mobile and satellite-mobile cell-based systems, meteor scatter systems (the "poor man's" satellite), and broadcast systems. A wide-area beacon-based "solution" is also looked into.

7.2.1.2 Short-Range Communications

In Phase I, Vehicle-to-Vehicle Communications (VtoVC) and Dedicated Short Range Communications (DSRC), were only briefly analyzed. In Phase II, some detail has been added based upon work being done in the DSRC area at the standards bodies.

Several subsidized and independent studies are underway in the VtoVC area, some in the U.S. and others in Europe. A review of the most promising candidates from a national U.S. perspective needs to be performed. Any ITS architectural implications regarding the adoption of certain solutions should also be identified. The role of the National ITS Architecture in the definition of VtoVC has been mainly of monitoring the progress in the area.

7.2.1.2.1 Dedicated Short Range (formerly Vehicle-to-Roadside) Communications

The applications for which the Dedicated Short Range (DSRC) wireless solution is appropriate have already been clearly identified in the *Physical Architecture* document. They include toll collection, parking fee collection, roadside safety inspection, and credentials pre-clearance.

The short range communication systems differ intrinsically from wide area wireless systems such as cellular. The former benefit from being in a confined geographical area (few hundred feet at most), and therefore are less susceptible to multi-user, multi-base station interference than systems that cover a whole metropolitan area. The key issues center around the adequacy of the different systems proposed (IR, RF Active, RF Passive) to accommodate the user requirements, and their flexibility and expandability towards the goal of national compatibility.

7.2.1.2.2 Vehicle-to-Vehicle Communications

Given that AHS is the subject of an ongoing, parallel study that is still in its initial stages, the Joint Team will restrict its analysis to a review of proposed interfaces and communication systems, an acknowledgment of the importance of AHS and its impact on the National ITS architecture. The objective is to insure inter-operability, especially concerning vehicle-to-vehicle and vehicle-to-roadside communications (VtoVC and DSRC), and that the National ITS Architecture does not inadvertently close any paths for the AHS Consortium to investigate.

7.2.2 Wireline Communication Analysis

Whereas wireless technologies are quickly evolving in a heated competitive environment, a host of wireline technologies have become generally accepted, and consequently broadly modeled by a host of general purpose simulation packages (e.g., OPNET, COMNET, BONES). These wireline technologies and techniques, however, span a great deal of range in capability, cost, and relative maturity (e.g., fiber versus coaxial versus twisted-pair; ISDN versus frame relay versus FDDI versus ATM). The wireline infrastructure to support ITS applications can, therefore, be an arena of much selection and variability depending on the disparate transportation needs, objectives, and budget of the many jurisdictions.

In Phase I, it was concluded that the wireline portion of the communication systems supporting ITS will not constitute the communications bottleneck. (The Phase I wireline simulation results are included in Section 8 for the reader’s convenience.) In fact, through proper design, and given the many alternatives available, the capacity and/or throughput of wireline systems can be made to meet the users’ requirements (with any desired margins) satisfying any least cost criterion. Thus, the emphasis in Phase II is on communication systems and protocols that could not be analyzed in Phase I due to lack of resources and because models were not available.

7.2.3 End-to-End Communication Analysis

The above separate analysis of the wireline and wireless components of the communications infrastructure needs to be combined with the objective of assessing the end-to-end system performance. Referring back to Figure 3.2-3 depicting the AID-level 0, end-to-end performance from an ITS service perspective can be viewed as comprising: 1.) communication system performance (wireless and wireline segments connecting two AID subsystems as well as the switching/routing elements), and 2.) the performance of the “transportation layer” subsystems themselves (their processing time, any data base access time, etc.). The overall end-to-end ITS service requirements are elucidated in the *Mission Definition* document and are derived, in many cases, from inexact human factors related to ITS service acceptance.

Since the performance of any ITS subsystem is a moving target, driven primarily be the stakeholders’ budgetary constraints, the focus here and in Section 8 will be only on the telecommunication segment (wireless and wireline). In the end, it will be seen that the communication layer implementations considered will not place any undue constraint or limitation on the provision of the ITS services.

7.3 Non-ITS Applications and Their Impact

When obtaining the communication systems' end-to-end performance for any deployed infrastructure with other users, it is intuitive that the traffic generated by non-ITS users will have an impact on the ITS performance.

To illustrate, we use CDPD here as an example. If the ITS data loads can be accommodated on one CDPD channel per sector (the so called minimal deployment even out to 20 years), and if the non-ITS traffic is a few times that of ITS, the total traffic may not be accommodated on only one channel.

On the other hand, the crux, as well as the advantage of cell based systems, is that the solution for the higher traffic is simply to deploy more (in this case CDPD) channels as needed. (Loaded data channels are more profitable than voice to the carrier.) In fact, the voice demand leads the way to the deployment of new cells and splitting the present cells into smaller and smaller ones, that continue to have more or less the same load. CDPD deployment (as that of any other overlay system) follows that of voice.[2]

The difficulty in assessing the effect of non-ITS users resides in the characterization of the traffic they generate. After long discussions both inside the Team and with wireless data experts in various companies, it was agreed that a few non-ITS applications are "promising":

1) Credit Card/Transaction Authorization and Fixed/Mobile POS
   - Taxis
   - Food Delivery
   - Door-to-Door Sales
   - Landscaping, Pool care, Snow Removal, etc.
   - Gas Stations
   - Fast Food
   - Other Retail
2) Telemetry
   - Oil, gas, water and power monitoring
   - Oil, gas and water well production monitoring and control
   - Oil and gas pipeline monitoring and control
   - Electric power demand monitoring
   - Storage tank level monitoring
   - Pollution and noise level monitoring
   - Vending machine remote inventory control and loss management
3) Field Service (Appliances, Cable, Utilities, High Tech, Office Equipment)
   - Job dispatch
   - Information access
   - Reporting
4) Health Care (Visiting Nurses, House Calls)

[2] In Phase I, an analysis was made regarding the case of one reserved CDPD channel plus another one dynamically assigned as a function of availability and demand. In Phase II the case was considered of one reserved CDPD channel, as well as a totally dynamic solution for the CDPD problem with no reserved channels.

- Job dispatch
- Information access
- Reporting

5) Field Sale

- Catalog/Information access
- Order placing

6) Public Safety

- NCIC inquiry
- State and Local data base access
- Incident and shift reporting

7) Security

- Keycard access
- Commercial Alarms

8) Mobile Office

- LAN access: File synchronization, file transfer, data base access, calendar update, etc.
- Internet access
- E-mail

9) Remote Access

- Internet access
- E-mail

Looking at the above list, which does not presume to cover all the upcoming uses of wireless data access, two distinct classes of applications can be observed: one corresponding to occasional, bursty transactions, including all entries 1) to 7), and another corresponding to a more or less continuous use of the system, with longer "transactions", constituting a traffic background for the first class of applications.

At this point, in order to get some feeling for the non-ITS traffic to be expected, it becomes necessary to predict the number of users in each category. This is obviously the subject of much heated debate with predictions covering the whole spectrum, depending on how optimistic, realistic, or pessimistic the authors want to be.

Based upon Market Research information GTE obtained from a few, well respected companies, and some internal market projections, the numbers of wireless data users for the year 2002, shown in Table 7.3-1 and Figure 7.3-1, were settled upon. Those figures are nothing more than just another projection. It will later be shown however, that it is a rather sensible projection.

7.3.1 Non-ITS Wireless Data Market Projections for 2002

A slightly different classification will be used in coming up with projections for the number of users for each type of applications.

Table 7.3-1 Wireless Data Market Projections (from External and GTE Market Studies)

Number of Wireless Data Users (x1000)	1994	1995	1996	1997	1998	1999	2000	2001	2002
Public Safety	90	111	132	160	207	273	367	498	677
Field Service	171	250	386	594	875	1229	1593	1900	2062
Transportation	145	198	291	425	614	865	1139	1372	1488
Field Sales	49	120	213	369	614	934	1293	1611	1806
Telemetry	1	9	39	92	192	389	758	1400	2395
Transactions/POS	1	8	29	68	146	282	461	622	671
Mobile Professional Sales (excluding Field Sales)	37	74	135	225	362	540	725	851	874
Mobile Professional Non-Sales	5	10	50	219	742	1886	3537	4893	4906
Public	1	4	15	55	189	587	1590	3661	6957
Total	500	783	1291	2207	3942	6984	11461	16808	21837

Particularly interesting are “Transportation”, which tries to account for the wireless data users in the transportation field not covered by other categories (from some commercial fleets, to transit and para-transit fleets), and “Public” which accounts for all private users with wireless access not used for job related purposes (the private usage of company provided equipment by a mobile professional is not considered in this category).

To put the figures in context, at the projected number of “Public” wireless data users in 2002 corresponds to 10.44% of the households so equipped for non-job related purposes. This number is very similar to the one used in the *Evaluatory Design* document: 10% of the households were assumed to have wireless data remote access capabilities.

In any case, the “Public” and the Mobile Professional (Sales and Non-Sales) entries correspond to 58.33% of the total number of users. In spite of the different types of traffic these categories generate, there are two underlying, common activities that gives rise to a background traffic that will dominate the non-ITS traffic: e-mail (retrieval and submission of messages), and Internet access.

These two activities are certainly distinct. E-mail is essentially a symmetric, two-way process, while Internet access (in its strict sense, i.e., not including e-mail), is essentially asymmetric, and forward direction intensive.

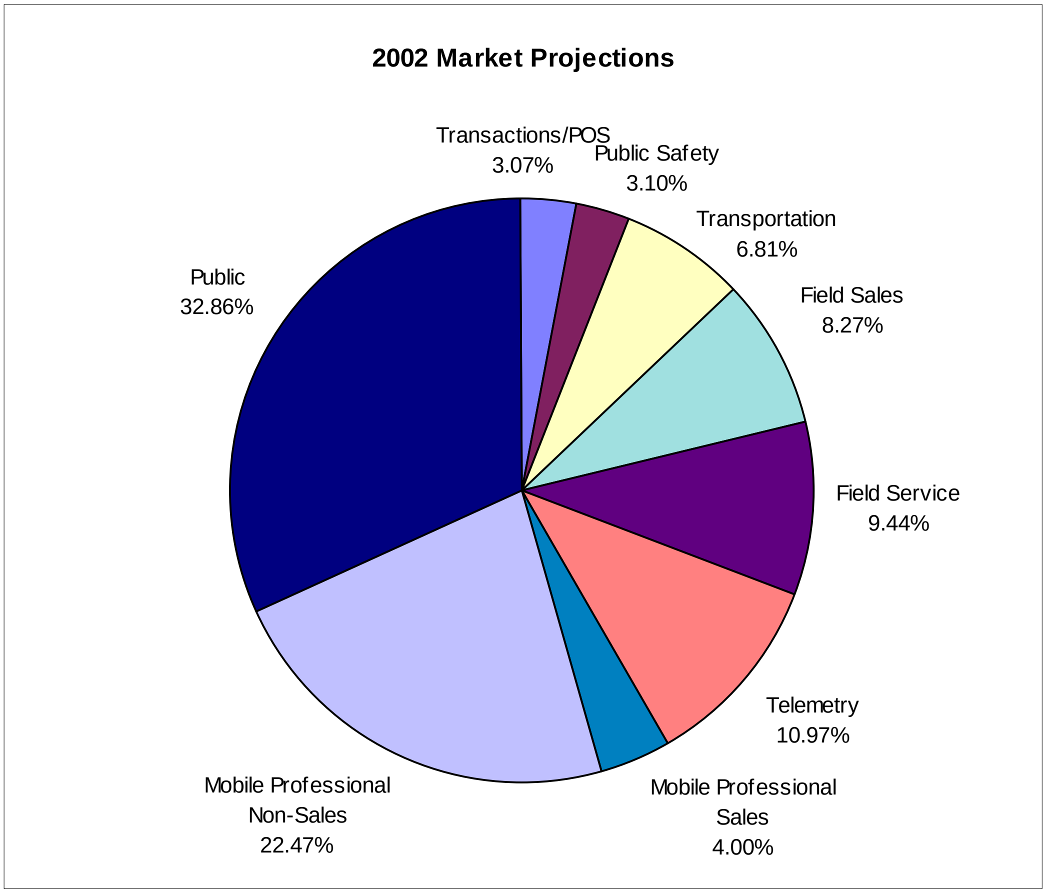


Figure 7.3-1 2002 Wireless Data Market Projections (from External and GTE Market Studies)

The projections above represent a middle ground, which is probably realistic. This represents neither an optimistic or pessimistic point of view. A good measure of that middle ground can be found in the projections related to the “Public” category, determined as will be shown by the traffic it originates.

It has already been mentioned that the projections for 2002 imply that 10.44% of the households are assumed wireless equipped are not for non-job-related purposes. For the year 2000, the last year for which non-GTE Market Research projections were available, that percentage is only 2.43%. This number is much higher than the 0.61% figure from one study. At the same time, the same 10.44% household penetration for 2002 is approximately half of the 20-25% predicted by some (optimistic) “experts”.

7.3.2 Characterization of Non-ITS Applications Traffic

This section provides a brief assessment of the traffic generated by non-ITS applications. For the specific cases of e-mail and Internet access, enough information exists so that guessing is unneccessary. Information on other non-ITS traffic is more difficult to obtain and validate, and will be addressed with the necessary caveats.

7.3.2.1 E-Mail Traffic Characterization (12.7 Million Users)

An extensive statistical analysis of e-mail traffic was performed at GTE Laboratories. Incoming and outgoing e-mail was tracked over the period of a few months (to discount the effect of holidays and vacations), and information was collected regarding the number of incoming/outgoing messages during different periods of the day, for different days of the week, and regarding incoming/outgoing message sizes.

7.3.2.1.1 Time-of-Day Characterization

The observed fluctuation of e-mail traffic during the day looks as expected, with two peak periods, one in the morning from 11am to 12 noon, and another, albeit smaller, in the afternoon from 4 to 6 pm. A third, even smaller peak occurs in the period 11pm to midnight as a result of delayed delivery of e-mail.

In terms of impact, it is the afternoon peak period that is of interest, since it coincides with the afternoon rush period. The morning peak coincides with the mid-day lull, and thus does not constitute a critical traffic source. E-mail characteristics over time are shown in Figures 7.3-2 and 7.3-3.

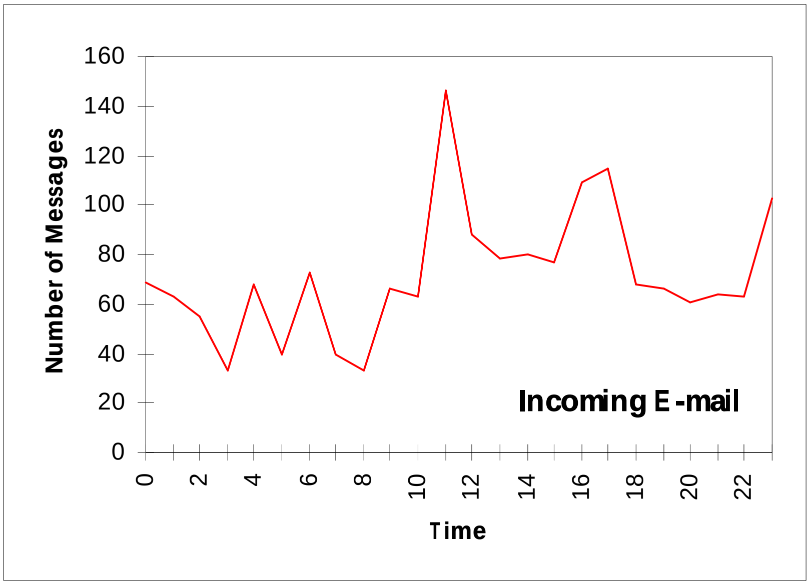


Figure 7.3-2 Time-of-Day E-mail Pattern -- Incoming E-mail

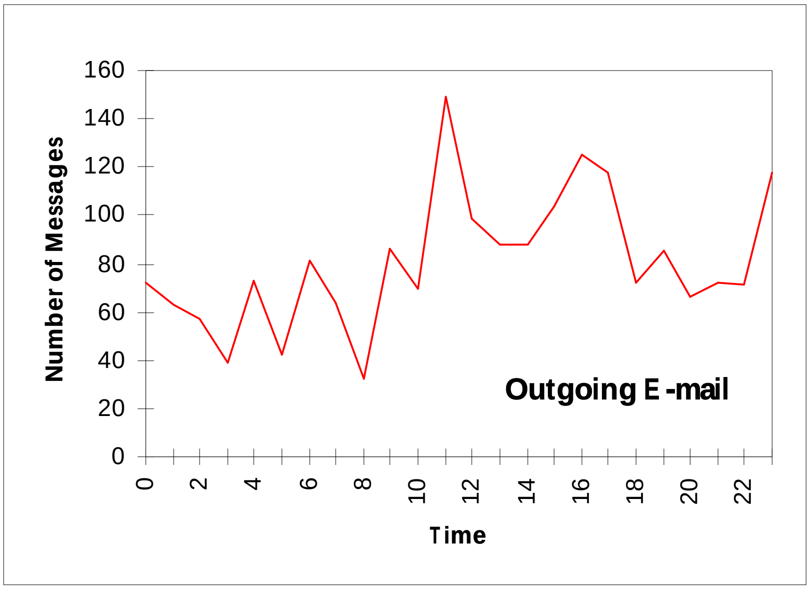


Figure 7.3-3 Time-of-Day E-mail Pattern -- Outgoing E-mail

7.3.2.1.2 Message Size Characterization

The first assessment is a look at the observed distribution of message sizes (see Figure 7.3-4 and 7.3-5), which includes both incoming and outgoing messages (no difference was observed). Please note that this represents traffic arriving at/departing from a fixed site, that is, the distribution below does not exactly correspond to a mobile situation.

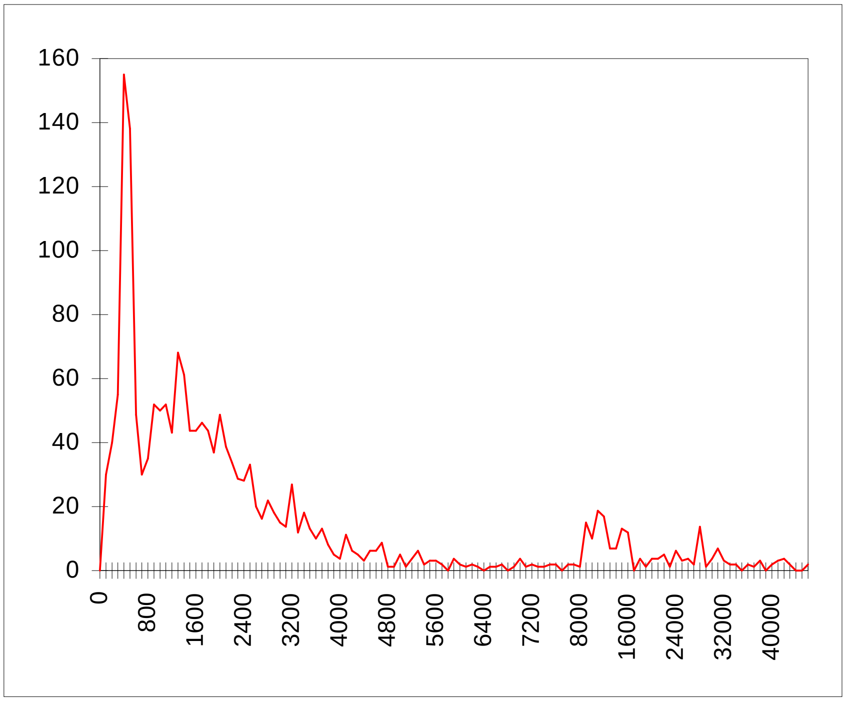


Figure 7.3-4 Histogram of Message Size up to 100 kbytes (Not to Scale)

Three underlying distributions can be identified: 1) Small Messages (<500 bytes); 2) Medium Messages (<5 kbytes); 3) Messages with small attachments (<50 kbytes).

It is our opinion that the third type of messages will seldom occur in a mobile environment. For instance, EUDORA lets you not download messages above a given size, which is set by default to 40 kbytes. Therefore, those long messages will not be considered for the purpose of projecting a “mobile” distribution.

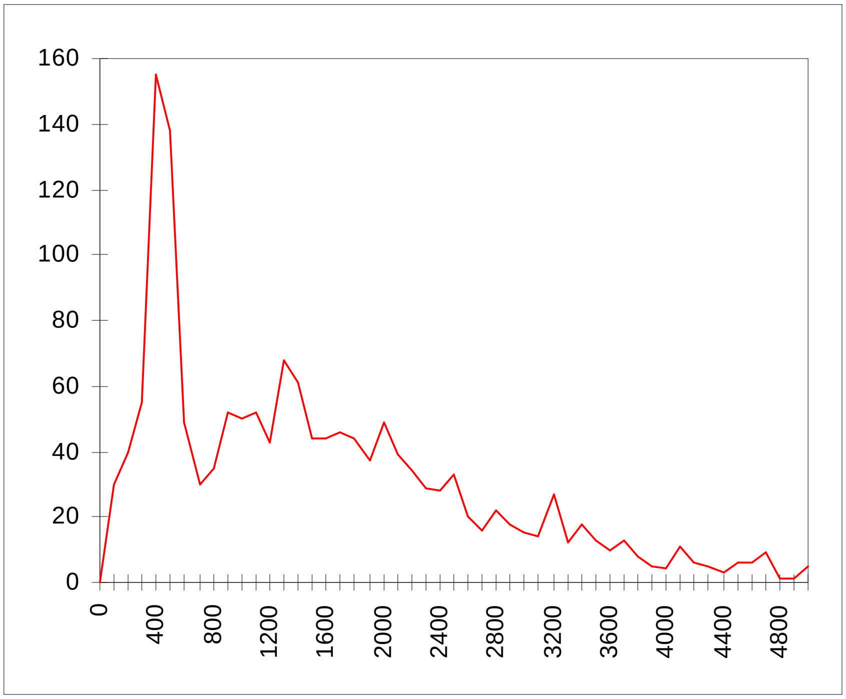


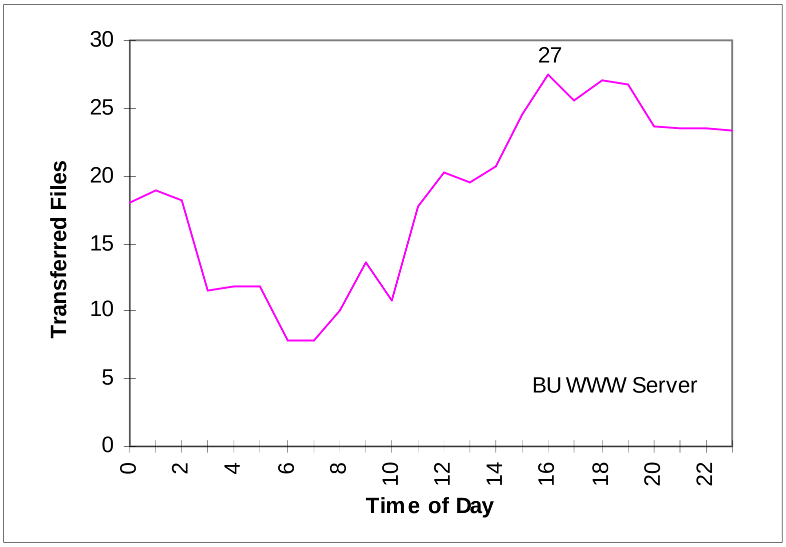
Figure 7.3-5 Histogram of Wireless E-mail Message Sizes (up to 5 kbytes)

The above distribution will be used in Chapter 8 to generate e-mail for the purpose of assessing the overall system performance accounting for non-ITS usage of the shared network.

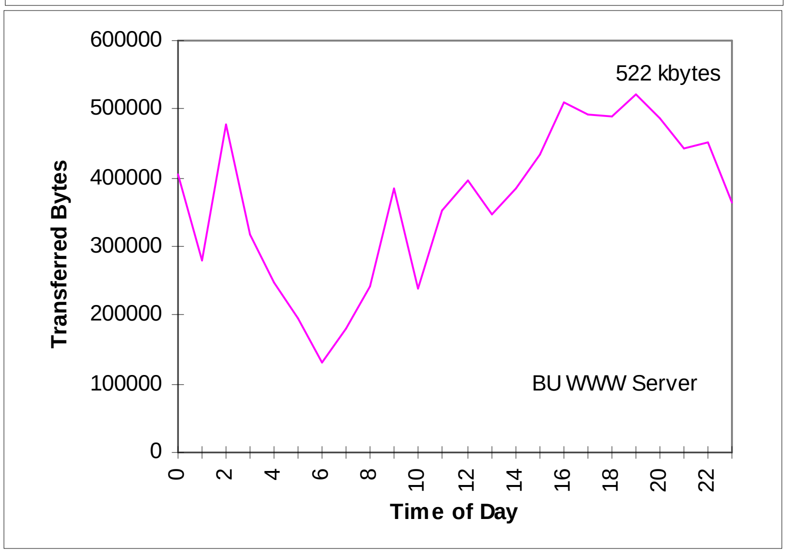
7.3.2.2 Internet Access Traffic Characterization (12.7 Million Users)

An increasingly important fraction of Internet traffic is associated with the World Wide Web (WWW). Given that its importance is bound only to increase, WWW traffic will be used here as a good approximation of overall Internet traffic. This applies particularly to mobile users – although file transfers (FTP) as well as remote login (Telnet) will still occur, most of the file transfers will occur in the process of using (and in fact be subsumed by) Web browsers. For the purpose of identifying the traffic patterns, the hits on two WWW servers at Boston University (BU), and MIT will serve as an example. The charts in Figures 7.3-6 through 7.3-9 were obtained by processing publicly available server statistics information.

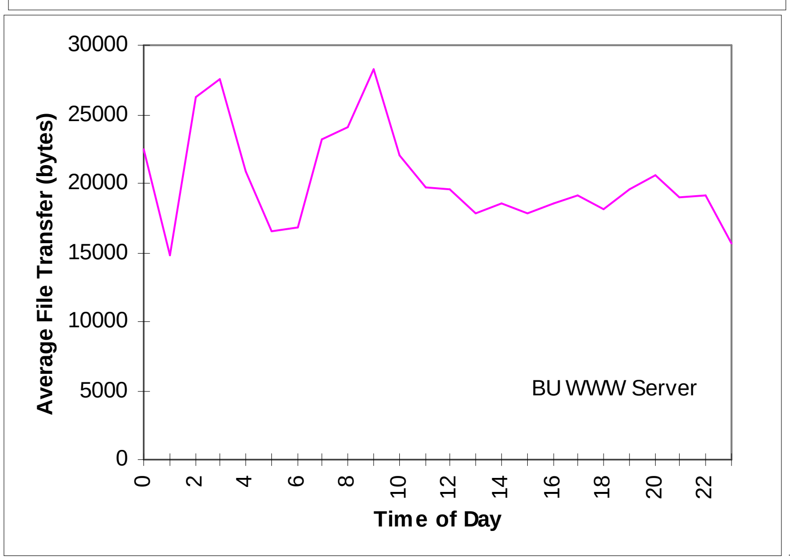
A single peak period has been identified beginning at 4 pm (sometimes extending up to 8 pm) both for file transfers (Web page hits) and transferred information (bytes transferred). The average size of the file transfers per hit does not vary much during the day, which is plausible since when one hits a new URL (even without downloading graphics) one never knows what to expect in terms of a Web site's information content (measured in terms of bytes, not in the information theoretic sense...).



Average of 444 files a day

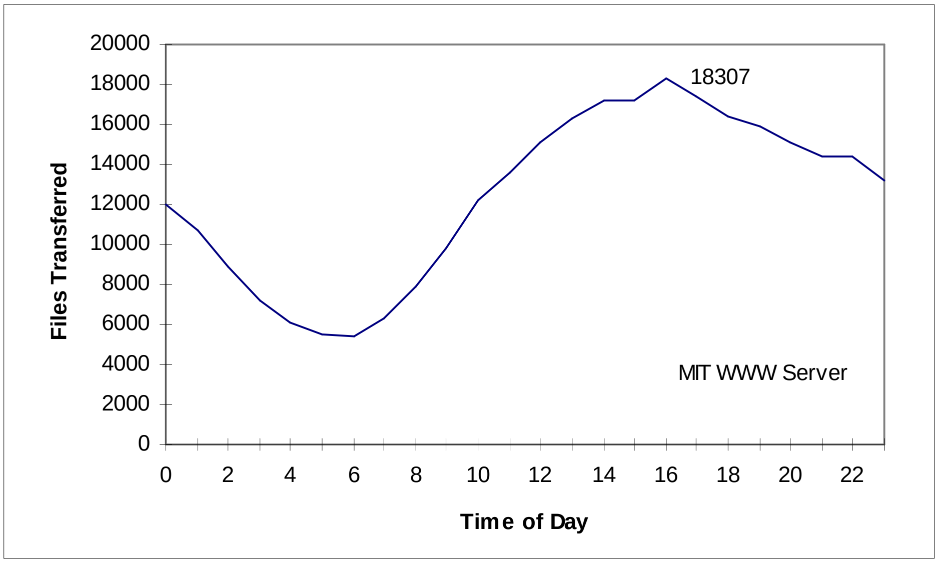


Average of 8.8 Mbytes a day

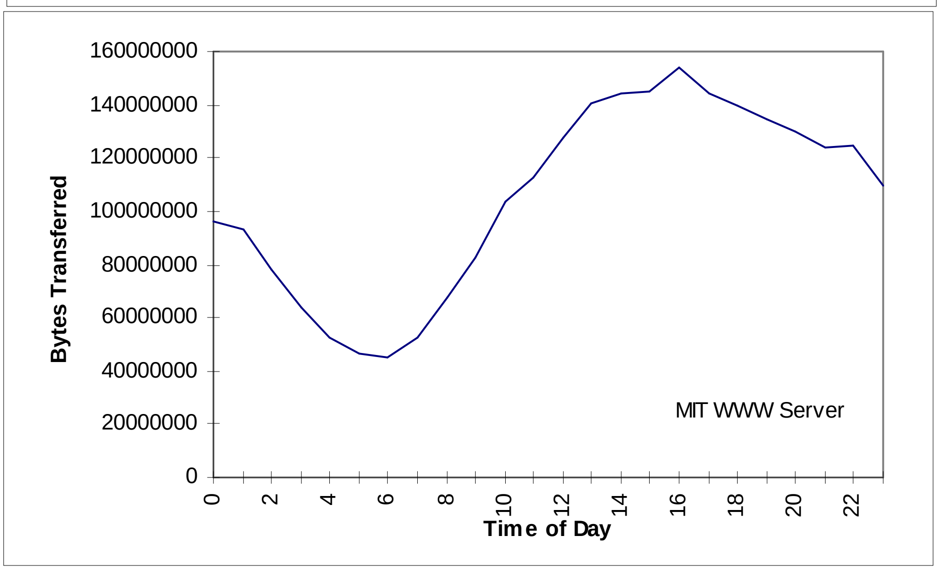


All Day Average: 19760 bytes

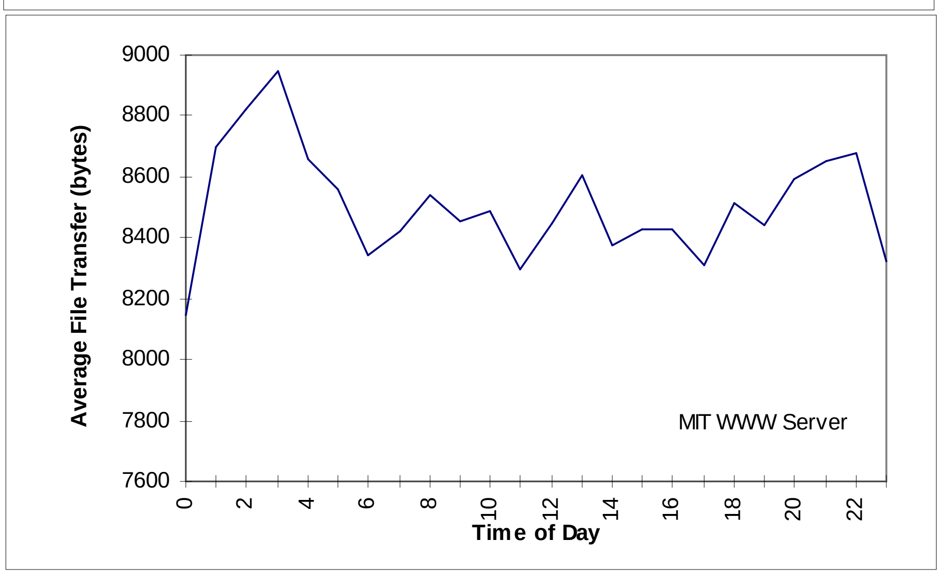
Figure 7.3-6 Daily Statistics for the Boston University WWW Server



Average of 296,217 Files a day



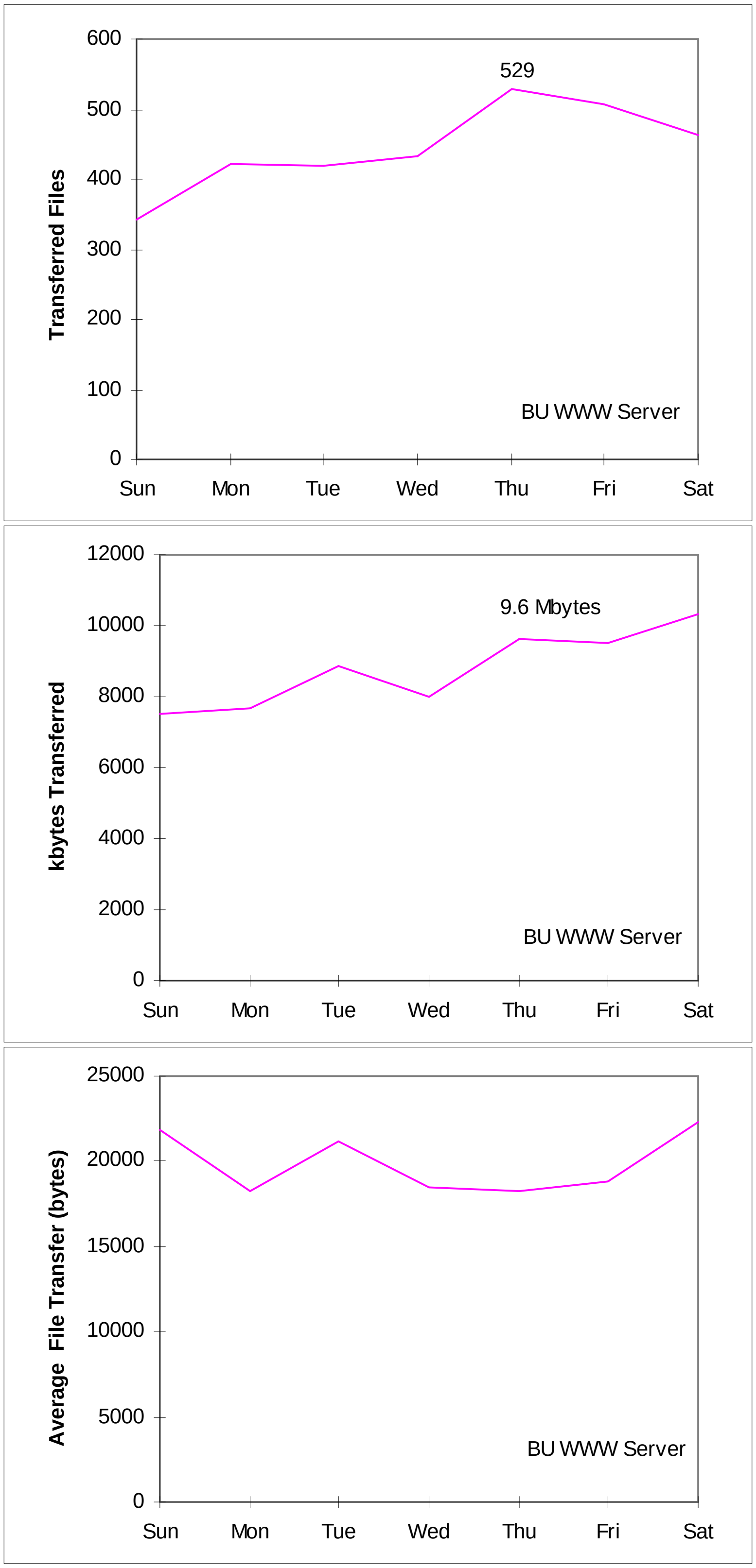
Average of 2,515 M bytes a day



All day Average: 8490 bytes

Figure 7.3-7 Daily Statistics for the MIT WWW Server

It is now necessary to verify that taking weekends into account here does not skew the traffic characteristics, and especially the average file transfer size per hit.

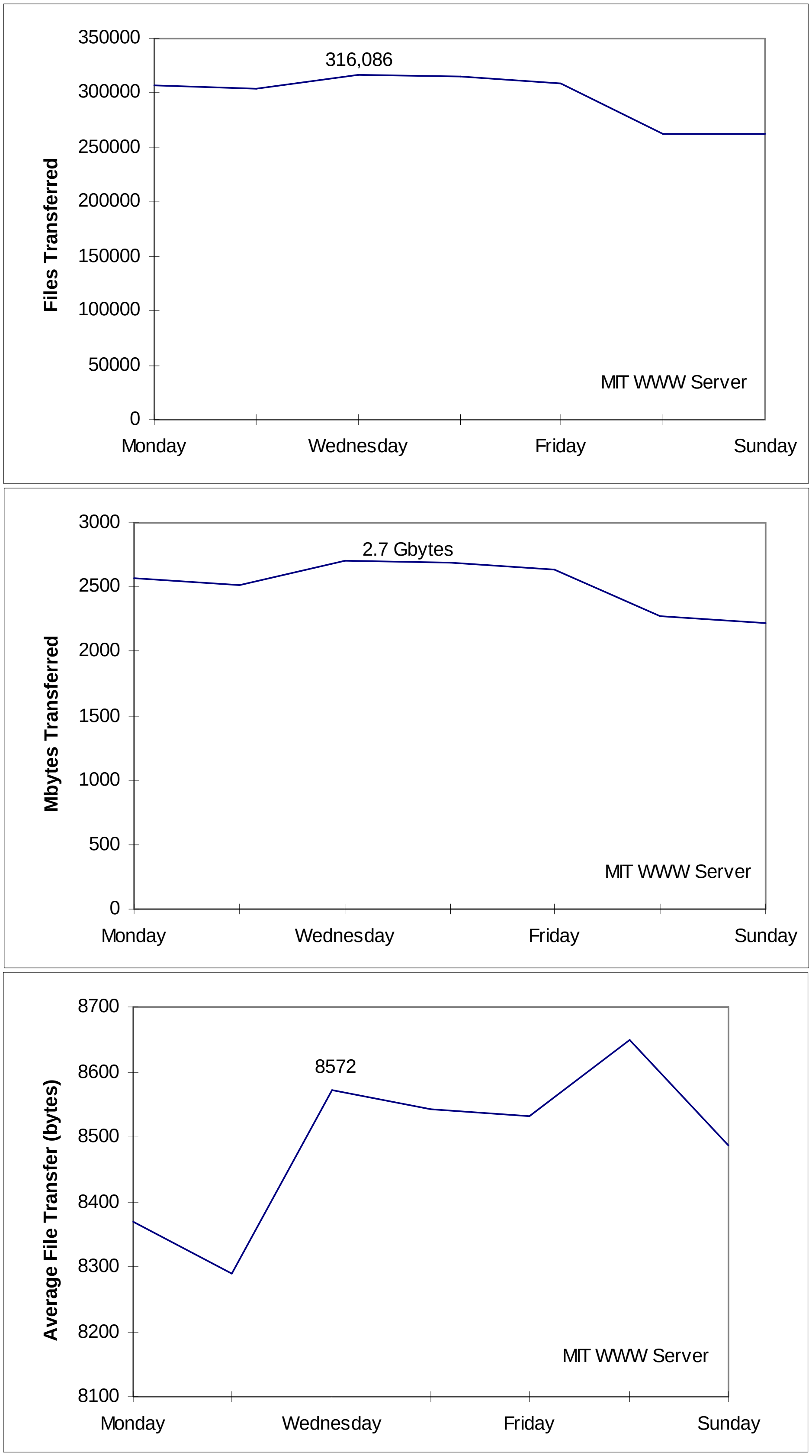


Average File Transfers: 445

Average Information Transfer: 8.8 Mbytes

Average File Transfer per Hit: 19,842 bytes

Figure 7.3-8 Weekly Statistics from the Boston University WWW Server



Average File Transfers: 296,217

Average Transfer: 2.5 Gbytes

Average Transfer : 8492 bytes

Figure 7.3-9 Weekly Statistics from the MIT WWW Server

Weighting the information above by the utilization of the servers (the MIT server is much more popular than the BU server), we conclude that the WWW peak usage occurs during the period 4 to 5 pm, and that the average file transfer per Web page hit is around 8572 bytes for the peak week day (Wednesday).

That average file transfer per hit will be used in Chapter 8 to generate Internet traffic as one of the components of the non-ITS traffic for the purpose of assessing the overall system performance when accounting for non-ITS usage of the shared network.

7.3.2.3 Other Non-ITS Applications

As stated before, the characterization of the wireless traffic resulting from most of the non-ITS applications is a very delicate task, given that only a few wireless applications exist today. Also, it is impossible to guess what services will be targeted by future applications.

This characterization will therefore be restricted to confirm that all other non-ITS applications contribute little to the non-ITS traffic relative to the E-mail and WWW Access “killer” applications. This is due not only because of their intrinsically sporadic and short burst nature, but because of the associated number of users (refer to Section 7.3.1).

7.3.2.3.1 POS/Transaction Authorization (0.7 Million Users)

Point-of-Sale activity consists of two distinct types of operations: Transaction Authorization, and (Daily) Settlement. Given that the latter occurs by definition after hours, it will not concern us. As for the Transaction Authorization traffic, it is typically as follows:

- From POS (Reverse Direction): 150-200 bytes
- To POS (Forward Direction): 60 bytes

Today’s national average is of 12 transactions a day per POS, with 15-20 transactions a day in the retail market and a dozen or so in the fast food business, 50-200 a day for gas stations, and 4-6 a day for taxis (variable on a city by city basis). The penetration in the retail and in the gas station markets is expected to be relatively small (mostly wired solutions), and so the bulk of the traffic will come from low traffic users (e.g., food delivery, door-to-door sales, landscaping, pool care, snow removal), and furthermore should have a mostly uniform distribution during the work-day (no peak-periods are to be expected in absence of major influence from retail and fast food).

7.3.2.3.2 Telemetry and Security (2.4 Million Users)

Within the wealth of activities included herein, without doubt utility (gas, water and power) monitoring dominates, with vending machine remote inventory control and loss management a distant second. In both cases, there is mainly one-way traffic from the meter/vending machine to monitoring/control center (Reverse direction).

Currently, the California Public Utilities Commission (PUC), among others, recommends a 30 minute billing cycle for gas and power. A monthly traffic of 50 kbytes per unit is expected corresponding to 40 bytes per meter every 30 minutes. Only 10% of the meters are considered viable for wireless connection, and substantially less will be thus linked in the near future. As an example, less than 100,000 meters are expected to turn wireless by 2002 in the whole Central and Northern California regions (around 15 million inhabitants). This periodic load will therefore be negligible compared to E-mail and Internet Access.

It is also very clear that vending machine originated traffic, due to its mostly “exception reporting” nature (warning message when “stock” below a given threshold) is negligible. The optional daily reporting will occur after hours and is of no concern.

Security related activity, is even more of an “exception reporting” in nature, especially regarding alarms, and is expected to have no impact. Keycard access reporting is usually restricted to after-hour periods, and so has no impact either.

7.3.2.3.3 Field Service/Sales and Home Health Care (4.7 Million Users)

In this broad category, there are mostly sporadic interactions – usually uniformly distributed during the work day. Catalog/Information access may lead to (infrequent) long transactions, but its overall impact is expected to be small.

Successful applications are expected to avoid transmission of baseline information, reducing traffic to something close to exception reporting. For field sales for instance, availability of an item is the only information that should be transmitted, not the item (from a small part to a house) characteristics themselves. Reporting and order placing are expected to generate even less traffic.

Job dispatch is at the boundary with ITS, and is again expected to limit itself to deviation from plan.

7.3.2.3.4 Public Safety (0.7 Million Users)

Public safety activity is generally an exception reporting nature (e.g., incident reporting), and heavier during the night. The associated traffic will have limited impact during the day, even during peak period. The traffic at night, when the (roadway and communications) network load is substantially smaller, is obviously of no concern.

NCIC inquiry, state and local data base access, shift reporting are all expected to be succinct in the good tradition of intensive code usage.

7.4 Protocol and Inter-networking Issues

This section, necessarily short, should not distract the reader from the criticality of the issues under analysis. Inter-networking through multi-layered protocols is the condition *sine qua non* for inter-operating, complex, but adaptable, even self-regulating, networks.

An important first conclusion when analyzing the communications layer of the ITS Architecture, is that it is heterogeneous and highly distributed. Given its impact on the overall system flexibility, there is a need to examine the coexistence of different communication infrastructures. Also within a given type of communication infrastructure, co-existence of competing technologies promoted by dual- and multi-mode terminals needs to be examined. Thus, given the multiplicity of communication systems contending for the ITS market, systems inter-operability issues will be discussed in general in this section, and will be mentioned again on a case by case basis in Section 7.5.

The multi-layer structure of the OSI model is a well established framework for achieving inter-networking. It is not, however, a panacea. One needs to realize that if more than one protocol is at play, a penalty has to be paid: an inter-networking function (not to be confused with the Inter-Working Function (IWF) inherent in all communication systems and discussed in the *Physical Architecture* document) needs to be implemented, usually in the form of a gateway.

Moreover, the multiplicity of protocols, adding to that of the underlying systems themselves, implies that application developers either limit themselves to one or a few system+protocol configurations, or they have to multiply correspondingly their investment to accommodate as many configurations as deemed necessary for a target market share. (This becomes clearer by analogy with the multiplicity of drivers in today's PC's, the only way an application can deal with different terminal+protocol configurations.)

In an ideal world, only one protocol would exist, and inter-networking would be a given. The flexibility of such a scenario would however be very restricted, since no pull would exist to improve the accepted solution. The message therefore seems to be that **a few well established protocols**, with open interfaces, i.e., open protocols, are needed in order to enable a healthy competition, while keeping inter-networking costs within reason.

The issue of protocol openness versus proprietary solutions is therefore a critical one. If a protocol is not open, it certainly provides protection to its developers from external competition. This is however a short sighted perception: by locking themselves out of the market, the protocol developers miss all the incentives to improve, do not keep the competitive edge technically either, and will soon be put out of business by smarter, more open(-minded) competitors. (The IBM versus Macintosh analogy is telling.)

As for the price, competition certainly benefits the consumer by enabling multi-vendor procurement (an aspect that will certainly speak to the heart of every implementor), but at the same time it also benefits the manufacturer (of software as of hardware): the market grows as the product prices are reduced. One could talk of a bootstrap mechanism. If this process is not ignited, small chances will remain for the manufacturer to recuperate the investment.

Another aspect where open protocols, as well as open architectures, clearly have the advantage is in the application/system development speed and cost. Not having to re-invent the wheel leaves more time for what is really important: to develop a killer application, and then keep improving it. Moreover, by "subscribing" to an open protocol the application developers automatically gain access to a segment of the market. Inversely, by facilitating application development, open protocols create a critical mass of applications that makes choosing the protocol more attractive, i.e., make the protocol more competitive.

The importance of the issues just glossed over, justifies the consideration in the technology assessment of Section 7.5 of inter-networking characteristics in terms of supported protocols and their openness or lack thereof, as well as application development suitability. In the side by side system comparison tables of Section 7.6 those entries are considered essential.

7.5 Technology Assessment

This section reviews both the wireless and the wireline components of the communication infrastructure, analyzing, mostly briefly, the available systems and technologies, while maintaining a National ITS Architecture perspective. Through the comparative evaluation of the alternative candidate communication infrastructures/technologies/implementations, it is expected that the communication analyses will provide a means for the implementors to choose, based upon the MOE's described in Section 3 of the *Evaluation Plan* document, the most suitable set that meets the requirements of (a specific set of) the ITS user services. Furthermore, by incorporating the evolutionary nature of technology into the evaluation methodology, it is expected that the proposed implementation be capable of progressively meeting the steadily increasing ITS demands expected for the next 20 years.

7.5.1 Wireless Communications

One important aspect of the technology evaluation in this section is addressing the evolution of the wireless technologies, with expanding capacities and increased sophistication. Another is examining the coexistence of infrastructures such as today's mostly analog cellular with upcoming digital cellular and with PCS, all with their tremendous potential to support ITS needs. Additionally, within a given communication infrastructure, competing technologies may have to coexist, like CDMA and TDMA.

Thus, given the expected multiplicity of communication systems contending for the ITS market, issues of systems inter-operability will be emphasized, given its impact on the overall system flexibility and the appeal to the end-user, as well as the wider market thus made available to all Information Service Providers (private and/or public).

Within the wide-area communication systems under consideration, different levels of detail will be considered, related to the amenability to simulation of the different systems. As an example, extensive work has been done to acquire simulation capabilities for Cellular Digital Packet Data (CDPD) as detailed later in Section 8, as well as for other cellular systems, such as TDMA- or CDMA-based. The same can not be said, however, of other communication systems that are either proprietary in nature or just not open (e.g., RAM, ARDIS), still far from standardization, or entirely new (e.g., Omnipoint, Geotek), or uncertain (e.g., Nextel). Whenever possible, analytical results will be made available for those systems still in the standardization phase, and performance information will be collected for the proprietary systems and will be reported with the necessary caveats later in this section.

Our wide-area analysis begins with a look into systems that if not exactly suited for mobile applications, provide communication over a wide-area, namely Wireless MAN's. Their use applies at least to wireless access to kiosks (RTS) and to remote access to ITS information (PIAS). Other low-mobility applications are also possible. The analysis here is only a review of technical information made available by the vendors.

The land-mobile arena is the one where more choice exists, given the exploding mobility market. Cellular is looked at first. CDPD is the first system to be analyzed. The analysis in this section is only of a very general nature. The performance information obtained in the course of the National ITS Architecture Study, and is reported in detail in Section 8.

CDMA data systems are evolving in the standards bodies, and thus elicit preliminary quantitative analyses, with the little that is known at this moment. Similarly, Europe has a packet radio system in the works for GSM. These systems will also be briefly analyzed. To the extent that information is available, PCS will also be addressed, although the data protocols are not expected to be specific — available data protocols will most likely be used.

Private Mobile Data Networks, as well as SMR systems will also be analyzed with a level of detail permitted by their proprietary nature. ARDIS, RAM, and a new entry from Geotek, as well as Nextel's digital system, will be assessed for their potential to provide mobile solutions.

Finally, Two-Way Paging, the first service made available over the newly licensed Narrowband-PCS, is analyzed to assess the potential of its somewhat limited scope.

To meet the requirements imposed by the 29 user services defined in the National ITS Architecture Plan, and to provide services to a wide range of areas including rural settings, a hybrid of terrestrial and satellite services may be required in some situations. The projected satellite services and their capabilities, as well as the integration of satellite services with other terrestrial infrastructures, such as cellular, in support of the ITS system architecture, will therefore be analyzed with the detail warranted by the scarce information available.

Meteor scatter systems will be analyzed in some detail given that the systems are being used among other purposes for long haul fleet management. It is interesting to realize that this system relies on the statistical availability of meteor trails to provide reliable service over large areas.

As for broadcast systems, attention will be given especially to high speed FM subcarrier systems. New systems like Digital Audio Broadcasting (DAB) and those based on the use of the TV stations' vertical blanking periods or the entire SAP channel will be alluded to. The level of detail of the analysis will be determined by the predicted role of the technology in supporting ITS services.

Finally, a beacon-based wide-area “solution” will be briefly investigated, given that a preliminary analysis clearly points to the fact that such an approach does not insure seamless coverage of a wide-area, is inappropriate for time sensitive services in a wide area setting, and has high cost and risk associated with it.

Also briefly discussed are short-range communication systems, focusing mainly on dedicated short range communication (DSRC), by comparatively describing the salient systems. Vehicle-to-vehicle communication systems are still in flux, many not even in the prototype phase, and thus are only briefly analyzed here. More detailed information will become available from the AHS Consortium.

7.5.1.1 Wide-Area versus Short-Range

The 29 ITS services defined by the Government fall into two distinct classes in terms of the range for the distribution and collection of ITS information, with correspondingly different associated coverage areas: wide-area and short-range. Wide-area services and applications disseminate information over a large area. Very often the information can be directed to a specific user. Natural candidates for this type of delivery are today’s cellular systems, tomorrow’s PCS, satellite, and even broadcast systems. Less natural would be the provision of wide area information via widely dispersed beacon systems, the most obvious problem being that seamless coverage is not possible (see Appendix G).

Short range services and applications, on the other hand, concern information transfer of localized interest. Two types of short services need to be considered: 1.)dedicated short range communications (DSRC), corresponding to a fixed end system (even if portable) to mobile system short range communications (e.g., toll collection, roadside vehicle inspection), and 2.) vehicle-to-vehicle communications (VtoVC) associated with AVSS/AHS. For the former type of application, beacon-like systems are appropriate. For the latter, most likely dedicated radio systems will be used. These are under consideration both in the U.S. and in Europe, but are far from maturity.

Given the dedicated nature of the beacon-like systems and their small coverage area, no need exists for simulating their capacity performance — the reduced number of active users simultaneously within range makes it possible for the specifications to insure they perform with acceptable reliability even in the case of multilane transceivers.

As for VtoVC, which is still mostly in its research phase, a meaningful analysis is not feasible and therefore the Joint Team will primarily report on the evolution of those systems.

7.5.1.1.1 Wireless MAN Systems for Stationary Users

One possible wide-area wireless data solution consists of systems that are cell-based such as RAM, CDPD, and ARDIS and can serve both mobile and fixed subscribers(described in detail in the following section). Another group of systems uses Wireless MAN systems, which targets exclusively the fixed wireless subscribers, due to the nature of the technology and of the network.

The fixed subscriber wireless data technology uses microcells (the footprint of a microcell is less than a 0.5 mile in diameter) which is less complex, but also less flexible, than cellular implementations. As a result, this service is restricted to fixed subscribers, with limitations on mobility and on coverage area to the supporting microcell (no hand-offs possible). Such systems generally utilize packet data communication, some even offer TCP/IP connectivity.

The network implementation is of a meshed nature, usually with only a few wired base stations (implying a multi-hop system). As a result, the delay varies widely, depending on whether the user is serviced by a wired or tetherless base station (that is, the system cannot guarantee an arrival time).

Intended services include on-line applications such as Internet access, mobile office applications, and even telemetry. The candidate ITS services, subscribers, and messages that can be supported using these Wireless MAN solutions include:

- Fixed ITS subscribers (e.g., home, office and kiosk).
- Low-mobility applications (i.e., pedestrian speeds) that are not time critical and do not require real-time response.

The two systems that are reviewed here are offered by Metricom Inc. and Tetherless Access Ltd. (TAL). Both systems utilize spread spectrum communication for their wide area wireless interface. Metricom uses frequency hopping and operates in the 902 to 928 MHz band. TAL uses direct sequence spread spectrum technology licensed from Cylink, in the 900 MHz, or 2.4 GHz band.

The occupied bands fall in the unlicensed ISM bands for spread spectrum (SS) systems (Part 15.247 of the FCC rule). Although this makes system deployment much easier and cheaper, it also raises problems of subsidiarity. In fact, unlicensed spread spectrum ISM devices are at the bottom of the priority list: they must accept all interference from other devices operating in that band, but cannot interfere with any other system. Presently, the FCC is considering lowering even further SS ISM's priority in favor of AVL systems.

7.5.1.1.1.1 Metricom's Ricochet

The Metricom system uses 162 channels for frequency-hopping spread spectrum (FH-SS) communication. In this system, each channel occupies 160 kHz and is selected using a unique pseudo random sequence.

Each radio in the network (bracket-mounted, shoe-box size, typically installed on utility poles, streetlights, and building roofs), is mesh connected on typically a one-mile grid. Each radio can originate messages, send and receive information, and select alternate routing paths in the event that other radios are busy or out of service (i.e., multi-hop mesh architecture). Transmission time from a Ricochet modem to a poletop, and from poletop to poletop, is typically less than 100 ms. To enhance network performance, wired access points (WAP) are interspersed among the mesh radios, and connected to a high-speed wired backbone. A WAP is deployed for each 100-120 poletops.

The system uses packet data communication (500 bytes/packet). Longer messages are typically broken into smaller packets and transmitted on different channels. However, these long messages are more difficult to be properly received, even by the intended user: sequential packets from the same message may end up following different paths (i.e., undergo different hops) to their common destination.

Metricom has deployed the system in the San Francisco Bay Area (3,500 repeaters covering more than two million residents in 35 cities; see Figure 7.5-1), Corvallis, OR (servicing 45,000 people in the city of Corvallis, Oregon Sate University, and Hewlett Packard's OmniBook division campus), Eugene, OR (50 transceivers servicing the University of Oregon campus), and in Dearborn, MI, where the Wireless Health Information Network services a group of physicians and clinics, providing real-time access to patient-authorized clinical data, as well as care guidelines. Metricom has visible presence in colleges and corporate campuses nation-wide (Stanford, UC Santa Cruz, UC Berkeley, CA; Austin College, TX; University of Miami, FL).

Metricom has already formed a joint venture with the Potomac Electric Power Co. to deploy the system in the Washington, DC, area to provide service to four million potential users. Metricom will deploy its system in the Seattle area during 1996. Next on their list are Boston, MA, and the Redmond-Bellevue, WA area.

Services offered include access to the Internet (through a proprietary gateway, since the system is not TCP/IP based, although the modem implements SLIP and PPP), and to e-mail, on-line services, and corporate LAN's and WAN's. (According to the UC Berkeley Telecommunication Services, services that are expected to work well are those that involve transfer of "large" amounts of data at once, like "FTP", POP-based e-mail, and Internet access, while "telnet" and "rlogin" are likely to be very frustrating to use because of their interactive, usually small "packets" nature.) Metricom also provides private wireless data networks to the utility, wastewater, gas and oil industries.

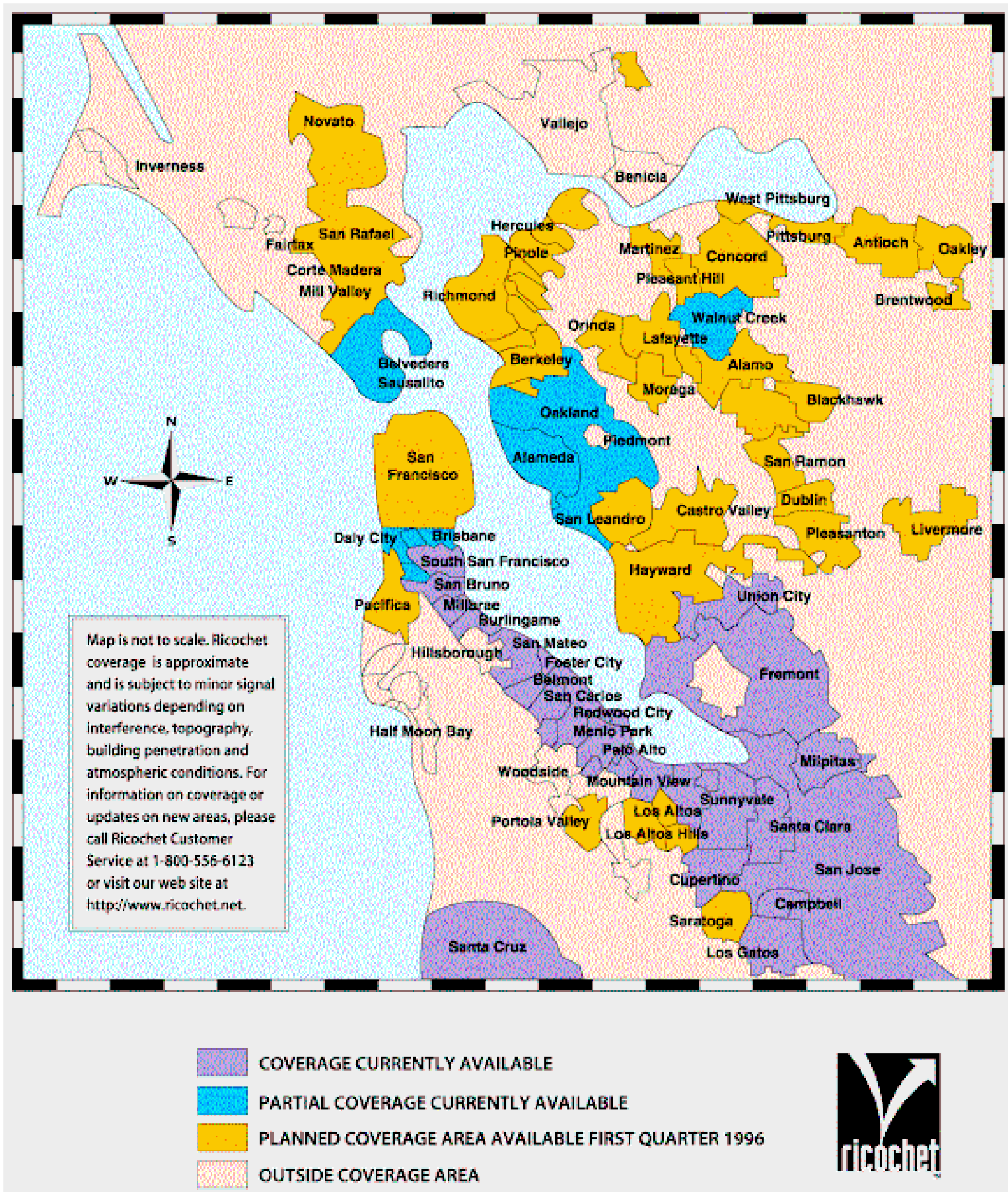


Figure 7.5-1 Metricom's Present and Planned Coverage in the San Francisco Bay Area

One issue affecting the deployment of a system like Metricom's, with so many base stations[3], even if pole mounted, is the need to obtain the right of way. This problem has to be resolved on a city by city, or county by county basis. (An example of a city-wide deployment of Metricom's system is shown in Figure 7.5-2.) That is one of the reasons why Metricom has entered into agreements with utility companies (PacifiCorp, a Portland, OR-based utility company serving portions of seven Western states, and the above mentioned Potomac Electric Power Co. in Washington, DC) and cities (30 cities in the San Francisco Bay Area, as of 10/18/95). In a representative arrangement, in Cupertino, CA, the network is used to support CityNet, providing education links through the city school system, links to emergency services and government departments, as well as communications between citizens and government officials.

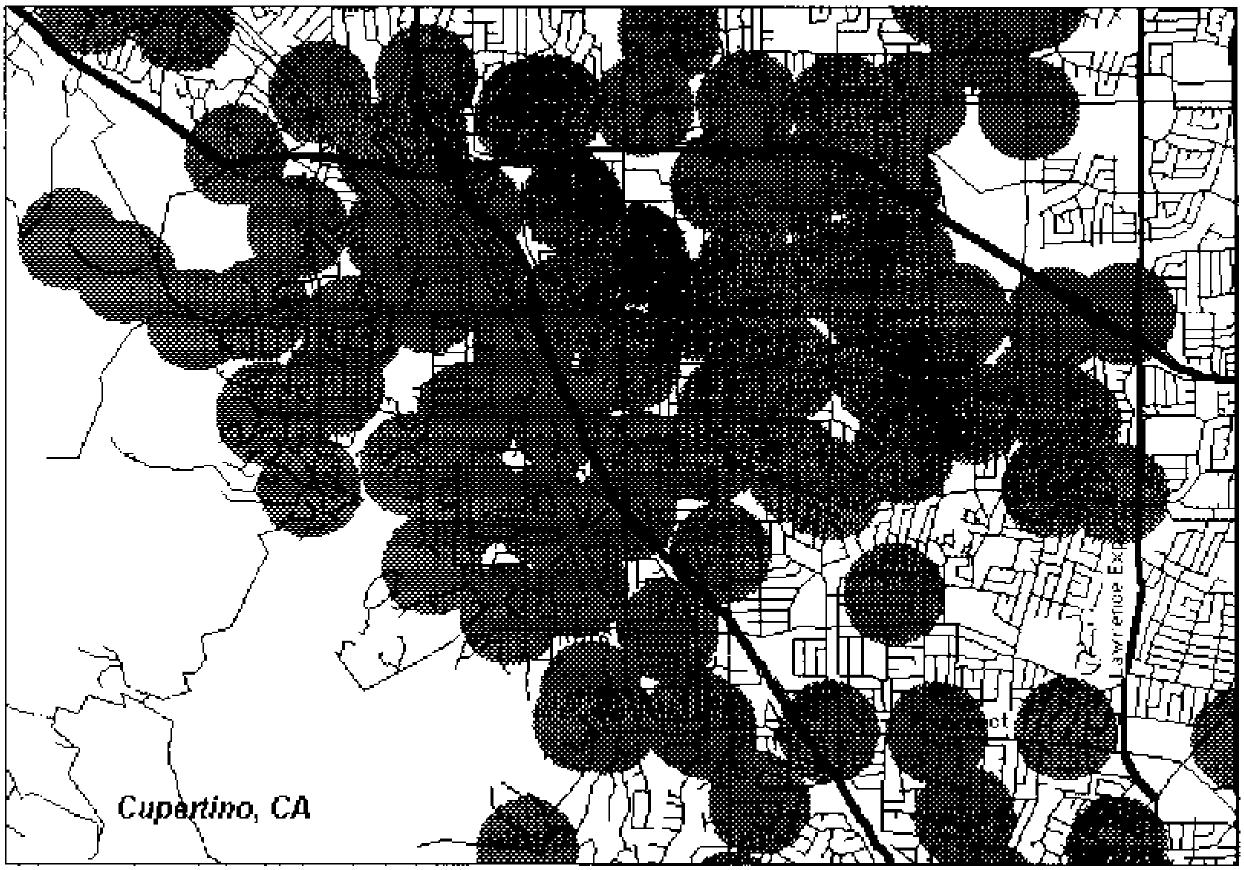


Figure 7.5-2 Example of a City-wide Deployment of Metricom's Ricochet System

7.5.1.1.1.2 TAL's SubSpace 2001

TAL's networking architecture is TCP/IP-based, using direct sequence spread spectrum (DS-SS) packet radio to deliver wireless data. The system selected direct sequence for its better performance against multipath, especially for the high data rates of the network (160 kbps). The radios operate either on the 902-928 MHz or 2.4-2.4835 GHz ISM bands, providing more flexibility than Metricom's alternative.

TAL provides peer-to-peer, multipoint networking, and TCP/IP routing over a wireless mesh network where each cell can extend up to 30 km (18.6 miles). The radio technology used by TAL, SubSpace™

[3] Base stations are situated every half-mile on average, or 4 to 5 per square mile, with downtown concentrations of up to 30 radios per square mile

2001, was jointly developed with Cylink Corporation. It is based on Cylink's AirLink MP product, incorporating unique features which are supported by TAL's packet router software.

The SubSpace 2001 system includes a Wireless Router^{TM} for wireless networking, a spread spectrum radio, and TALtalk, the proprietary wireless network operating system software. The SubSpace router is wirelessly connected to the gateway (called POP, provider's point of presence), which provides the subscribers backbone connectivity.

TAL deployed pilot networks in Colorado Springs and Telluride, CO, and in the San Francisco Bay Area. Numerous systems have also been deployed abroad (São Paulo, Brazil; Sidney and Melbourne, Australia; China). Contrary to Metricom's direct involvement in exploiting its networks, in fact acting as a service provider, in the US, TAL follows a partnering model: TAL licenses its technology on a non-exclusive basis to regional Internet Service Providers and local system integrators developing data networking services.

7.5.1.1.1.3 Comparative Analysis

Table 7.5-1 summarizes the technical specifications of Metricom's, and TAL's systems, and includes some cost information.

Table 7.5-1 Technical Specifications of the Wireless Data Technologies for Fixed Subscribers

System Specifications	System Name	
	Metricom	**Tetherless Access Ltd. (TAL)**
Band	902-928 MHz (ISM band)	902-928 MHz or 2.4-2.4835 GHz (ISM bands)
Raw Data Rate (kbps)	up to 100	160
Sustained System Throughput (kbps)	9.8 to 28.8 half-duplex (depending on hardware, location, and application)	64 half-duplex
Interface	PC, Mac and PDA serial port Proprietary interface	PC's, workstation TCP/IP
Hardware and Software	Proprietary software	Wireless router and proprietary network operating software
Service Cost	$40 setup $40 monthly fee, with unlimited Internet access	The service cost will depend on the size of the network, and on the service provider.
Terminal Cost	$300 for modem	?
Deployment Cost	$700 bracket-mounted radios ?	$1995 per node for SubSpace™ 2001 wireless router (L band). + $1500 licensing fee (software) + $150 antenna
Services	Internet Access	LAN access,...
Mobility	Walking (within the coverage area of a microcell); No Hand-off	Fixed (stationary)
Deployment	San Francisco Bay Area, CA; Corvallis, Eugene, OR; Dearborn, MI; Miami, FL; Austin, TX 1996: Washington, DC Future: Redmond-Bellevue,WA; Boston, MA	Pilot networks: Colorado Springs, Telluride, CO; San Francisco Bay Area, CA Abroad: Brazil, Australia, China
Technical Maturity	The system is commercially available and in operation in limited markets	The system is presently available, for transfer/sale to candidate service providers
Latency	Delays are a function of the location, network load, and application. No guarantee for time critical interactions.	NA
Message size (packet)	500 bytes per packet Long messages are broken into small packets and sent on multiple channels	NA

Note: The data in this table was obtained from material provided by the service providers, and has not been verified, through field measurements and/or simulations, by the ITS Architecture Team

7.5.1.1.2 Land-Mobile Cell-Based Systems

Land-mobile systems, as opposed to satellite-mobile and broadcast systems, are analyzed in this section. The section begins with Cellular Digital Packet Data (CDPD), under its conventional and circuit-switched (CS-CDPD) forms, and looks also into future developments (CDPDng = CDPD next generation). Also considered are other, not fully standardized (as of yet) data systems based upon CDMA, TDMA, hybrid TDMA/CDMA, and GSM/DCS 1800. Private Data networks, ESMR, and two-way paging systems are also examined.

7.5.1.1.2.1 Cellular Digital Packet Data (CDPD)

Cellular Digital Packet Data (CDPD) was designed to provide packet data services as a digital overlay to the analog cellular (AMPS) network. CDPD was developed by IBM and a broad consortium of cellular carriers (McCaw Cellular, GTE Mobilnet/Contel Cellular, Ameritech Cellular, Bell Atlantic Mobile Systems, NYNEX Mobile Communications, PacTel Cellular, Southwestern Bell Mobile Systems, and US West) that cover 95% of the US, including all major urban areas. The first specification was published in July of 1993, and commercial operation began in 1994.

In mid-1994, 69 cellular carriers and equipment manufacturers, formed the CDPD Forum, whose purpose is to foster the widespread deployment of CDPD service. Today, approximately one hundred companies belong. While the group is not a formal standards organization, it formed technical working groups to study various enhancements to the original CDPD specification, leading to Release 1.1 of January 1995. The CDPD Forum is effectively in charge of the evolution of the CDPD specification.

By leveraging the enormous pool of radio infrastructure and network resources fielded by the cellular industry, and by being the only open system architecture digital packet data system already standardized, and by undergoing rapid deployment across the US, it is poised to be a strong contender for a wide range of ITS applications, at least in the near to medium term (5- to 10-year time frame). Due to the resilience of deployed technologies (e.g., FM broadcast has been around for almost 60 years), CDPD could still play a significant role not only at the 10 year snapshot but also to the 20-year time frame.

A simulation of CDPD capabilities in an ITS context, particularly within the confines of the Urbansville scenario, was the starting point in the architecture evaluation in Phase I. The emphasis has in the meantime shifted to obtaining an assessment of the ability of CDPD to satisfy the projected ITS data loads for different scenarios and time frames, both under normal conditions and in presence of incidents. All these issues will be dealt with in Section 8.

Note that this in-depth analysis of CDPD should not be construed as a selection of CDPD as the basis for ITS service provision. Other technologies will certainly be available, but CDPD will likely be one of the alternatives.

7.5.1.1.2.1.1 CDPD

CDPD is a digital overlay on analog cellular (AMPS) that makes use of idle voice channels. Its first specification, Release 1.0, dates from 1993 and many commercial systems are already in operation across the U.S. (see Figure 7.5-3) and abroad (Canada, Mexico, Brasil). Release 1.1 has been available since January 1995 and has already been deployed widely by some providers. The following paragraphs briefly describe the CDPD network structure (see Figure 7.5-4), which is very similar to that of the cellular network with which it shares transmission channels.

Each mobile end system (M-ES) communicates with a mobile base station (MDBS), which is expected to be collocated with the cell equipment providing cellular telephone service to facilitate the channel-sharing procedures, as well as the real estate. All the MDBS’s in a service area are linked to a mobile data intermediate system (MD-IS) via wireline or possibly microwave links. The MD-IS provides a function analogous to that of the Mobile Switching Center (MSC) in a cellular telephone system. It also provides connection to a network management system. The MD-IS may be linked to other MD-IS’s and to various fixed end-systems (F-ES’s) outside of the CDPD network.

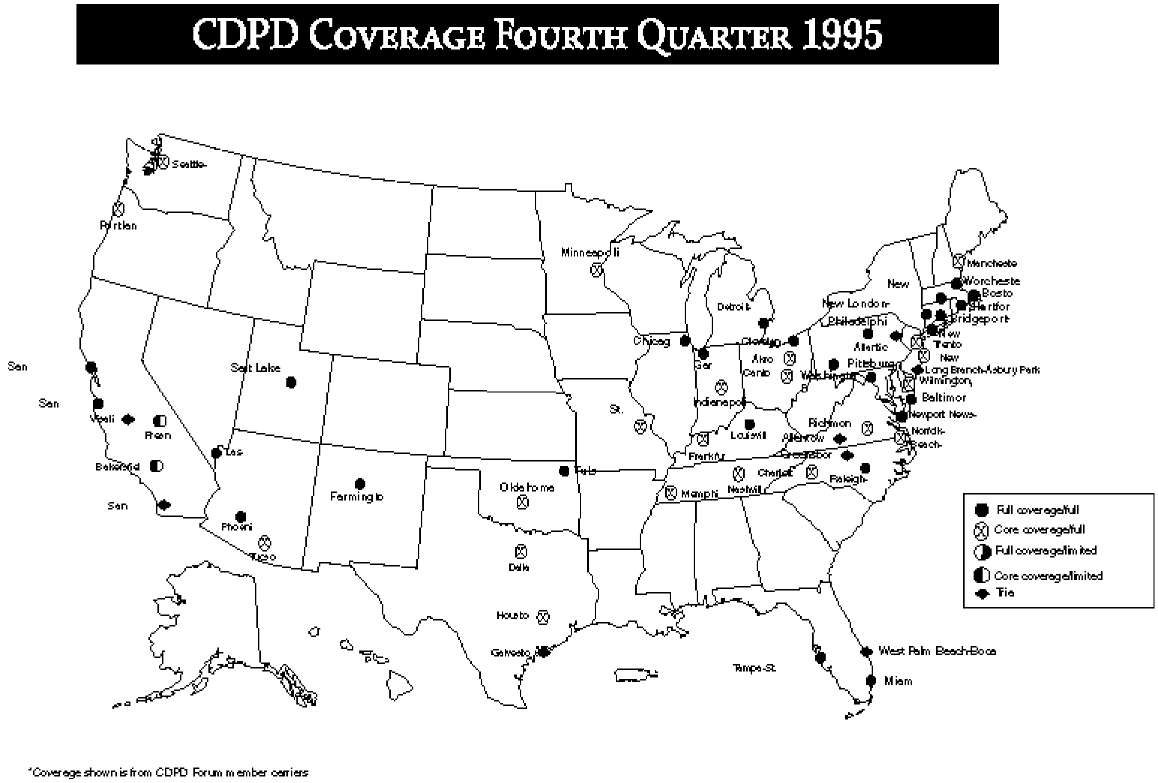


Figure 7.5-3 CDPD Deployment as of the Fourth Quarter of 1995

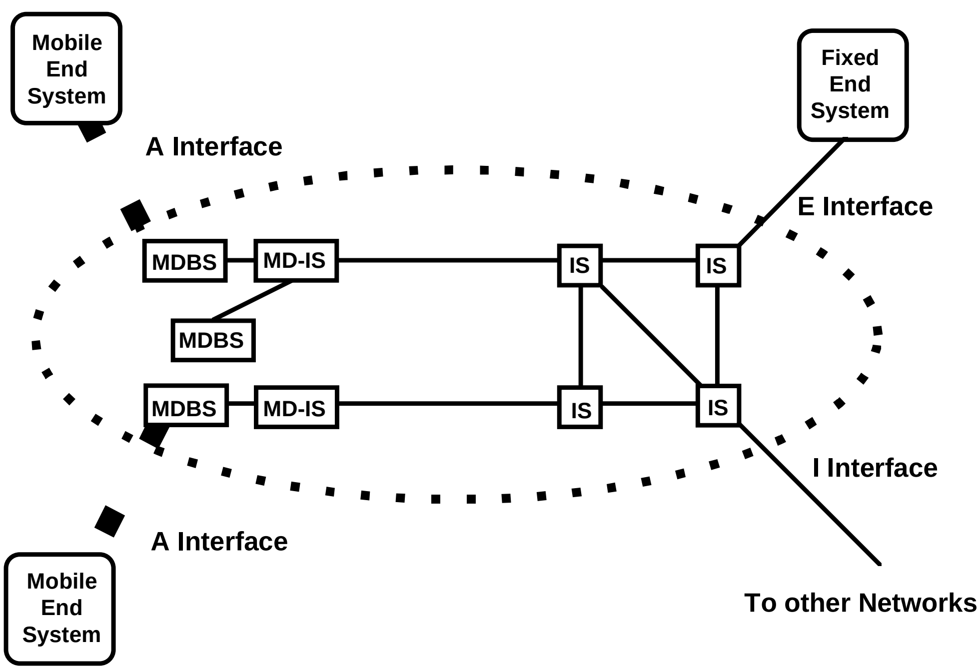


Figure 7.5-4 CDPD Network Architecture
(From *Wireless Information Networks*, K. Pahlavan, A. Levesque, John Wiley & Sons, Inc., 1995. Note: the A interface is referred to in this document as the u1t interface).

Service endpoints can be local to the MD-IS (E interface) or remote, connected through external networks (I interface). An MD-IS can be connected to any external network supporting standard routing and data exchange protocols (it inherently supports IP and ISO CLNP routing and can be connected through appropriate gateways to other types of networks). It can also provide connections to standard modems in the PSTN (using SLIP or PPP's) by way of appropriate modem interworking functions (modem banks).

Connections between MD-IS allow routing of data to and from M-ES's that are roaming (i.e., operating in areas outside their home service areas) by allowing the MD-IS's to exchange information required for mobile terminal authentication, service authorization, and billing. (Roaming has been extensively and successfully tested by the many CDPD providers.[4])

CDPD employs the same 30 kHz channels used by AMPS. Each CDPD channel will support channel transmission rates of 19.2 kbps. However, packet collisions (and radio channel impairments) will limit the actual information throughput to lower values, and will introduce additional time delay due to the Forward Error Correction (FEC) and re-transmission protocols. In Section 8 we will see that the Reverse Link capacity is approximately 11 kbps, corresponding to 8 kbps of user data. As for the Forward Link, without contention, the capacity is very close to the raw data rate, corresponding to approximately 14 kbps of user data.

The performance of CDPD equipped cellular infrastructure for a mix of voice and data users hinges on the combined performance of the Physical layer and the Medium Access Control (MAC) layer on top of it. The task of the Physical layer design is to control the interference induced by co-channel voice users in other cells through the use of power control and forward error correction (FEC), in this case using a Reed-Solomon (RS) (63,47) code. The MAC protocol, on the other hand, resolves contention on the common reverse channel due to the competition with the other data users within the same cell.

The selection of a channel for CDPD service is accomplished by the radio resource management entity in the MDBS. Through the network management system, the MDBS is informed of the channels in its cell or sector that are available as potential CDPD channels (channels not in use for analog voice service). The MDBS can determine whether a given channel is in use either through a communication link to the AMPS system, or, if that link is not available, it can use a forward power monitor (a "sniffer") to detect channel usage on the AMPS system.

Multiple access to the CDPD channel occurs in two very distinct forms, depending on the direction of the communication. On the forward channel, from the MDBS to the M-ES, there is no contention, since the MDBS broadcasts information to all users, which will then filter out the portion directed to each of them. (It must be noted here that Release 1.1 of the CDPD Specification now enables actual Broadcasting -- sending messages to all users, and Multicasting -- sending messages to a group of users.) It is important to realize that even if the information is openly broadcast to everyone, only the intended user can make sense of the message due to the encryption performed (see Figure 7.5-5).

On the reverse channel (from the M-ES to the MDBS), access control is more complex, since several users share the same channel. CDPD uses the multiple-access technique called Digital-Sense Multiple Access/Collision Detection (DSMA/CD), whereby the MDBS announces the channel status (idle or busy), and more importantly immediately broadcasts the occurrence of collision, avoiding a lengthy recovery process. The conflicting users promptly enter into exponential back-off, thereby reducing the associated dead-times.

[4] Unlike cellular voice, there are no "roaming fees" in CDPD.

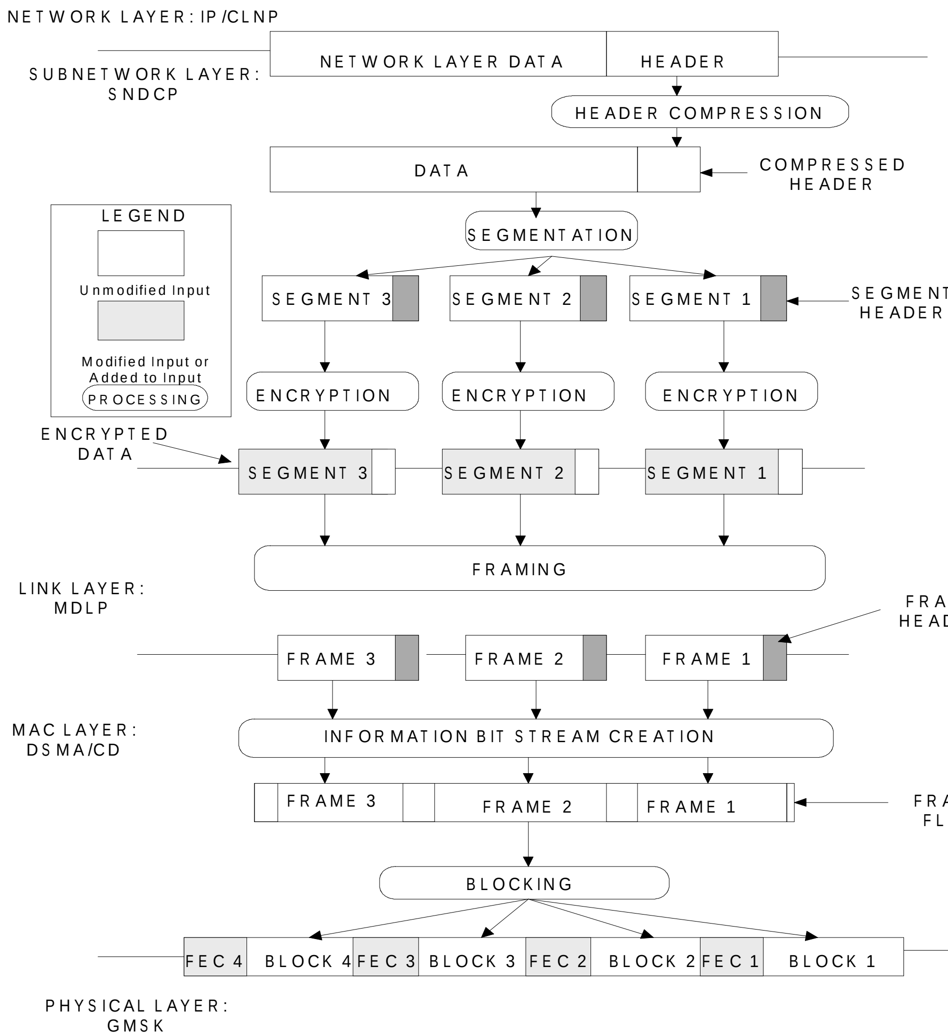


Figure 7.5-5 CDPD Protocol Stack (CDPD System Specification, Release 1.0)

CDPD is a TCP/IP-based packet data system, therefore making immediately available all TCP/IP applications in a mobile environment (e.g., FTP, Telnet, Internet access) through the use either of the TCP/IP stack included in certain CDPD modems, or of a TCP/IP stack available in the laptop/computer.

Recently, Release 1.1 has become operational in many markets. The advantages of the new release are obvious for high traffic markets, since the data compression mechanism in Figure 7.5-6, V.34, provides a gain that can be as high as 4, depending on the data being sent. The users will see, as a result, a correspondingly increased throughput.

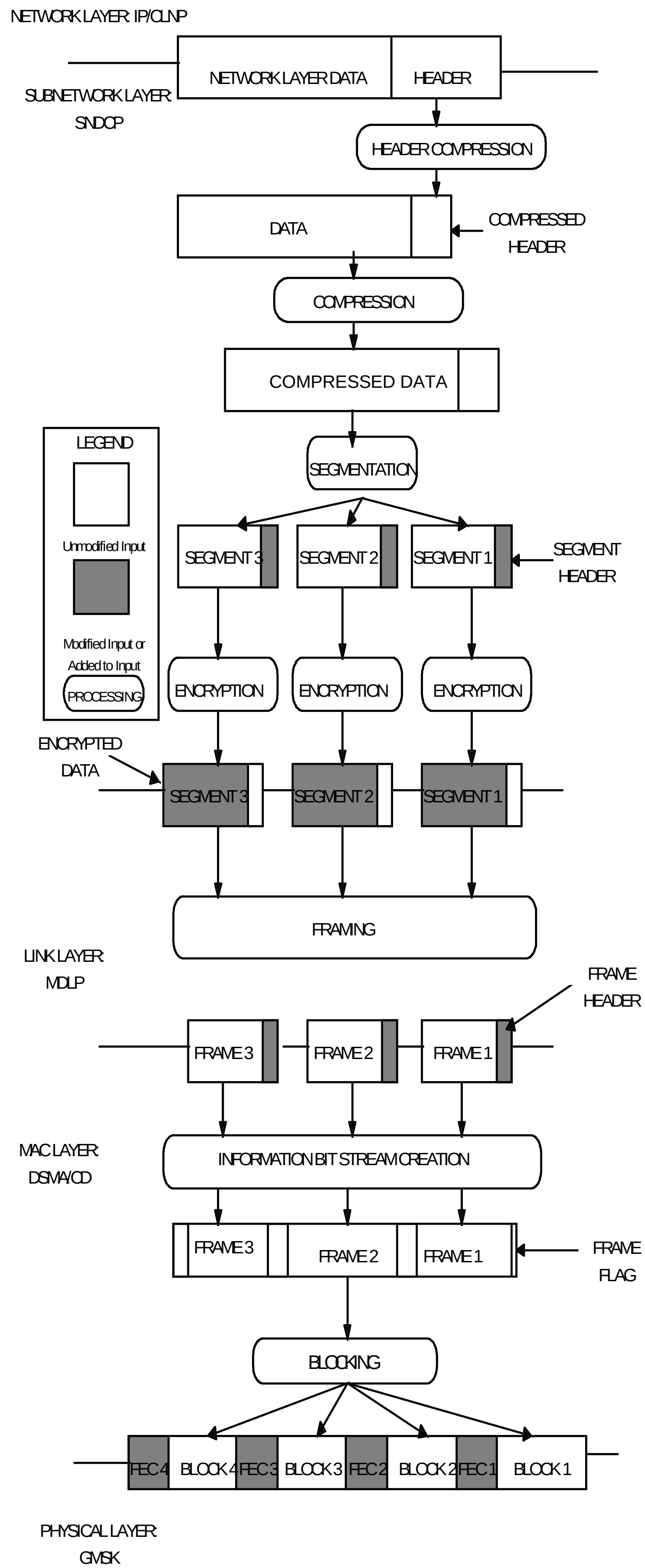


Figure 7.5-6 CDPD Protocol Stack (CDPD System Specification, Release 1.1)

7.5.1.1.2.1.2 Circuit-Switched CDPD

An extension to CDPD providing circuit-switched (dialup) access to CDPD service has been recently proposed (*Circuit-Switched Cellular Digital Packet Data*, Release 1.3, April 14, 1995) as an alternative to the standard CDPD radio interface. This new form of access uses existing technology to extend the geographic regions and the range of applications that can use the CDPD network. The general attributes of the new service include:

- Customer-selected access to the CDPD network via CDPD radio, AMPS cellular, or land-line PSTN
- Support for Multicast and point-to-point IP services
- Support for all CDPD security features (authentication, and encryption)
- Seamless roaming between conventional and Circuit-Switched CDPD
- Extension of CDPD service to regions that lack CDPD radio coverage
- Support for economy measures that allow a user to divert non-interactive, bandwidth-intensive applications, such as facsimile, and large file transfers to a circuit
- The ability for either the MD-IS or the MES to drop the dialup circuit when traffic temporarily ceases and to re-dial it when traffic resumes – this feature will save the subscribers considerable amounts of money in air-time charges with no impact on their applications.

Circuit-Switched CDPD's suitability for ITS service is not restricted to areas where CDPD is not deployed, but it also provides an alternative to packet-switched transmission of information for long messages. Examples would be downloading the map of a region, a list of points of interest with detailed descriptions, extensive local yellow-page information, written route guidance, etc.

The CS-CDPD upgrade became available in May 96, although the first modems/phones will not be available before August 96. At the time of this writing, only software prototypes are available. GTE Mobilnet plans to deploy CS-CDPD commercially in the 3rd quarter of 1996.

7.5.1.1.2.1.3 CDPD Next Generation (CDPDng)

The CDPD Forum has already shown interest in investigating higher data rates. Under consideration are ISDN rates (56/64 kbps and possibly 144 kbps). Also on the horizon is the possibility of allowing for "bandwidth on demand", a term that describes the negotiated assignment of a given number of channels to a user to allow for higher data rates.

By keeping the upper layers of the CDPD protocol, and only changing the MAC and Physical layers, most of the infrastructure investment will be maximized. Given the common migration from AMPS to CDMA, it seems very plausible that the new physical layer for CDPDng would be CDMA-based. As with CDPD today, CDPDng would be (CDMA-)voice-friendly. This an area still requiring considerable study.

7.5.1.1.2.2 CDMA (IS-95-A)

In this section, an analysis is presented on data standards based upon the EIA/TIA IS-95-A CDMA, a.k.a. Q-CDMA, standard. IS-95-A defines a 9.6 kbps service, and there is an extension for 14.4 kbps service, termed TSB 174. We examine both circuit-switched and packet-switched CDMA data, even if the former is *a priori* oriented to long "transactions" like voice, and is not expected to compare with packet systems (like CDPD), which were designed specifically for "short" packet data. On the other hand, one cannot yet speak of a full fledged packet-switched service over CDMA. (IS-657, the 9.6/14.4 kbps standard, is still in the ballot process.) **IS-95-A-based short message service (SMS).** We will briefly mention the ongoing work on High Speed Data Services at the CDMA Development Group (CDG).

Both GRANET and MOSS, the GTE Laboratories simulation tools described in Appendix I and used in Section 8, already have significant CDMA capabilities. However, no simulations of CDMA-based data is appropriate at this moment since their standards are still being developed by the industry.

7.5.1.1.2.2.1 Circuit-Switched Data (IS-99)

The EIA/TIA IS-95-A standard deals mainly with CDMA technology in support of circuit-switched service (speech mode). Analyzed in this section is IS-99, its circuit-switched data derivative, from the perspective of carrying ITS data traffic.

For IS-99, the transfer of a “typical” ITS message on a cellular reverse link, from mobile to base station, entails setting up a CDMA channel, transmitting the message, and then tearing down the connection. The purpose of analyzing this mobile-originated message transfer over the reverse link of IS-95-A, is that its delay performance can be immediately compared to that of a packet system.

Obviously, any ITS service provider would like to perform efficiently. Packet delivery systems are rated based on their delay-throughput characteristics – the calculation of which turns out to be a complex problem. A simpler performance measure in the case of a circuit-switched service is the overhead when carrying short messages (“short” relative to the circuit set-up and tear-down times). The overhead ratio, R, defined as

$$R = \frac{(\text{overhead + information transmission time})}{(\text{information transmission time})} ,$$

can be used as a first measure of the efficiency of a circuit-switched service. In what follows, the overhead calculation is performed.

The duration of the calling steps incurred by a mobile originated ITS message is well documented. Four cases are of interest, corresponding to minimum/typical delays and slotted/non-slotted modes. The slotted mode is defined in IS-95-A as a mode in which a registered mobile unit disables most of its functions most of the time (i.e., it "sleeps") to prolong its battery life. While in this mode, the mobile monitors and updates stored parameters at a low, predetermined rate.

Data delivery on a CDMA circuit-switch involves 3 stages (4 for slotted mode terminals): (0) Access (System Parameters Update for slotted mode terminals); (1) Channel Set-up; (2) Information Transmission; and (3) Tear Down.

To add to the above, there is the processing time both at the base and the mobile. If it is assumed that the processing per operation can be performed in one CDMA frame, the call duration is increased by roughly 180 ms.

Table 7.5-2 shows the duration of each of the call steps incurred in IS-95-A. Even in the best case scenario, and even for non slotted mode mobiles, there is a sizable amount of time spent preparing the data transfer, and at the end in cleaning up. This points out the well known fact that circuit-switched operation begins to make sense when the duration of the transaction significantly exceeds its handling time.

Table 7.5-2 Typical and Minimum Duration of IS-95-A Call Steps

Stage 0: Access System Parameters Update

Mode	Time [ms] (typical)	Time [ms] (minimum)
Slotted	640	80

Stage 1: Channel Set-up

Phase	Time [ms] (typical)	Time [ms] (minimum)
Origination message	240[5]	80
Channel assignment message	80	80
Mobile acquires fwd traffic channel	40	40
Base acquires reverse traffic channel	40	40
Base acknowledges order message	20	20
Base response order message	20	20

Stage 2: Information Transmission

Phase	Time [ms] (typical)	Time [ms] (minimum)
Message Transmission	80	80
Base Acknowledgment	20	20

Stage 3: Tear down

Phase	Time [ms] (typical)	Time [ms] (minimum)
Mobile release order	20	20
Base release order	20	20

Table 7.5-3 shows how the overhead ratio is arrived at under typical and optimistic (minimum "overhead") conditions. The overhead ratios for the so called slotted mode are 8.5:1 (minimum) and 17.5:1 (typical). For the non-slotted mode they would be 7.5:1 (minimum) and 9.5:1 (typical).

Table 7.5-3 Summary of ITS Call Duration for IS-95-A Circuit-Switched Service (Slotted Mode)

Phase	Typical Time [ms]	Minimum Time [ms]
Circuit set-up	1080	360
Information Transmission	80+20	80+20
Circuit Release	40	40
Processing Time	180	180
Total duration [ms]	1400	680
Overhead Ratio	1400:80=17.5:1	680:80=8.5:1

[5] In the event two mobile access attempts are needed, after a first failed transmission trial (80 ms) there is a back off time of 80 ms followed by a successful transmission (another 80 ms).

The column marked “Typical Time” in Table 7.5-3 provides:

- Circuit set-up time [ms]:
  Stage I (640) + Stage II (240+80+40+40+20+20) = 1080
- Transmissions of other than ITS payload bits [ms]:
  Stage III (20) + Stage IV (20+20) = 60
- Processing Time [ms] = 180; Total overhead (items 1 through 3) [ms] = 1320;
  ITS message transmission [ms] = 80
- Overhead ratio = (1320+80)/80 = 17.5

The numbers in the previous tables were arrived at in less than an optimistic analysis, which somewhat underestimates the time needed to accomplish certain tasks. That approach therefore yields a total duration figure which lower-bounds the real duration to be expected in the field. Two examples of this optimistic analysis are described below:

1. *Ignored times* — to allow a meaningful comparison with other ITS candidate technologies, the clock is started from the moment the user originates a message transfer. Thus, previous setup times, such as those taken for power up and first initialization, are ignored in the call duration budget.
2. *Shortened access time* — it is assumed that two mobile access attempts (probes) are enough to get the base station response. Field and preliminary analysis suggests that this is typical, but far from worst case.

The comparison with a packet radio system, such as CDPD, does not favor circuit-switched CDMA data. Figure 7.5-7 shows the typical call durations (ignoring the effect of the ITS data load) with the delay curves for CDPD which provides packet-switched service on a random-access protocol platform. For CDPD, at S~0 Erlang, the overhead ratio is by definition 1:1 — given that the reverse link CDPD channel is contention based, if there is no offered traffic, any message will go through without any delay (provided enough C/I is available). Consequently, it is apparent from the figure that the use of CDPD as the platform for ITS will result in equivalent “overhead ratios” varying from 1:1 (at S~0 Erlang) to 9:1 (at S~0.7 Erlang). This is always less than even non-slotted CDMA. It can be seen that even under the most optimistic assumptions, IS-99 remains a grossly inefficient platform for the purpose of carrying the usually small ITS messages.

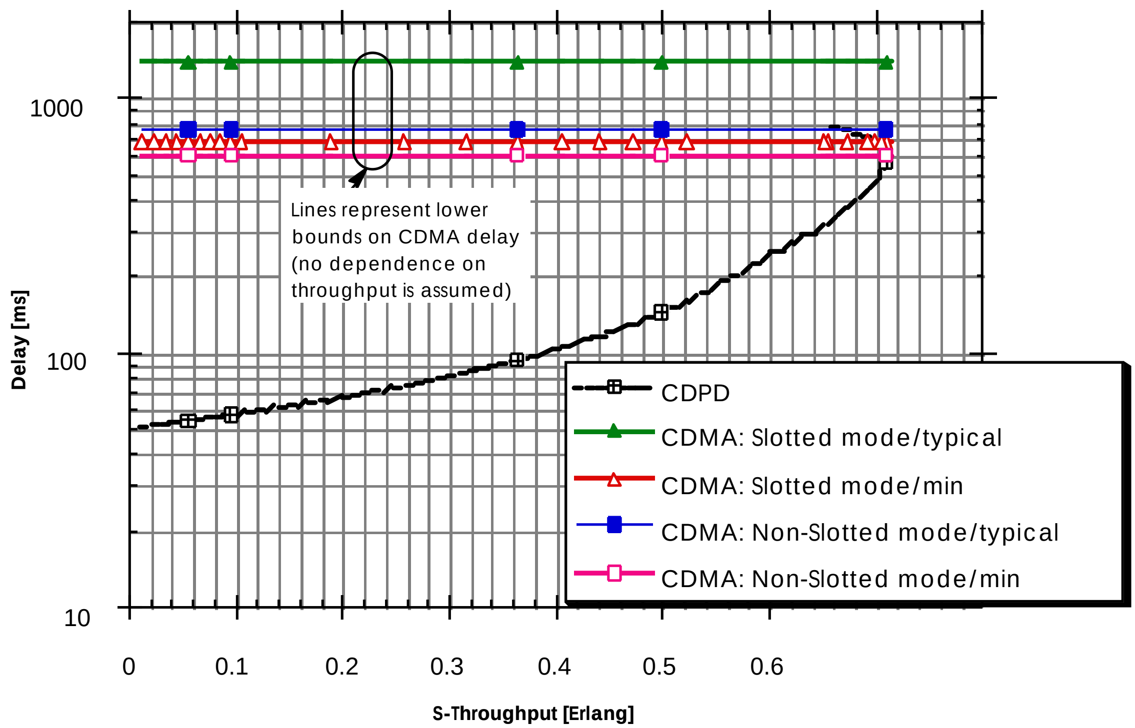


Figure 7.5-7 Average Delay/Call Duration Ratio: CDPD versus Circuit-Switched CDMA

7.5.1.1.2.2.2 CDMA Short Message Service (IS-637)

IS-95-A based CDMA currently has very limited packet-switched data capabilities. The primary limitation is imposed by the reverse link. On the forward link, the paging channel can be used to accommodate outbound traffic, although the maximum data rate is currently restricted to 9.6 kbps under IS-95-A, or 14.4 kbps under TSB-137. On the reverse link, two mechanisms exist which can be used to facilitate data traffic.

The existing IS-95-A channel structure associates a group of reverse access channels with a single forward paging channel. The paging channel is used to carry system configuration information as well as user data. Up to seven paging channels can be supported currently, each delineated within a cell sector by a separate Walsh code. Different sectors within the network are delineated by covering all channels in the sector with a complex valued pilot code. The modulation employed on the paging channel is essentially BPSK, using data rates of either 4.8 kbps or 9.6 kbps. Currently, there are 64 Walsh codes for channelization on the forward link. Extensions permitting each Walsh code to be reused to facilitate greater capacity and/or data rates have been proposed. The paging channel is currently segmented into fixed 80 ms slots.

Associated with each paging channel are 32 reverse link access channels. Access channels are chosen at random by users and are delineated by non-orthogonal codes. The codes within a sector are a function of the sector pilot code, paging channel code and the access channel chosen. The random access protocol employed is based on slotted ALOHA, with the slot size being a system configurable parameter. The parameters governing the protocol permit additional randomization of packets through time offsets to further reduce the possibility of collisions. All packets employ a minimum of 20 ms (one frame) of un-modulated preamble to allow for acquisition by the base station. The access channel data rate is currently fixed at 4.8 kbps, with 64-ary orthogonal modulation being employed.

For long messages, as we have discussed, negotiation of a dedicated traffic channel is warranted. While the traffic channel is capable of supporting 9600 bps sustained, the set-up times can be prohibitively long for short messages (~800 ms), as reviewed in the previous section.

Short messages of 110 bytes or less can be accommodated by using the one-way data burst message on the access channel. The peak data rate supported by the access channel is, as mentioned above, 4.8 kbps.

7.5.1.1.2.2.3 Packet-Switched Data (IS-657)

A new packet-switched data standard over CDMA (IS-95-A and TSB 174) has already been submitted to ballot. Service Option 7 provides generic PPP support for packet data services. An accompanying Service Option 8, which would have supported CDPD networks was vetoed by Lucent Technologies (ex-AT&T) pending clarification of Intellectual Property Rights (IPR) associated with the CDPD standard, and TIA's recognition of the CDPD standard. In any case, the support of PPP allows for interaction between the two networks.

The main limitation of this packet data service is its data rate, limited to 9.6 kbps for IS-95-A or 14.4 kbps for TSB 174, significantly less than the 19.2 kbps of CDPD.

7.5.1.1.2.2.4 High Speed Data Services over CDMA

The CDMA Development Group (CDG), an autonomous organization of CDMA manufacturers and future carriers, is already in the process of standardizing the future high speed data services, both circuit-switched and packet-switched, over CDMA. The goal is first to standardize the 64 kbps services, and then define multimedia data services at 500 kbps, and eventualy at 1-2 Mbps. Unfortunately, any of these new data services will definitely require re-designing the CDMA physical layer, and thus imply still a long process.

7.5.1.1.2.3 Omnipoint's Hybrid CDMA/TDMA/FDMA System (IS-661)

Omnipoint's PCS proposal is now an official industry standard under the designation IS-661. Omnipoint's system can be integrated into either the GSM or AIN switching networks. It also allows for the use of IS-41 inter-operability for roaming and system interconnection. In addition, the handset can operate with both (GSM and AIN) networks, which enables easy roaming and inter-operability. The system also provides inter-operability with indoor, low-cost, privately owned systems that offer wireline quality voice and high data rates, while providing for full vehicle mobility (up to 65 mph) and ubiquitous coverage. A high level architecture for Omnipoint's system is depicted in Figure 7.5-8.

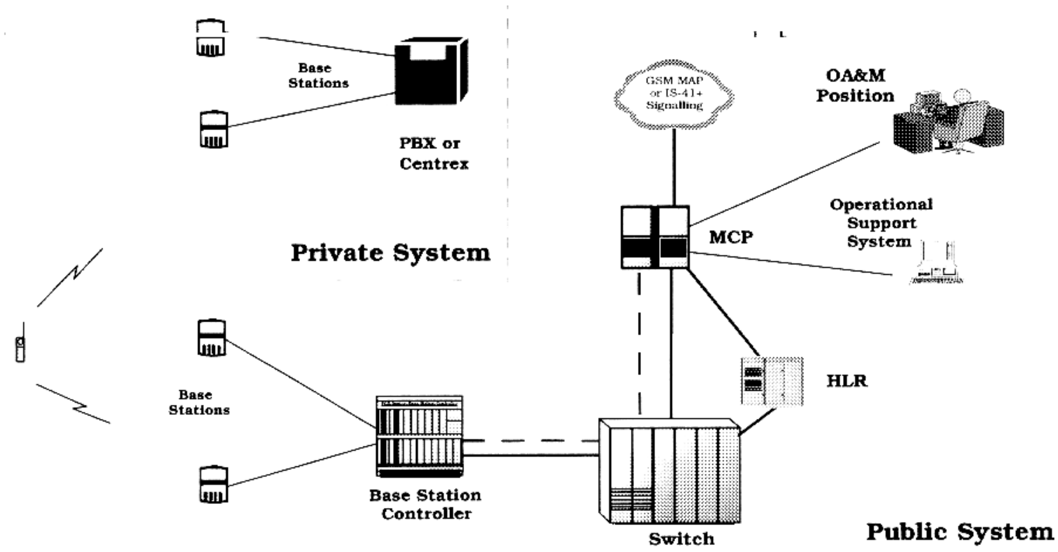


Figure 7.5-8 Omnipoint's System Architecture and Public-Private Operation

Omnipoint's system attempts to combine the major advantages of CDMA, TDMA, and FDMA in a hybrid solution. All signals employ a proprietary spread spectrum modulation waveform. Within a cell, multiple access at the data level is achieved through time division (TDMA). Either time-division duplexing (TDD) or frequency-division duplexing (FDD) can be used. In a standard configuration this technology provides 9.6 kbps full-duplex service to 16 simultaneous users in a single 1.875 MHz channel (or 32 users in 3.75 MHz). The 9.6 kbps reflect user throughput after all overhead for addressing, error checking, etc.

Adjacent cells are set to different frequency channels (FDMA) under a nominal N=3 frequency reuse architecture (like in GSM). Cells beyond those immediately adjacent use a variety of separation techniques, including different PN codes (CDMA), power control, directional antennas, and Time Slot Interchange (TSI) for additional inter-cell isolation. By utilizing a TDMA approach within a cell, and not relying solely on CDMA for separating multiple mobile signals at the base station, self-interference at the receiver is greatly reduced, permitting greater area coverage for a given mobile transmitter power.

Unlike CDMA-only architectures, cell sizes remain constant as a cell becomes loaded near capacity. CDMA is used in the Omnipoint system to mitigate multipath while providing high data rates, and to achieve better C/I ratios for inter-cell isolation.

Omnipoint's TDMA structure is based on a 20 ms polling loop for mobile access to the base station. In the 1.875 MHz per RF channel version, the system provides 32 simplex time slots, each of 9.6 kbps, or 16 paired, 9.6 kbps full-duplex time slots per RF channel. In the 3.75 MHz version, a single RF channel supports 64 simplex time slots or 32 full duplex users each at 9.6 kbps. There are provisions for each mobile to aggregate multiple time slots, giving users more bandwidth for higher data rates as required, to a maximum data rate of 153.6 kbps (higher than the 144 kbps of ISDN) full duplex per 1.875 MHz channel.

In fact, the Omnipoint system is reported to support data rates from Short Message Services to ISDN data rates and higher. In its 1.875 MHz version it can support over 144 kbps full duplex and over 256 kbps simplex. In the 3.75 MHz version it can support over 256 kbps full duplex or 512 kbps simplex. Note, however, that these higher data rates can only be achieved if the time slots are not in use by someone else, which is not what the system is designed for. Moreover, no data protocol has been defined or selected for this variable rate data service.

In addition to the user voice/data channel, the system provides for a D channel that allows for continuous 400 bps data traffic for every user. This channel is separate from (but simultaneous with) the bearer channel for messaging even when the handset is in use. The D channel can carry information for applications such as paging, voice mail notification, and Short Message Service.

The Omnipoint system is frequency agile in the entire 1850-1990 MHz band, including the unlicensed band (1910-1930 MHz) recently allocated to PCS by the FCC. It can also make use of the unlicensed band at 2.4-2.483 GHz). This aspect enables the system to be simultaneously used as an outdoor mobile, with in-building PBX, key system, or Centrex, or as a residential cordless phone.

Omnipoint's base stations are very small (as small as 27"x15"x13"), and light (less than 100 pounds), enabling them to be pole-mounted on street lights, or telephone/utility poles, or attached to the sides of buildings. The cell radius varies from 100 feet to 10 miles, depending on the environment (urban, suburban, rural) and the height of the antennas used.

Omnipoint was granted a Pioneer's Preference 30 MHz PCS license to compete in the New York Major Trading Area (MTA). The IS-661 system will apparently be launched on top of a GSM (PCS 1900) system Omnipoint will deploy soon.

7.5.1.1.2.4 PCS 1900 (GSM/DCS 1800)

Another technology candidate that requires evaluation is GSM, the well established Pan-European cellular standard. Actually, the American version of its DCS 1800 incarnation, PCS 1900, is what is proposed for evaluation here. The recent PCS auction results make it essential to analyze the proposed GSM solution. Pacific Bell Mobile Services, Bell South Personal Communications, American Personal Communications (APC), Western Wireless Co., Intercel, American Portable Telecommunications, and Omnipoint recently formed the North American Interest Group of the GSM MoU, and are all adamant to deploy GSM as soon as possible. Together, this group holds licenses to cover over 125 million people, including 12 of the top 25 cities in the U.S. In fact, APC, teamed with the Sprint Telecommunications Venture (a partnership between Sprint and the nation's largest cable companies), recently deployed the first commercial PCS systems in Washington, DC, Maryland, and Virginia, with a population base of more than eight million people.

In addition to voice, GSM offers certain data capabilities under the form of short message services (SMS). Besides SMS, the recent availability of circuit-switched data equipment will also be analyzed for its suitability to ITS services.

Within the scope of GSM Phase 2+, still in progress and under no disclosure at ETSI (European Telecommunications Standards Institute), a true packet data service is being designed for use with GSM, namely GPRS, General Packet Radio Service. Similarly, a High Speed Circuit Switched Data (HSCSD) standard is in the works. Both will be briefly discussed below.

7.5.1.1.2.4.1 GSM System Description

GSM (initially named after the standards body that conceived it, Groupe Speciale Mobile), now standing for Global System for Mobile Communications, refers to the Pan-European standard for digital cellular mobile telephone service. This system is being deployed throughout Western Europe, replacing first generation mobile systems conforming to five different incompatible standards, and has enjoyed considerable success in many countries (128 have already signed agreements to deploy GSM systems).

GSM, which operates in the 900 MHz frequency region, will not be deployed in the United States. However, in the form of PCS 1900, which is essentially GSM Phase 2 (or DCS 1800) re-configured to operate in the 1900 MHz band, it is a strong contender for future PCS service in the United States. There are a number of small differences between GSM and DCS 1800, the most important of which is that the transmitted power levels of DCS 1800 are lower to promote the deployment of smaller cells.

There are eight (full rate) voice channels per GSM carrier with the capability to introduce half-rate codecs in the future. The carrier spacing is 200 kHz. As deployed in Europe there is a total bandwidth of 25 MHz giving 125 radio channels or 1000 (one-way) traffic channels. (Spectral allocations in the United States for PCS will be 10, 20 and 30 MHz.)

The frame and slot structure of GSM is shown in Figure 7.5-9. A TDMA frame consists of eight time slots of length 0.577 ms. A multi-frame consists of 26 TDMA frames, 24 of which carry traffic. The gross bit rate is 270.8 kbps giving 33.85 kbps per user which is used as follows: (1) 13.00 kbps for Codec Voice; (2) 9.80 kbps for Error Protected Speech; (3) 0.95 kbps for SACCH gross rate; and (4) the equivalent to 10.10 kbps for Guard Time, Ramp Up, and Synchronization.

There are two control channels associated with the traffic channels. The fast associated control channel (FACCH) is a blank-and-burst channel and replaces a speech block whenever it is used. Two frames of the multi-frame are allocated to the slow associated control channel (SACCH). With full rate users the second SACCH frame is idle. In a SACCH frame the slots are assigned in the same way as for traffic frames. The gross bit rate on this channel is 950 bps and the net rate is 383 bps.

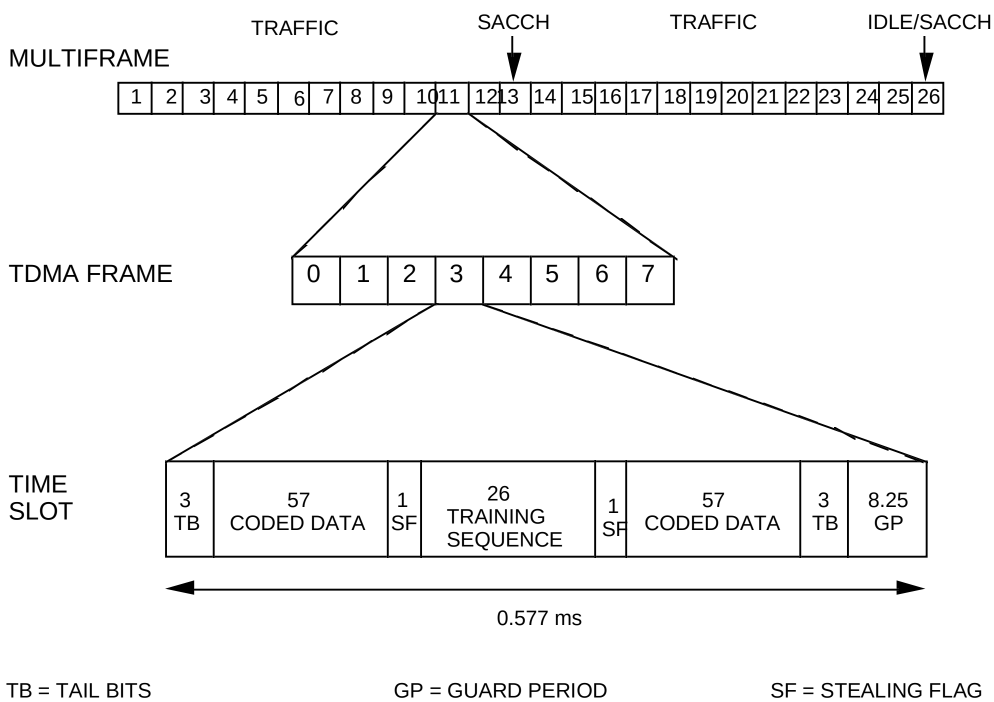


Figure 7.5-9 GSM Frame and Slot Structure

7.5.1.1.2.4.2 GSM Short Message Services (SMS)

In addition to voice and circuit-switched data services, GSM will provide certain packet data capabilities known as short message services (SMS). There are three distinct services offered under SMS. Point-to-point short message service is divided into mobile-originated and mobile-terminated categories with a service center being one of the endpoints in both cases. The two services can be combined to form a mobile-to-mobile service via the service center. The messages in these services are limited to 160 characters and are carried in control channels. The third category is cell broadcast SMS which allows messages to be broadcast on the control channel. Message length is limited to 93 characters. However, there is a provision to concatenate 15 such messages of 93 characters each. Unlike point-to-point SMS, a mobile may not be able to receive a message broadcast on the control channel if it is in the middle of a call. However, this service has not been fully defined or implemented yet.

The point-to-point short messages services described above are carried in what is known as the slow access control channel (SACCH) which occupies one frame out of the 26 in the GSM multi-frame structure. The SACCH frame, like traffic frames, is composed of eight time slots. In a SACCH frame the time slots are assigned in the same way as for traffic frames. That is, one is dedicated to each of the eight voice channels. Thus, a digital message can be transferred efficiently if a voice call is in progress. However, use of the short message service in the absence of an existing voice call is rather inefficient, since the time slots normally used by the voice call would be unused.

7.5.1.1.2.4.3 Circuit-Switched Data

Unfortunately, only scant information is available. The manufacturers promote the equipment as *adapters* (no longer modems!) that allow the user to send faxes and data at up to 9.6 kbps over the GSM air-interface. The users can retrieve e-mail messages through a connection to their Internet service provider of choice, but do not have full IP capabilities -- the adapter does not have an IP address.

7.5.1.1.2.4.4 High Speed Circuit Switched Data (HSCSD)

A High Speed Circuit Switched Data (HSCSD) transmission mode is currently being standardized at ETSI. HSCSD is a GSM bearer service intended to use multiple consecutive time-slots for increased data rate over the GSM air interface.

7.5.1.1.2.4.5 General Packet Radio Service (GPRS)

A new packet-switched data service over GSM, General Packet Radio Service (GPRS), is in the workings at ETSI. The standardization process is still under way, and only preliminary, vague information is available. A comparative study of this new packet data system (and its associated network) with CDPD would be quite instructive. Two things, however, seem certain. First, each data channel cannot provide more than 9.6 kbps, and to get higher throughput two or more TDMA time slots within a GSM carrier frame have to be used. A similar concept is proposed in CDPDng, except that each CDPD channel has now 19.2 kbps, and each CDPDng channel will have 56/64 kbps.

7.5.1.1.2.5 Private Mobile Data Networks

A few data systems exist in the land-mobile radio (LMR) 800-900 MHz band (in fact, part of this band is SMR), mostly of a proprietary nature. To the extent possible, these proprietary systems will be analyzed briefly, with emphasis on capacity, availability, and coverage. The most important ones, in terms of coverage, are ARDIS and RAM. (RAM effectively operates in the SMR band.)

7.5.1.1.2.5.1 ARDIS

ARDIS (Advanced Radio Data Information System) is a two-way packet radio service. It was launched in 1983 as a joint venture between IBM and Motorola, and is now a wholly-owned subsidiary of Motorola. ARDIS is deployed in 400 metropolitan areas (see example of coverage in Figure 7.5-10), reaching over 90% of the urban business population, and 80% of the total U.S. population including Alaska, Hawaii, Puerto Rico, and the U.S. Virgin Islands. ARDIS has 45,000 users in the US, and another 7,500 in Canada, serviced by Bell-ARDIS, a subsidiary of Bell Mobility Canada. IBM is still ARDIS' largest customer, with more than 12,000 field engineers using the service.

Figure 7.5-10 ARDIS Coverage in the Mid-Atlantic and Southern California Regions

The ARDIS network (Figure 7.5-11) consists of four network control centers with 32 network controllers presiding over 1250 base stations. Remote users access the system from laptop radio terminals that communicate with the base stations. The backbone of the network is implemented with leased lines. The four ARDIS hosts (Chicago, New York, Los Angeles, and Lexington, KT) serve as access points for a customer's mainframe computer, which can be linked to an ARDIS host via async, bisync, SNA or X.25 dedicated circuits.

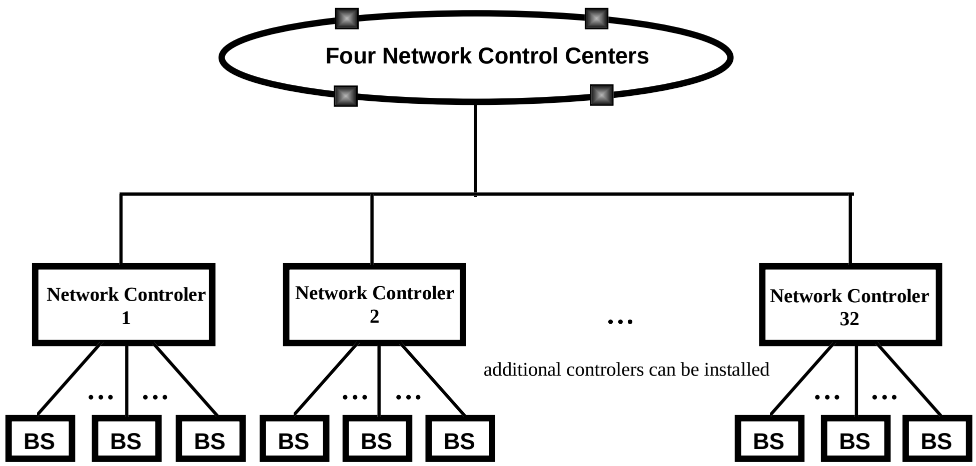


Figure 7.5-11 ARDIS Network Architecture

The system architecture is cell-based, with cells overlapped to increase the probability that the signal transmission from a portable will reach at least on base station. The base station power is 40 W, and the cell radius extends to 10-15 miles. Portables operate with 4 W radiated power. The overlapping coverage, combined with error-correcting coding ensures that ARDIS can support portable communication from inside buildings, as well as on the street.

ARDIS uses a concept known as single frequency reuse, where all cells in a given area share a single frequency. While the use of overlapping coverage, and the same frequency, does provide for reliable radio connectivity, it raises the problem of interference when signals are transmitted simultaneously from adjacent base stations. To deal with this, ARDIS turns off neighboring transmitters for 0.5 to 1 second when a forward link transmission occurs. The system uses very little spectrum, but single frequency reuse significantly limits system capacity.

ARDIS operates in the 806-821 MHz (reverse link) and 851-866 MHz (forward link) bands, and the channel bandwidth is 25 kHz. The multiple access method is FDMA.

ARDIS has recently implemented nation-wide roaming and is in the process of raising the data rate in a few markets to 19.2 kbps (8 kbps of user information) from 4.8 kbps. Initially, ARDIS offered MDI's (Mobile Data International Inc.) proprietary MDC-4800 protocol that achieved only 4.8 kbps on the 25 kHz channel using FSK modulation. Recently, Motorola developed and began offering its proprietary RD-LAP protocol for ARDIS, offering 19.2 kbps on the same channel using QFSK – with significantly less overhead, nationwide roaming, more robust link layer protocols and coding schemes, and better overall message throughput. Today, the ARDIS network accepts both protocols and offers modems that can be configured for either of them.

The laptop terminals access the network using *digital-sense* multiple access (DSMA). Essentially, a remote terminal listens to the base station transmitter to determine if a "busy bit" is on or off. When it is off, the terminal is allowed to transmit (very much like in CDPD). However, if two remotes begin to transmit at the same time, the packets may collide, and re-transmission will be attempted. Unlike CDPD, however, the system does not have Collision Detection. Therefore, the system has to reject the garbled packets and it will take a certain time for the remote terminals to realize that such an event took place. The busy bit only lets a remote terminal know when other terminals are transmitting, thus reducing the probability of packet collision, but does not allow the system to "immediately" react to collisions.

As a packet switched data network, ARDIS carries only data, and does not offer any voice integrated products. The packet length is 256 bytes. The service is suitable for transmission of files up to 10 kbytes long. ARDIS is used in support of computer-aided dispatching, such as is used by field service personnel, often when they are at a customer's premises.

7.5.1.1.2.5.2 RAM

RAM Mobile Data, a joint venture of Bell South and RAM Broadcasting Corporation, introduced the Mobitex system in 1991 in the U.S. Today, the network covers almost 100 metropolitan areas, and has around 30,000 users in the U.S., with another 2500 in Canada serviced by Cantel Data (Rogers Cantel). RAM plans to cover most of the U.S. business population, and is targeting the mobile professional.

The Mobitex system is a nationwide, interconnected trunked-radio network developed by Ericsson and Swedish Telecom. The first network that went into operation was in Sweden in 1986; other networks have been implemented in the meantime in a growing number of countries including Norway, Finland, Canada, UK, France, Germany, Netherlands, Belgium, Poland, Australia, Korea, Singapore, Chile, Nigeria, and recently Mexico. The Mobitex system specification is managed by the Mobitex Operators Association (MOA).

While the system was designed to carry both voice and data, the U.S. and Canadian networks are used to provide data only.

The Mobitex network architecture is hierarchical, as shown in Figure 7.5-12. At the top is the Network Control Center, from which the entire network is managed. The top level of switching is the national switch (MHX1) that routes traffic among service regions. The next level comprises regional switches (MHX2), and below that are local switches (MOX), each of which handles traffic within a given service area. Many reliability features are implemented, such as alternate network pathways, autonomous operation at each network level, multiple connections between nodes, and a backup network control center.

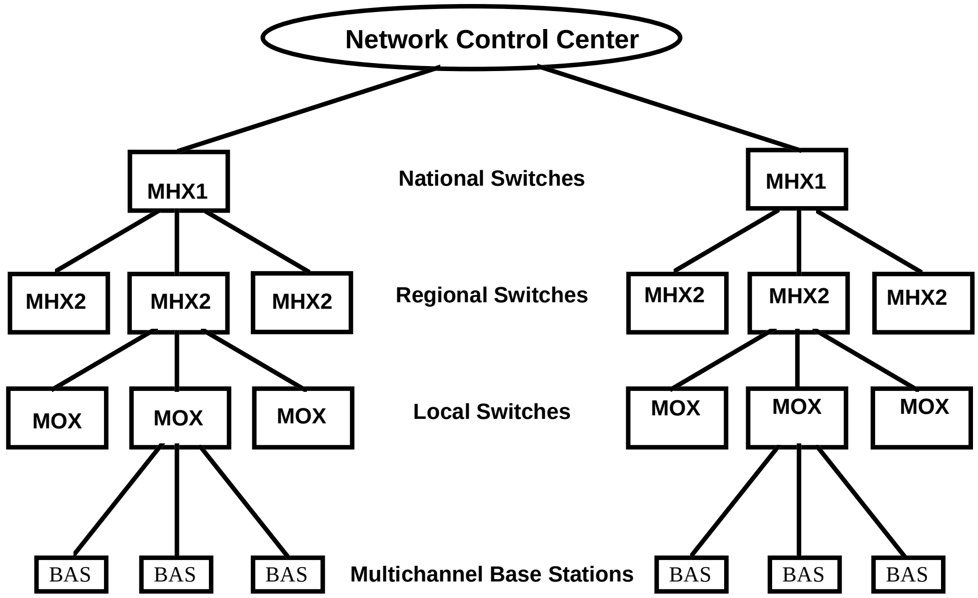


Figure 7.5-12 MOBITEX Network Architecture

Mobitex uses packet-switching techniques to allow multiple users to share channels. Message packets are switched at the lowest possible network level (only billing information is sent up to the network control channel).

The Mobitex system operates in much the same way as a cellular telephone system, except that hand-offs are not managed by the network. When a radio connection is to be changed from one base station to another, the decision is made by the mobile terminal, not by the network intelligence. To access the network, a mobile terminal finds the base station with the strongest signal and then registers with that base station. When the mobile terminal enters an adjacent service area, it automatically re-registers with the new base station, and the user's whereabouts are relayed to the higher-level network nodes, providing for the roaming capability. Other features include broadcast and store-and-forward messaging.

RAM operates in the SMR band (896-901 MHz for the reverse link; 935-940 MHz for the forward link), in 12.5 kHz channels. The system's transmission rate is 8 kbps half duplex, and the modulation is GMSK. Block interleaving, forward-error correction (FEC), as well as selective ARQ, are used to ensure the integrity of the delivered data packets. A reservation slotted-ALOHA-type scheme is used for channel access, providing a good balance between efficiency and responsiveness.

RAM supports existing standards such as X.25 and TCP/IP through gateways, since it is based upon proprietary protocols. Mobitex uses a proprietary network layer protocol (MPAK) with up to 512 bytes of user data per packet, and 24 bit addressing (Mobitex Access Number). A transport protocol, MTP/1, also proprietary and optimized for the mobile radio environment, was introduced by the MOA to facilitate development of multi-packet applications. The standard, proprietary Mobitex terminal interface, MASC (for Mobitex ASyncronous Communication), provides for reliable transfer of data to/from, and the control and status monitoring of the modem.

7.5.1.1.2.6 ESMR

Specialized Mobile Radio (SMR), began as an analog system which is still used today mainly for dispatching of buses and taxis. Most SMR providers cover only a relatively small area, though many do offer some sort of networking and interconnection with the public telephone network. Roaming under SMR is less user friendly than under cellular, and though it is technically possible to send data over SMR, it is not practical; SMR mainly offers wide-area analog voice dispatch service.

Enhanced SMR (ESMR) uses digital technology to allow more users per channel and to increase the number of services available to a user. ESMR providers such as Nextel, Dial Page, and CenCall own licenses to SMR frequencies across the country.

Some of the services provided by ESMR are dispatching, cellular-like mobile phone service, alphanumeric paging and messaging, and eventually other data services. An (E)SMR cell is larger than a cellular telephone cell, meaning that it will be cheaper to cover a particular area, but the available capacity will be smaller. A disadvantage of ESMR is that the handsets are more expensive and bulkier than current cellular phones, because of the new technology involved and the integration of voice and data into one unit.

As with the mostly proprietary systems above, to the extent possible, the ESMR systems will be briefly analyzed, with emphasis on capacity, availability, and coverage. The main data entry is, at the moment, Geotek's, since Nextel has not yet clarified its data options.

7.5.1.1.2.6.1 Nextel

Nextel Communications Inc., after completing the acquisition of Dial Call Communications Inc., OneComm Corp., and American Mobile Systems Inc., as well as Motorola's SMR licences, and after getting Geotek's network (in exchange for 900 MHz spectrum), owns FCC licenses to a potential customer base of 180 million people. Nextel, the only nationwide SMR provider, already has 916,000 subscribers (approximately 80% of the total). Their plan is to build a nationwide digital network to compete with cellular voice. No plans to provide *packet* data service have been announced yet, but they have circuit switched data and fax capabilities.

7.5.1.1.2.6.2 Geotek

Geotek uses a proprietary Frequency-Hopping Spread Spectrum system to provide circuit-switched voice and data, as well as packet data services. The packet data service is TCP/IP based, and an option to provide CDPD compatibility is in preparation. Geotek's macro cellular system supports hand-off, and provides 9.6 kbps raw data rate.

Services offered are cellular-type voice, half-duplex dispatch, full-duplex private telephony, two-way messaging, and data dispatch. Geotek has already deployed its system in Philadelphia, New York, Baltimore, Washington, DC, and Boston, and is now deploying in Miami.

The network can provide information to mobile users through the Geotek Mobile Workstation and a top-of-the-line device that combines the functions of a cellular phone, two-way radio, pager, and PDA, or through a simple add-on to a cellular phone.

7.5.1.1.2.7 220 MHz

The 220 MHz service is a land mobile radio service that may be used for either commercial or private purposes. The service consists of two hundred 5 kHz paired channels, some of which are licensed on a national basis and some on a "local" basis. One hundred of the two hundred channel pairs are licensed as five-channel trunked systems on a local basis. There are few restrictions as to the type of service that may be provided by these systems. Some view this service as a potential competitor to PCS, cellular, or wide area SMRs, but the limited channel capacity will hinder its competitiveness unless license consolidations occur in the future.

7.5.1.1.2.8 Narrow-Band PCS

Two-way paging or messaging systems are among the first services that will utilize the Narrow-band Personal Communication Services (PCS) frequency band. The Federal Communication Commission (FCC) defines Narrow-band Personal Communication Services (PCS) as a family of mobile services that includes advanced voice paging, acknowledged paging, data messaging and both one and two-way messaging on a nationwide, regional, major trading area, and basic trading area basis. The FCC has licensed Narrow-band PCS at 901-902 MHz, 930-931 MHz, and 940-941 MHz. Six companies have paid a total of $617 million for 10 nation-wide, narrow-band PCS licenses for channels in the 930 MHz band. The Narrow-band PCS providers include: AirTouch Comm. Inc., Bell South Wireless Inc., Destine Corp. (in fact MTel), McCaw Cellular (now AT&T Wireless), Pagenet, and Pagemart.

7.5.1.1.2.8.1 Two-Way Paging

SkyTel is presently offering the first two-way messaging service. This service uses Motorola's ReFLEX™50 two-way transport protocol, and the Tango™ 2-way pager. SkyTel offers paging service in approximately 300 markets; two-way paging is being deployed nationwide, and is offered now in the top markets.

Fundamentally, a two-way messaging service is similar to the existing paging services with an addition of a response channel. Applications include: message reply, message initiation, and control actions such as automatic registration and acknowledgment.

A two-way paging/messaging system is not an interactive system. The messages are stored, queued, and then sent to the subscriber. Therefore, the system has an inherent delay that can be on the order of many seconds to a few minutes. Such a system is clearly not suitable for supporting ITS messages that require real-time response. However, 2-way messaging may suffice for personal access type messages that don't require immediate response and are not time critical.

The candidate ITS messages that could utilize two-way paging are those with the following attributes:

- Short (up to 500 characters)
- Messages that can be responded to using a set of canned responses
- Messages that can tolerate long delays and do not require real time response
- Messages that are not time critical

Tables 7.5-4 and 7.5-5 provide the specifications of SkyTel's paging/messaging service and Motorola's Tango™ 2-way paging unit.

Table 7.5-4 SkyTel 2-Way Paging Service Specifications

Features	Specifications
Message type	Text and binary
Maximum Message size	500 character per transmission
Broadcast Rate (update)	The message is transmitted once every 5 minutes for the 1st hour, and once every hour for the next 72 hours
Coverage	Over 100 markets -coverage will be similar to regular paging
Hardware Cost	$400 for the Motorola Tango™
Present Service Cost	$40 to $90 per month (wide area, regional and nationwide) 200 messages free (80 characters per message) $0.5 for each additional message
Capacity	Similar to paging
Interface Methods to a subscriber	Telephone keypad, Operator, computer interface (i.e. modem), alphanumeric pager, Tango messaging unit, Electronic mail, and Message Duet system
Subscriber Respond Methods	• Selecting a response from a set of pre-programmed responses • Selecting a response from a set of multiple choice options that are included in the message • Using a palmtop to respond or initiate a message.

Table 7.5-5 Motorola's Tango™ Two-Way Messaging Unit Specifications

Features	Specifications
Frequency Band	Receiver 940-941 MHz (Narrowband PCS) Transmitter 901-902 MHz
Channel Spacing	Receiver 25 kHz Transmitter 12.5 kHz
Bit rate	Receiver 6.4 kbps Transmitter 9.6 kbps
Signaling Format	QFSK
Received message type	Numeric (4 bit data), alphanumeric (7 bit data), or binary data (8 bit). 8 bit systems are used for transmission of long messages.
External interface	Serial RS 232 interface for initiating messages and sending long messages using a palmtop computer
Message Memory	100k bytes
Canned Messages	Up to 120 preprogrammed messages

7.5.1.1.3 Satellite Systems – A Survey

During the next few years, many companies are planning to launch hundreds of satellites designed to provide wireless communications to mobile users virtually anywhere on the globe.

Proposed systems will offer voice and data, or data only. Most will also offer position determination. The different systems will determine the position of the user by various techniques, some more accurate than others. Even without a radio location service built into the system, the user terminal may be integrated with a GPS engine. It is important to assess those proposed systems in what they can offer for ITS users in remote or poorly-serviced areas.

This section first compares the advantages and disadvantages of satellite-based versus terrestrial-based mobile radio networks. Then, the different orbits and the different communication subsystem types are characterized.

The many proposed satellite systems are briefly analyzed, focusing mainly on their data capabilities. Currently operating satellite systems are also analyzed, including those providing positioning, like GPS and GLONASS.

7.5.1.1.3.1 Terrestrial versus Satellite Mobile Radio Networks

Terrestrial-based networks offer obvious, distinct advantages over satellite-based systems. These advantages stem from the much shorter distances between the mobile terminals and terrestrial base stations compared to distances in the order of 200 to 36,000 km, over which satellite mobile terminals must operate. Terrestrial base stations are easier and cheaper to plan, deploy, and integrate into the network then satellites. In comparison, a satellite system lacks the flexibility for adding more and more channels as a function of traffic increases.

The relative advantages that are likely to hold for terrestrial mobile networks include:

- Cheaper and smaller terminals and lower call charges
- Superior radio coverage in urban and in-building areas
- Minimal signal propagation delay
- Greater network capacity

However, satellite-based networks can exploit a few advantages, such as:

- Wide-area coverage
- Network flexibility
- Broadcast capability

Wide-area coverage enables satellite networks to offer services nationally to customers who operate in rural areas. This may be at the expense of greater call charges and more expensive radio equipment than conventional terrestrial services. However, it is possible to offer a diverse range of services using the inherent flexibility of satellite systems. By increasing the mobile terminal's usefulness, effectively one can expect user charges to be lowered. This enables the satellite service to not only complement, but also to compete against terrestrial mobile radio networks in certain market segments.

This is the bet on which all the proposed satellite systems are based. Industry analysts, however, think the market is not big enough to accommodate the proliferation of satellite offerings, and that in the end only a few will survive.

In any case, customers will naturally seek the cheapest, most reliable mobile communication system that meets their requirements. In high density population areas, terrestrial networks offer unbeatable advantages. Therefore, mobile satellite services can be expected to be complementary to terrestrial-based services, primarily in outlying areas.

7.5.1.1.3.2 Orbits: Acronyms and Characteristics

The most frequently chosen orbit for communication satellites has traditionally been the geostationary earth orbit (GEO), a unique circular orbit in the equatorial plane at an altitude of 35,786 km. Geostationary satellites can cover large areas of the globe and allow fixed pointing ground stations. Three such satellites would, in principle, be enough to cover the whole earth. However, they require high transmitter powers and large antenna apertures. They produce long communication delays, and require high cost and high risk satellite launches. Moreover, they do not properly cover high latitude regions of the earth. In fact, one deficiency of the GEO satellites is the low elevation look-up angle at higher latitudes, such as in Alaska and North Canada (and Northern Europe as well). These areas require link margins of 20-30 dB to overcome blockages. Also, most of the Arctic and Antarctic regions do not have any coverage from GEO satellites.

Looking at the link budget for a satellite link, four terms can be identified:

1. Transmitter EIRP
2. Path Loss
3. Fade Margin + required C/No + Boltzman constant
4. Receiver G/T

In essence, the design of any satellite link involves consideration of the division of relative performance requirements between the satellite repeater and the ground terminals. Given that path loss is practically a constant (or is upper bounded) for a given orbit and frequency band, the important design parameters are the G/T ratios and the EIRP values of the satellite and the earth terminals. These are determined by the antenna gains, receiver noise, and transmitter power, which then become the design variables.

Each communication satellite system design represents one solution to the cost/performance trade-off for the system – taking into account the postulated population of terminals. The history of satellite communications began with small, low performance satellites and a few very large earth stations. Over the years, satellites have grown in function and size. Earth terminals have decreased in size but increased in numbers. These trends are due to the fact that the savings made on a large population of terminals can offset the cost of satellite improvements.

The recent concept of Personal Communication Systems (PCS), however, requires a new approach to the equation. PCS terminals will be required to have small antennas, low output power, and high equivalent system noise temperature, i.e., they will be preferably hand-held terminals with very low EIRP and G/T ratio. Such a requirement presents a new challenge in system design.

There are three possible solutions to the problem of utilizing miniature terminals in satellite communications. The first is to further improve the performance of the satellite itself to compensate for small terminals. Some limitations exist to this approach, however. For instance, satellite receiver noise performance is limited by the noise temperature of the antenna looking at the “warm earth”. Moreover the satellite transmitter power is limited by the satellite power supply capability, a function of its mass. If a spot beam approach were used, increasing the satellite antenna gain (i.e., its size) would improve both G/T and EIRP. However, the antenna size is restricted by the launch vehicle cargo capability, and by the antenna mass, complexity, and cost. In summary, increasing the satellite G/T and EIRP, with the associated build-up in satellite mass and cost, may not be the most cost effective solution for the PCS design.

A second solution would be to use a frequency band at which even the small antennas would have high enough gains. For example, at the Ka-band (26-40 GHz), antenna gains of 20-25 dB can be achieved with small portable antennas. The use of such frequencies would also enable a GEO satellite cellular system to utilize a high number of cells with a satellite antenna array of moderate size and mass. The current availability of higher frequency bands mitigates in favor of this solution. However, several problems present serious impediments for such an approach. These include path loss increase with frequency, low power efficiency of Ka-band transmitters, dependence of link availability on weather, lack of technology, incompatibility with existing and projected terrestrial PCS systems (1900 MHz band).

A third, radically different solution is to decrease the path loss by bringing the satellite closer to earth, by placing the satellites in lower orbits. In return for the advantages of lower path loss and shorter communication delays, this technique unfortunately presents several disadvantages. Instead of the three satellite geo-stationary constellation, many such non-geo-stationary satellites are required in order to provide coverage equivalent to that of the geo-stationary system. The associated control telemetry and network management systems become quite complex. In addition, high Doppler frequency shifts are introduced into the satellite-terminal link, since the satellite is no longer fixed relative to the terminal.

Furthermore, inter-satellite cross links may be required for coverage extensions. Still, such a solution has potential for reducing the cost of a satellite-based PCS system, and it is, as shown later, the preferred choice within the proposed satellite systems.

The non-geostationary orbits are grouped as either low earth orbits (LEO), medium earth orbits (MEO), or highly elliptical orbits (HEO) as shown in Figure 7.5-13. LEO are those in the range 200-3000 km between the so called constant atmospheric density altitude and the Van Allen radiation belts. MEO start above 3,000 km, and extend up to GEO. Satellites in these orbits cross the radiation belts, and thus face high radiation levels.

Finally, HEO can put the satellite within several hundred kilometers of the earth's surface, during its inactive phase, and then take it even beyond the GEO, during its active phase. All elliptical orbits have two characteristic points: the perigee, point of closest approach to the earth, and the apogee, the point farthest from earth.

The choice of optimum satellite orbit is usually determined by the intended earth coverage. All stable orbits can be divided into four classes:

1. Inclined[6] Circular geosynchronous[7] orbits
2. Inclined Elliptical geosynchronous orbits
3. Non-synchronous orbits of the above two and the equatorial type
4. Geostationary[8] orbits

Not all orbits are suitable for communications. Non-synchronous orbits are seldom used for commercial communications, although they may be preferred for defense and scientific applications. Class 1 circular LEO and MEO orbits are particularly suited for cellular mobile communications, since the cell sizes remain constant throughout the orbit. Constellations of geosynchronous satellites in polar and/or inclined circular orbits can be combined to provide optimum continuous earth coverage.

Most of the LEO and MEO orbits are polar. A MEO system however exists that borrows the name of its orbit, ICO, Inclined Circular Orbit. This can cause some confusion, since an alternative, although less accurate acronym for MEO, more frequent in European literature, is Intermediate Circular Orbit (i.e., ICO). Here, the most usual MEO acronym is used, reserving ICO for the proposed system with that name.

A general problem with Class 2, low-perigee, inclined orbits is the rotation of the orbital plan due to the earth's oblateness. This rotation would constantly move the coverage area. The larger the eccentricity, the smaller the perigee height, the shorter the period, and the greater the instability of the orbit. The only way to stabilize such an orbit is to use a particular value of inclination, namely 63.435°. One such stable inclined elliptical geosynchronous orbit is the so called *Molnyia* orbit. It has a period of half a sideral day, a perigee height of 500 km, and an apogee height of 39,800 km. The apogee of this orbit always remains at a constant geographic latitude. Another orbit from this class with lower eccentricity is called the Tundra orbit. Its period is a full sideral day. In both cases, the most useful part of the orbit is the region of the apogee (active phase); there the satellite appears to move slowly, and stays close to the observer's zenith for a long time.

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[6] Inclination is referred to the equatorial plane. Polar orbits are inclined 90°.

In a geo-synchronous orbit (classes 1 and 2), a satellite completes an integral number of orbits per day.

[8] Geostationary orbits are geosynchronous orbits with a period of one day, the result is the relative stationarity of the satellite in reference to a point on the earth's surface.

A final observation is that the higher the satellite orbit, the greater its coverage, the lower its relative velocity and thus the Doppler shift, and the longer it stays above the horizon. The advantages are balanced by the fact that the propagation delay worsens with increased satellite altitude.

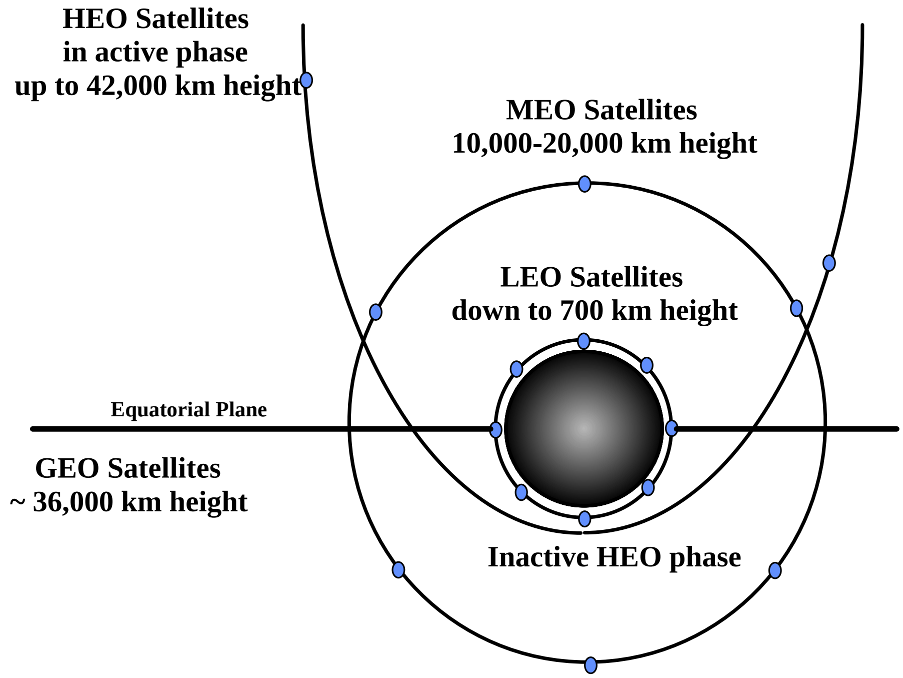


Figure 7.5-13 Satellite Orbits

7.5.1.1.3.3 Communication Subsystem Characterization

The communication subsystem on a communications satellite consists of a number of repeaters which amplify the signal received from the uplink, and condition them in preparation for transmission on the downlink. Each repeater belongs to one of the following types:

- Transparent, Non-Regenerative, or Bent-Pipe Repeater, referred to as Transponder -- they perform solely a frequency conversion from the uplink band to the downlink band (the conversion may be done in two or more steps);
- On-board Processing Repeater -- they first perform signal regeneration, and then they act as "switchboards in the sky", circuit-switching between antennas, and possibly multiplexing the reconstructed received signal for transmission at a higher bit rate.

The advantage of the "transparent" repeater is that their transponders impose minimal constraints on the characteristics of the communication signals. For example, they are "transparent" to different modulation types, whether analog or digital. They therefore offer maximum flexibility for designers of large communication networks. However, there is the risk of increasing the bit error rate (BER) at each conversion.

7.5.1.1.3.4 Proposed Satellite Systems

The panoply of proposed satellite systems ranges from the ambitious, 840-satellite LEO constellation advanced by Teledesic, to the "down-to-earth", three-satellite GEO constellation of Skycell, including also the very vague, 12 satellites in the Ka-band for voice, data, and multimedia services proposal from

AT&T, an even more ambiguous 9-satellite proposal from Lockheed Martin for the same Ka-band, and the Picosats concept, which calls for literally a myriad of pico-satellites which one can virtually own (if one wishes to invest $50,000). The three latter systems are not analyzed herein for lack of concrete information.

Most of the mobile satellite systems are low earth orbit (LEO) systems, which are much closer to the earth than the geostationary (GEO) satellites normally used for telecommunications thereby significantly reducing communications delay. Because of their proximity to earth, LEO systems accommodate low-powered and compact user terminals.

7.5.1.1.3.4.1 Little LEO’s

The little LEO’s are low earth orbit satellite systems that operate in the VHF range and carry only data communications. They are not very complicated, and are therefore easier and less expensive to build and operate than a system that also carries voice communications, for example.

7.5.1.1.3.4.1.1 ORBCOMM

ORBCOMM plans a system of 20 LEO satellites costing less than $150 million. The ORBCOMM system is a good example of a bent-pipe architecture, which all but two of the mobile satellite systems utilize. The mobile user sends a message to a satellite and that satellite routes the message to one of four gateway earth stations located in the four corners of the continental United States.

The four earth stations will be connected to the network hub in Virginia and will route the message there to determine where it should be sent. The messages can be sent from Virginia through the public and private e-mail networks, a leased line to a specific location, or back through the system to another mobile user.[9]

ORBCOMM began operation in February 1, 1996 after successfully launching in April 1995 the first two satellites of its intended 20/26/36 satellites constellation. (According to NASA, the two satellites had communication problems after launching, but are now operational. Coverage of the two satellites is shown in Figure 7.5-14.) ORBCOMM has become the world’s first commercial satellite-based two-way messaging and positioning system. However, from **Error! Reference source not found.**, we can see that the first two satellites cannot offer more than sporadic coverage of the Continental U.S. This situation will obviously improve with the deployment of further satellites.

[9] It is not possible, in a bent-pipe architecture, to send a message from one satellite to another; the satellites basically link the user with the land-based network.

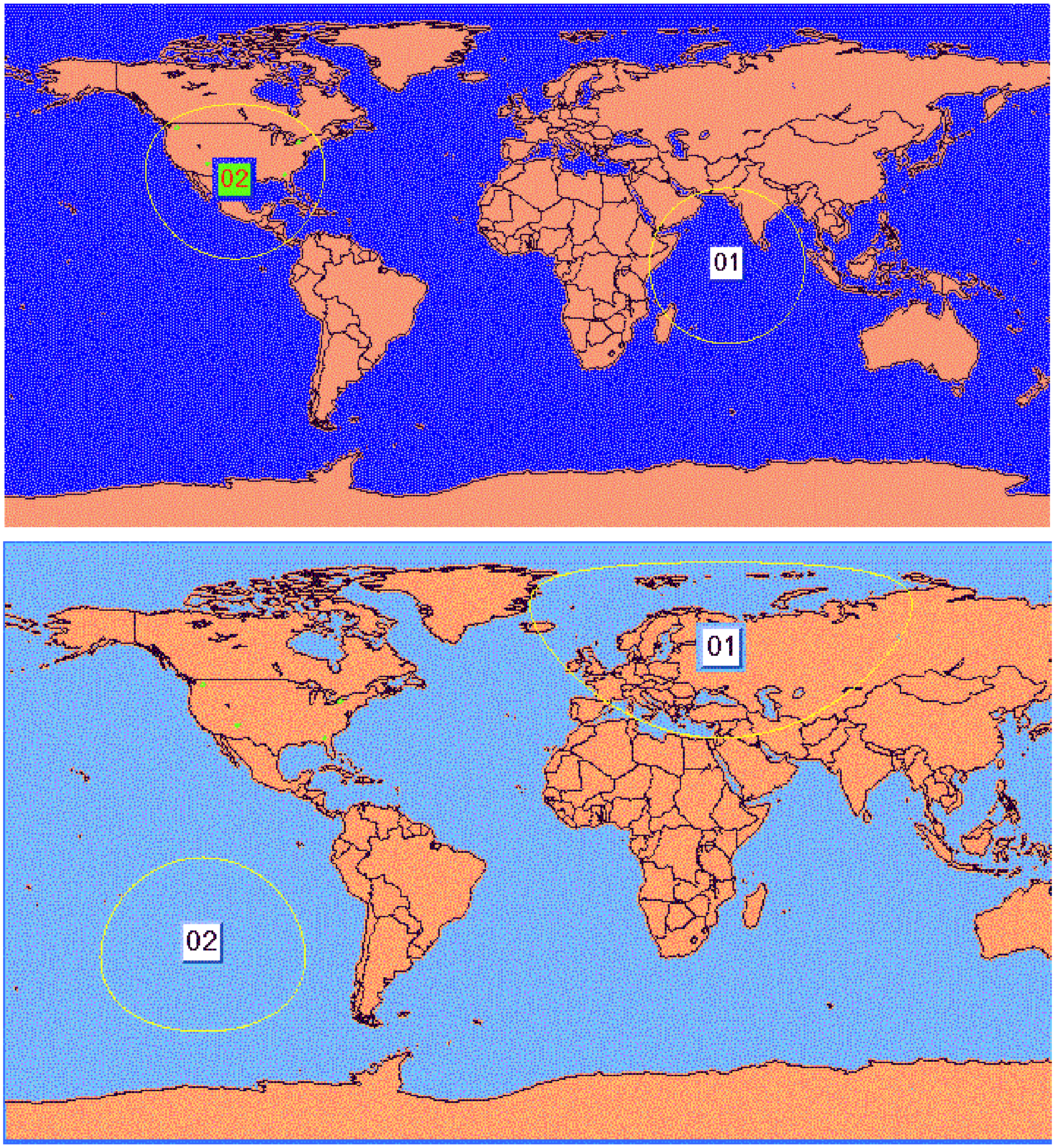


Figure 7.5-14 Location of, and Coverage Provided by, the Two Already Deployed ORBCOMM Satellites at Two Instants in Time

ORBCOMM has signed up 17 candidates to become international users. They plan to charge about $1 per message (100 byte), plus a fixed monthly fee. The terminal will eventually cost between $100 and $400 dollars.

7.5.1.1.3.4.1.2 STARSYS

Starsys is a U.S. company that provides global positioning services. It plans to start initial service in 1996 with a data-only, two-way radio communications system with 24 satellites to connect remote users' portable terminals to a central ground station. Starsys claims it will be able to locate the terminal to within 100 meters. The system is estimated to cost $200 million. Subscriber terminal costs are estimated at $75 to $250 for the 3rd generation.

Like ORBCOMM, Starsys plans to offer emergency communication, stolen asset recovery, and hazardous materials tracking services.

7.5.1.1.3.4.1.3 Comparative Analysis

Issues that need clarification include multiple access technique, dual-mode versus single mode user terminals (cellular and satellite), supported mobility, and most importantly, overall system cost. Table 7.5-6 provides the side-by-side comparison.

Table 7.5-6 Little LEO's

SATELLITE SYSTEMS	**ORBCOMM**	**STARSYS**	**VITASAT**
PARTNERSHIP	Orbital Sciences Corp., Teleglobe, TRW	North America Collection and Location by Satellite (NACLS), and ST System	Volunteers In Technical Assistance (VITA, VITACOMM)
NUMBER OF SATELLITES	20, 26, 36 depending on reference	24	2 satellites since 1984, 3rd added in 1995 (VITASAT-A, a.k.a. GEMSTAR-1)
COVERAGE	US now, Global future	Global	Global, designed for developing countries including South America, Africa
SCHEDULED OPERATION	Currently Operational in US; 1996 Canada and Mexico; 1997 Europe and Latin America	1996	End of 1995
PERCENTAGE OF OBTAINED FINANCING	"100%"	?	?
FCC LICENSE	late 1994	1992 Experimental License	?
DATA RATE (kbps)	2.4 uplink, 4.8 downlink	?	?
HAND-HELD vs. PORTABLE USER TERMINALS	Portable and Hand-held	?	Portable
USER TERMINAL COST	$100 -$400	?	$3500
DATA RATE COST (US Dollars per kilobyte)	$1.00 per 100 bytes	?	$50/month for up to 100 kbytes
SERVICES	two-way messaging, RDSS	one-way data, two-way messaging	two-way messaging; store and forward with typically 90 minute and as much as 12 hour message delay.
TARGETED APPLICATIONS	emergency comm. 2 way-mail, remote resource monitoring	emergency comm. stolen asset recovery, hazardous material tracking	Store-and-forward data

7.5.1.1.3.4.2 Big LEO Systems

The big LEO systems are distinguished from the little LEO's by their bandwidth. Big LEO's operate above 1 GHz and are able to carry voice as well as data. Most use more satellites for greater capacity and reliability. Because big LEO's are able to carry voice, many of the systems will be marketed and priced with voice service in mind, meaning that sending data might not be as cost effective as it would be using a little LEO system. Big LEO's are also much more expensive to build and operate.

7.5.1.1.3.4.2.1 Constellation

Formerly called Aries, the Constellation satellite system consists of 48 satellites, and plans to provide service for mobile phone users outside of cellular's coverage. Constellation Communications Inc. also expects their service to be used in rural areas of developing nations, where installing telephone switches and wires may not be cost-effective. The equatorial plane of the system, dubbed ECCO, will be deployed as a joint venture with Embratel, Brazil’s government telecommunications holding company.

7.5.1.1.3.4.2.2 GlobalStar

GlobalStar plans to commence initial commercial operation via a 24-satellite LEO constellation in 1998 (full 48-satellites coverage is anticipated for 1999). The constellation will be deployed in a 1,410 km orbit (resulting in no perceptible voice delay), and provides multiple satellite coverage (2-4 satellites will usually be visible at any time). The satellites are of the “bent pipe” type for simplicity and reliability, as well as cost reasons. GlobalStar employs CDMA spread spectrum access techniques to provide full global services.

GlobalStar intends to provide high quality telephony, data transmission, paging, fax, and position location to areas currently poorly or not at all served by existing wireline and cellular systems. The service, however, has to be authorized by the local telecommunications regulatory authorities. Users of GlobalStar should expect to make and receive calls using hand-held or vehicle-mounted terminals similar to today’s cellular telephones. Because the system will be fully integrated with existing fixed and cellular networks, GlobalStar’s dual-mode handset units will be able to switch from conventional cellular telephony to satellite telephony as required. Calls will be routed to customers through existing public and private telephone companies. GlobalStar handsets will be able to be used as mobile phones anywhere in the world using an individual subscriber number accessing either the local network or the satellites directly.

The GlobalStar system consists of the same number of satellites as Constellation, though its expected capacity is much larger. The added complexity is reflected in the anticipated cost of $2 billion. $1.4 billion has already been raised. Anticipated average call prices range from 35¢ to 53¢ per minute although this may seem optimistic. No data pricing information is available.

Leading an international coalition of companies teaming up to build the GlobalStar system are Loral and Qualcomm and Space Systems/Loral. Their strategic partners are Air Touch Communications, Italy's Alenia Spazio and Elsag Baley (Finmeccanica), France's Alcatel and France Telecom, Korea's Dacom Corporation and the Hyundai Electronics Group, UK's Vodafone Group, and Germany's DASA (formerly Deutsche Aerospace AG).

7.5.1.1.3.4.2.3 Iridium

Iridium plans to be operational in 1998 with a 66-satellite system for worldwide mobile communications services to provide direct-via-satellite global voice, data, paging, and radio-determination services to pocket terminals anywhere in the world. Total system cost is estimated at $3.4 billion.

Iridium will use TDMA whereas others plan to use CDMA. Five experimental models have approval for 1996 to demonstrate system feasibility. The consortium includes Motorola, Sprint, Lockheed/Raytheon, Japan's Nippon Iridium, Saudi Arabia's Mawarid Corp., Canada's BCE Mobile, Venezuela's Muidiri Investments, Italy's STET, Korea's Hyundai Electronics, Thailand's United Communications, Russia's Krunichev Enterprises, China's China Great Wall Industry, Taiwan's Pacific Electric Wire & Cable Co., India's Infrastructure Leasing & Finance Services, Germany's Deutsche Aerospace, and UK's Vodafone Group.

Motorola's ambitious Iridium system incorporates inter-satellite links (see Figure 7.5-15), which greatly raises the complexity of their satellites. A system with inter-satellite links, though, will be more robust and offer greater world-wide coverage than a comparable one without them. In an area without ground stations, a bent-pipe satellite would be unable to open a voice connection and could only store or send previously stored messages to a mobile unit.

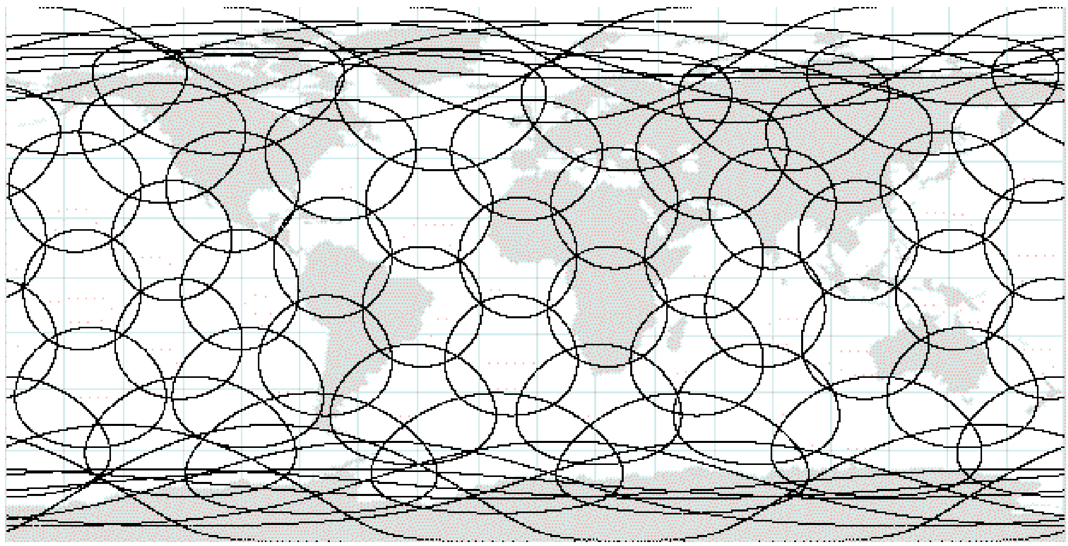


Figure 7.5-15 Iridium System Footprint at a Given Point in Time

7.5.1.1.3.4.2.4 Teledesic

By far the most ambitious LEO is Teledesic, an 840 "refrigerator-sized" satellites system backed by Bill Gates and Craig McCaw. The satellite trajectories to cover the globe are shown in Figure 7.5-16. Teledesic plans to operate in the 20/30 GHz range. Teledesic Corp. anticipates a basic channel rate of 16 Kbps, and channels may be combined by fixed ground units up to a maximum of 50 Mbps. It also will incorporate inter-satellite links. Teledesic does not plan to be operational until 2001 and will cost at least $9 billion. Teledesic is ***not*** intended for mobile terminals.

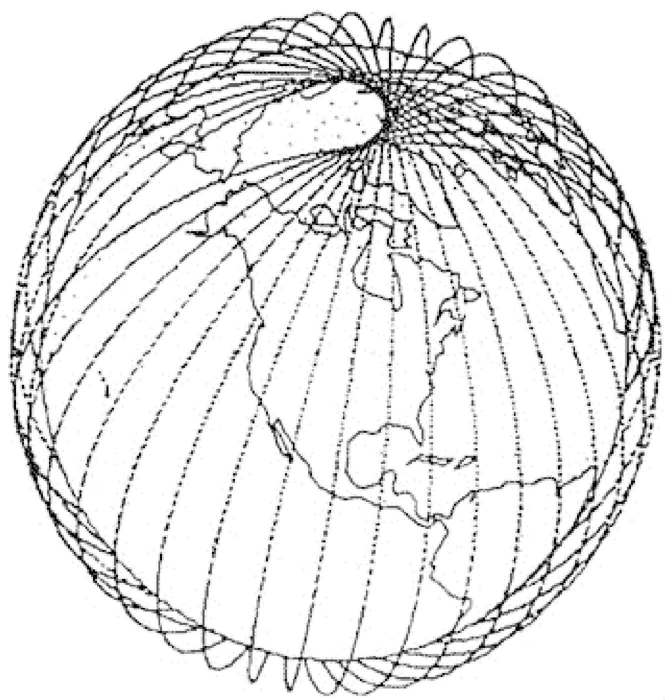


Figure 7.5-16 Path Described by a Teledesic Satellite

7.5.1.1.3.4.2.5   Comparative Analysis

Key issues in the success of any of these systems will be voice and data service costs, user terminal costs, system security, and supported mobility. All this, however, assumes the systems get deployed, which is not guaranteed given the huge costs involved. Obtaining the operating licences needed to provide service globally is certainly not an easy task and is another area of risk. Table 7.5-7 provides a comparative summary for the LEO satellite systems.

Table 7.5-7 Comparative Analysis of Big LEO's

SATELLITE SYSTEMS	CONSTELLATION (formerly ARIES)	GLOBALSTAR	IRIDIUM	TELEDESIC
LEADERSHIP	Constellation Communication	Loral, Qualcomm	Motorola	Bill Gates of Microsoft, and Craig McCaw founder of McCaw Cellular Communications, Inc. and chairman of Teledesic
NUMBER OF SATELLITES	48	48 plus 8 spare	66 plus 6 spare	840 plus up to 84 spare
COVERAGE	Global	within +/- 70 degrees latitude	Global	Global, except for 2 degree hole at poles; 95% of earth's surface
SCHEDULED OPERATION	1998	1998	1998	2001
PERCENTAGE OF OBTAINED FINANCING	~15%	~70%	~100%	?
FCC LICENSE	?	Jan. 1995	?	?
MULTIPLE ACCESS TECHNIQUE	CDMA	CDMA	FDMA/TDMA/TDD	TDMA, SDMA, FDMA, Advanced TDMA
VOICE CIRCUITS PER SATELLITE	?	2000-3000	1100 (power limited)	100,000 (16 kbps channels)
VOICE RATE (kbps)	4.8	adaptive 2.4/4.8/9.6	2.4/4.8	16
DATA RATE(kbps)	2.4	7.2 sustained throughput	2.4	16 to 2048
MOBILITY	?	?	?	Fixed
DUAL-MODE vs. SINGLE MODE USER TERMINALS (land and satellite)	?	DUAL	DUAL	SINGLE
HAND-HELD vs. PORTABLE USER TERMINALS	Hand-held	Hand-held	Hand-held	Portable
SYSTEM SECURITY	?	?	?	encryption
SYSTEM COST (Million US Dollars)	$1,700	$2,000	$3,700	$9,000
USER TERMINAL COST	?	~$750/terminal; $1000-$1200 for telephone	$2500-$3000	?
VOICE SERVICE COST (US Dollars per minute)	?	$0.35-$0.55	$3.00	?
DATA SERVICE COST (US Dollars per kilobyte)	?	?	?	?
SERVICES	voice, data, fax	Voice, data, fax, paging, short message service, RDSS	Voice, data, fax, paging, messaging, RDSS	Voice, data, fax, paging, video
TARGETED APPLICATIONS	extension of the cellular network	worldwide communication	worldwide communication	ISDN to rural businesses and remote terminals (fixed)

Note: The information in this table is based on inputs provided by the marketing organizations for the vendors and have not been validated by the Architecture team.

7.5.1.1.3.4.3 Other Mobile Satellite Systems

A few companies believe LEO is not the best configuration for a mobile satellite system. Hence, they are proposing highly elliptical orbit (HEO), Medium Earth Orbit (MEO), and Geostationary (GEO) systems.

7.5.1.1.3.4.3.1 Ellipso

Ellipso plans to be operational in 1997 and to provide combined position determination and mobile voice services using up to 24 satellites. Six experimental spacecraft have approval from the FCC. They will use FDMA and CDMA techniques.

Ellipso's unique elliptical orbit will provide more coverage to areas with high traffic at a certain times of the day. For example, if the time of maximum duration visibility over New York were selected to be mid-day, maximum duration visibility for Chicago, Denver, and Los Angeles would also be mid-day. To complement the elliptlical orbit, the Ellipso system has a second component, MEO, providing additional coverage of intermediate latitudes.

Ellipso also plans to become an extension to the cellular network, providing service where cellular is not available. Costs to users will be comparable to those of cellular. Contracts exist with countries including Canada, Mexico, Israel, and Australia.

7.5.1.1.3.4.3.2 Odyssey

Odyssey is a MEO system. Its higher orbits allow it to cover the globe with only 12 satellites. The smaller number of satellites makes Odyssey slightly cheaper than the big LEO’s, but its capacity will be smaller, and user terminals will probably be more complicated and more expensive. Ground control stations will serve as gateways to local networks for voice and data communications to hand-held terminals worldwide.

Odyssey’s main partners are Teleglobe and TRW. Participants in the system design group include Harris Corporation, France's Thomson-CSF, Canada's Aerospace Ltd. and Northern Telecom, Germany's ANT Nachrichtentechnik GBH.

7.5.1.1.3.4.3.3 ICO Global Communications

ICO Global communications, backed by 44 international investors, plans to have its 10-satellite MEO (or ICO), 10,400 km orbit system (see Figure 7.5-17) in service by the year 2000. When fully operational, the ICO system intends to provide a low-cost global satellite phone service, as well as data, fax, and paging, using hand-held pocket-sized terminals. It will be fully complementary with terrestrial cellular/PCS. ICO is already a member of the GSM MoU, but it will also support D-AMPS and other 2nd and 3rd generation digital cellular systems.

Two or more satellites will be usually visible to the users at relatively high angles of elevation to minimize blocking by terrain, buildings, and other obstacles. The satellites will relay calls between the user and a Satellite Access Node (SAN) within the satellite’s view. SAN’s are interconnected using terrestrial facilities to form a network, the ICO-Net, and are linked through gateways to the PSTN.

ICO began as Inmarsat P, or Project 21, later spinning into a separate commercial entity, since its scope expanded beyond coastal areas. The system cost is estimated at $2.6 billion and $1.5 billion have already been secured. Hughes is ICO’s first strategic partner, and has invested an amount ($94 million)equal to ICO’s largest non-institutional investors (Inmarsat invested $150 million, becoming the major investor).

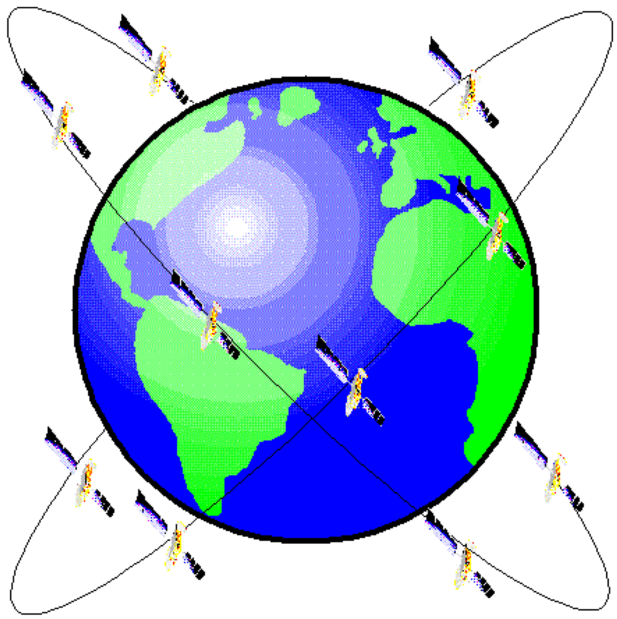


Figure 7.5-17 ICO's Satellite Orbits

7.5.1.1.3.4.3.4   Skycell

The American Mobile Satellite Corp. (AMSC) plans to offer voice, data, and location service with its new Skycell system, a series of three GEO satellites. Figure 7.5-18 shows the planned coverage. Because of the much greater distance to the satellites compared to LEO, hand held terminals will not be offered. Vehicle mounted units are expected. Skycell has already obtained an FCC license.

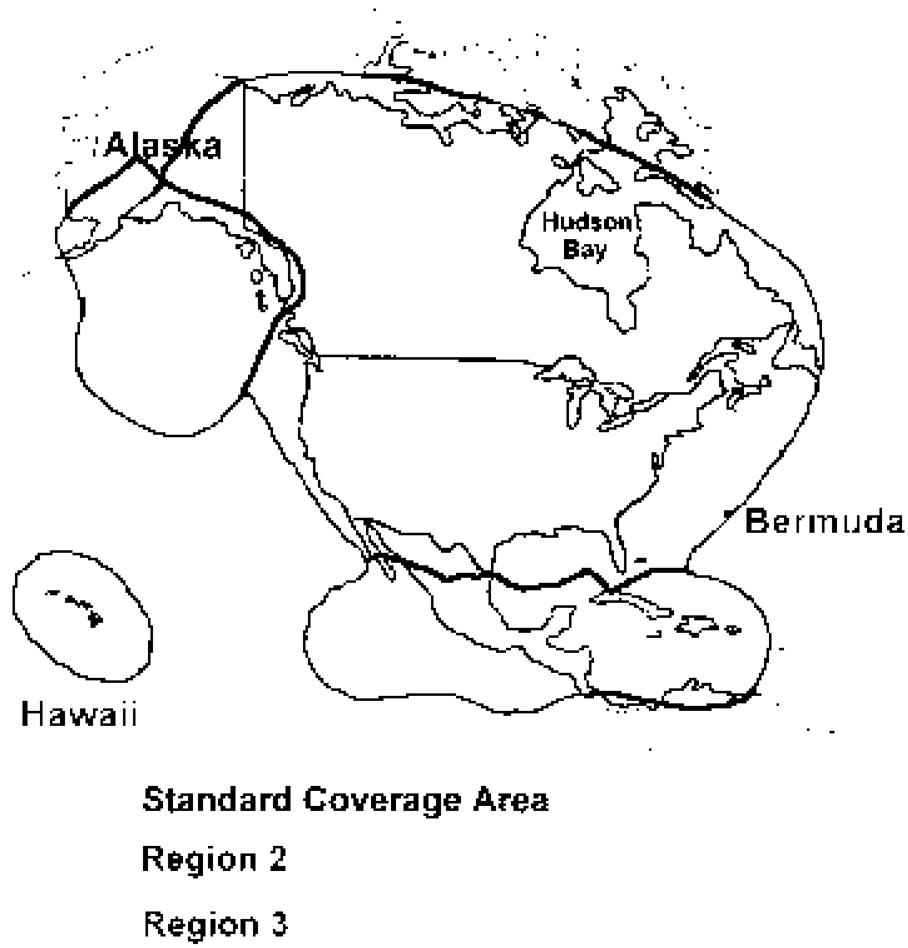


Figure 7.5-18 SKYCELL Coverage

7.5.1.1.3.4.3.5 MSAT

TMI and AMSC were the companies that initiated, funded, developed and launched the satellite that will be used to provide commercial mobile satellite service in North America. Commercial service is anticipated for early 1996. MSAT extends mobile and fixed telephone (6.4 kbps codec), fax, data (2.4 and 4.8 kbps), and dispatch radio communications to all of North America plus up to 400 km of coastal waters, the Caribbean, and Hawaii, as well as Mexico and Central America. The system is fully connected to the PSTN, and to public and private data networks.

Figure 7.5-19 shows the type of terminal supported. Mobile units use a small 7” dome antenna, and transportable units use a 30” flat antenna that can be easily set-up by the user. Call rates vary from $1.55 to $2.75 per minute, depending on the plan, and on the service modality, fixed or mobile.

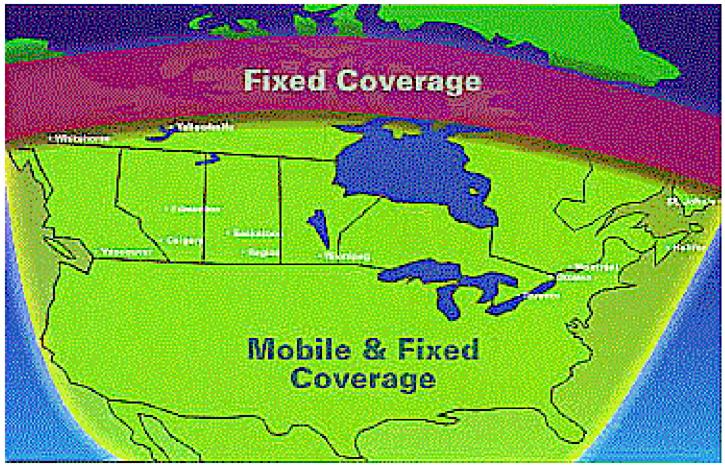


Figure 7.5-19 MSAT North American Coverage

7.5.1.1.3.4.3.6 Comparative Analysis

Issues of mobility, service, and terminal cost will be determinant for the success of MEO/HEO systems. Tables 7.5-8 and 7.5-9 provide comparison summaries for the MEO/HEO and GEO satellite systems respectively.

Table 7.5-8 Comparative Analysis of MEO and HEO Satellite Systems

SATELLITE SYSTEMS	ELLIPSO	ICO (formerly Inmarsat-P)	ODYSSEY
PARTNERSHIP	Ellipso	Inmarsat, Multiple Government Agencies, and Hughes	Teleglobe, TRW
ORBIT CLASS	MEO and HEO	MEO (Intermediate Circular Orbits, ICO)	MEO
NUMBER OF SATELLITES	MEO is 6; HEO is 10	10 plus 3 spare	12 plus 3 spare
COVERAGE	North of 50° South	Global	major land masses
SCHEDULED OPERATION	1998	2000	2000
SYSTEM COST (Million US Dollars)	$750	$2,600	$1,800
PERCENTAGE OF OBTAINED FINANCING	?	59%	?
FCC LICENSE	?	Aparently available	?
MULTIPLE ACCESS TECHNIQUE	CDMA	TDMA	CDMA
VOICE CIRCUITS PER SATELLITE	?	4500	2300
VOICE RATE (kbps)	4.15	4.8	4.8
DATA RATE (kbps)	0.3 to 9.6	2.4	9.6
MOBILITY	?	?	?
DUAL-MODE vs. SINGLE MODE USER TERMINALS (land and satellite)	Dual	Dual	Dual
DUAL-MODE vs. SINGLE MODE USER TERMINALS (land and satellite)	DUAL	DUAL	DUAL
HAND-HELD vs. PORTABLE USER TERMINALS	Hand-held	Hand-held	Hand-held
USER TERMINAL COST	~$1000 or $300 add-on to digital cellular unit	"Several Hundred"	~$300
VOICE SERVICE COST (US Dollars per minute)	$0.50	$1-$2	$0.7 5 ; $24 monthly charge
DATA SERVICE COST (US Dollars per kilobyte)	?	?	?
SERVICES	Voice, data, fax, paging, messaging, RDSS	Voice, data, fax, paging	Voice, data, fax, paging, messaging, RDSS
TARGETED APPLICATIONS	extension of cellular network	global phone integrated with cellular services	extension of cellular network

Note: The information in this table is based on inputs provided by the marketing organizations for the vendors and have not been validated by the Architecture team.

Table 7.5-9 Comparative Analysis of GEO Satellite Systems

SATELLITE SYSTEMS	INMARSAT (A,B,C,M)	MSAT	SKYCELL
PARTNERSHIP	Multiple Government Agencies (International Maritime Satellite Organization, consortium of 76 countries)	Mobile Satellite Corp., Glentel, Inc., BCE, Spar Aerospace, Hughes, Mitsubishi, Westinghouse	American Mobile Satellite Corp. (Hughes, AT&T, MTel, Singapore Telecom)
NUMBER OF SATELLITES	Inmarsat phase 2: 4 satellites (since 1992); Inmarsat phase 3: 5 satellites (projected for 1996)	2	?
COVERAGE	Global	North America, Hawaii, Caribbean	North America
SCHEDULED OPERATION	Operational since 1993	1996	?
SYSTEM COST (Million US Dollars)	?	?	?
PERCENTAGE OF OBTAINED FINANCING	?	?	?
FCC LICENSE	WARC, WRC	?	1989
MULTIPLE ACCESS TECHNIQUE	?	TDMA/TDD	FDMA
VOICE RATE (kbps)	6.4 to 16 depending on system	?	?
DATA RATE (kbps)	0.6, 2.4, 9.6, 64 depending on system	2.4	1.2-4.8
MOBILITY	Fixed to Aeronautical	Fixed (Canada and Alaska); Mobile (Contiguous 48 States)	Full mobility (vehicles, ships, and airplanes)
DUAL-MODE vs. SINGLE MODE USER TERMINALS (land and satellite)	Dual (drivers for ARDIS, CDPD, GSM)	Dual	?
HAND-HELD vs. PORTABLE USER TERMINALS	Portable	Portable	Portable
USER TERMINAL COST	$5000-$35,000 depending on system	$5000-$6000	?
VOICE SERVICE COST (US Dollars per minute)	$2.00-$8.00 depending on system	$2.50	Standard : $25/month, $1.49/minute Business:$175/month, 200 minutes free, $0.85/minute voice, data, fax
DATA RATE COST (US Dollars per kilobyte)	$1.00-$1.50	?	similar to voice service costs
SERVICES	Voice, data, fax, e-mail, store-and-forward, alerting, position determination	Voice, data, fax, dispatch radio	Voice, data, fax, location determination
TARGETED APPLICATIONS	Worldwide communications	Mobile office, position determination, e-mail, monitoring, voice dispatching (2-way), broadcast and multicast messaging	Transportation, maritime, aeronautical, remote site industries

Note: The information in this table is based on inputs provided by the marketing organizations for the vendors and have not been validated by the Architecture team.

7.5.1.1.3.5 Operating Mobile Satellite Systems of Interest

7.5.1.1.3.5.1 OmniTRACS

In the late 80's, QUALCOMM developed a geostationary (GEO) two-way Ku-band (11 and 13 GHz) data/messaging service called OmniTRACS. The system is spread-spectrum based, and is aimed at providing position reporting and messaging services for the trucking community. By early 1992 QUALCOMM had over 25,000 in use on trucks across North America and were successfully marketing their services world-wide. Today OmniTRACS claims more than 135,000 terminals all over the world, including its European counterpart, EutelTRACS, a joint venture of QUALCOMM and Alcatel QUALCOMM (established in 1990, 34% owned by QUALCOMM). Systems are currently operational in Mexico, Brazil (where it is known as OmniSAT), Japan, Russia, and Malaysia.

The OmniTRACS system is a low-rate interactive data communication tool that links fleet dispatch centers to their vehicles. This system uses QUALCOMM dedicated satellite systems, as well as commercially available satellite systems (i.e., transponders) as needed, for providing the interactive data services. For example, QUALCOMM has signed an agreement with ORBCOMM giving it the right to resell ORBCOMM's communication services with the OmniTRACS expanded trailer tracking and cargo monitoring applications.

The messaging and positioning information is sent, via satellite links, through the OmniTRACS Network Management Center to the fleet dispatch center. The mobile communication units provide the computing capability to send and receive text messages to and from the vehicles. The mobile units are also available with QUALCOMM's Automatic Satellite Position Reporting (QASPR). QASPR uses satellite triangulation to provide vehicle position to within 1/4 of a mile. The system also supports direct input from Global Positioning System (GPS) receivers. The system uses a proprietary Ku-band directional antenna that is encased in an aerodynamic dome. An electronically driven motor directs the antenna toward the satellite at all times. A new C-band system has been introduced for those regions where Ku-band is not readily available (e.g., Malaysia). In this case, vehicle tracking is made possible only through the use of a GPS receiver.

The OmniTRACS mobile terminal can be used for monitoring vehicle's status. The sensor information is made available to the driver using the onboard terminal, and is transmitted to the dispatchers. Because of the cost of the satellite terminal, this system is only suitable for long-haul truck operations that need very wide area coverage that includes remote areas.

7.5.1.1.3.5.2 INMARSAT Satellite Systems

Inmarsat (International Maritime Satellite Organization) was formed by a consortium of 28 founding countries upon adoption of the Inmarsat Convention in September 1976. The corresponding operating agreement came into force in July, 1979. Today 76 countries are Inmarsat signatories.

Although its charter was to "make provisions for the space segment necessary for improving distress and safety of life at sea, communications, efficiency and management of ships, maritime public correspondence services, and radio determination capabilities", its scope has extended beyond coastal regions, encompassing today land mobile applications.

Before discussing the types of Inmarsat services which are operational, two terms must first be defined: 1) Mobile Earth Station (MES), which can also be a ship or even a plane, and, 2) Coastal Earth Station (CES). The services offered by Inmarsat are:

1. Inmarsat A (1980): Analog FM system offering telephone, telex, fax or data circuits between an MES and a CES with data rates up to 56 kbps. The MES's are relatively complex, and expensive

($25,000 to $50,000 each), usually they are only present in the larger ocean-going vessels. Recently, "suitcase" Inmarsat terminals were introduced particularly for land mobile applications.

2. Inmarsat B (1993): Digital replacement for Inmarsat A. It utilizes a 16 kbps voice codec.
3. Inmarsat C (1991): Based on a low cost MES, it was designed to provide a two-way data messaging service. The objective was to reduce, besides the cost, the size and weight of the terminals. The MES uses a small, omnidirectional, low gain antenna, to support a 600 bps data channel. The smallest available MES weighs 4 kg. The terminals cost $5,000- $8,000.
4. Aeronautical System (1991): Designed to provide a digital voice and data service between jet aircraft and Land Earth Stations (LES). It provides voice and data services up to 9.6 kbps using high gain, steerable antennas on the aircraft. The use of a small, omnidirectional antenna supports a low bit rate (600 bps) data service.
5. Inmarsat M (Global beam, 1992; Spot beam, 1995): Provides low cost digital voice, fax, and data services for maritime and land mobile applications. A 6.4 kbps digital codec is used for voice transmission, and data is only supported up to 2400 bps. Terminal cost ranges between $10,000 and $15,000. For transportable applications, "briefcase" terminals weighing around 10 kg were introduced, offering far greater mobility than the current Inmarsat A "suitcase" units.

Another Inmarsat phase, Inmarsat P, evolved to become a separate program, dubbed ICO Global Communications, analyzed elsewhere in this document.

7.5.1.1.3.5.3 VSAT

VSAT networks are networks of satellite earth terminals with antenna diameters in the region of 1 meter, and therefore said to have very small aperture (VSA Terminals). Such earth stations make inefficient use of the satellite power and bandwidth, but are attractive because they are relatively cheap. VSAT networks are usually arranged in a star configuration in which each terminal communicates via satellite with a large central earth station known as a hub station. In some cases, the terminal instead of being fixed at the user premises, can be mobile (then it would be called MSAT). Not to create any confusion with the system of the same name, the term VSAT will be used here.

Apart from providing telex-type low-rate data services, the VSAT systems are now planned to support voice calls as well as higher-rate data communications. A typical VSAT system is today expected to be able to provide at least three types of services to its users:

1. Continuous Voice Service
2. Continuous Data Service
3. Packet Data Service

The continuous services for voice and data are similar in that both are circuit-switched services. The difference between voice and data "calls" is that a mobile terminal participating in a voice call will use a voice activity switch to provide TASI (Time Assigned Speech Interpolation). The voice activity switch turns off the transmitted signal from the earth terminal during idle periods of voice, thus reducing the power required by the satellite repeater (only active voice sources will be broadcast).

The packet data service is expected to carry low-rate, low-volume data for applications like messaging, paging, or telex-type services.

Systems required to carry both data and voice often have somewhat conflicting requirements. Data can be sent with random and possibly large delays, but must be sent error-free. Systems carrying data must have built-in automatic repeat request (ARQ) techniques for the recovery through retransmission of packets in error. In addition, buffering and sequencing may also be required to ensure that a receiver can properly reconstruct the transmitted data stream. On the other hand, because of its inherent redundancy, voice traffic can tolerate some errors without a significant loss in quality, but delay requirements are more stringent.

In order to be economically viable, satellite communication systems should make efficient use of the satellite's limited resources of bandwidth and power. This is especially important in VSAT systems where a large number of essentially uncoordinated and statistically bursty users are expected to share these resources in an efficient manner. The appropriate Multiple Access technique has to be selected.

Numerous multiple access algorithms are discussed in the literature. They can be divided into three basic types:

1. Fixed Assignment
2. Random Access
3. Controlled Access

Fixed assignment schemes, such as those using FDMA, TDMA, or CDMA, permanently assign a "channel" to each (active) user. Such schemes are best suited to links carrying large quantities of steady traffic. For a VSAT system with a large population of bursty traffic sources, such a permanent assignment would be extremely inefficient.

Random Access techniques like pure or slotted ALOHA, would be better suited for the bursty traffic, despite the fact that they have to be operated at low efficiencies in order to avoid problems of instability.

For a system where the information generated by an active user tends to be long (voice calls and long data transfers), Controlled Access may be a better alternative. In such schemes, a fraction of the system's resources (bandwidth or time) is set aside to carry requests for resource assignment. For voice traffic, a demand assignment multiple access (DAMA) scheme is often preferred in which a circuit-switched channel is assigned to the user only for the period of the call for which it is needed.

From the above, and given the mix of traffic expected over such systems, a combination of the Random Access and Controlled access is warranted. DAMA schemes with Random Access are preferred. In these, short messages are transmitted directly on randomly chosen slots reserved for that purpose, instead of going through the reservation process. Using these advanced multiple access techniques, the VSAT system ends up performing efficiently and to everyone's satisfaction.

Figure 7.5-20 below presents the overall architecture of a typical VSAT satellite network. Apart from the mobile or fixed terminal, such systems rely upon one or more Network Management Stations (NMS), and other Base Stations or Gateway Stations. The NMS is responsible for the management of the overall system and provides appropriate control and signaling information to the other stations in the network. The Gateways are intended to be the primary interfaces to the PSTN. Direct communication between mobile/fixed terminals is not supported (in fact it is physically impossible due to the L/Ku-band mode of operation). If required, such communication will have to be carried out through an appropriate base station.

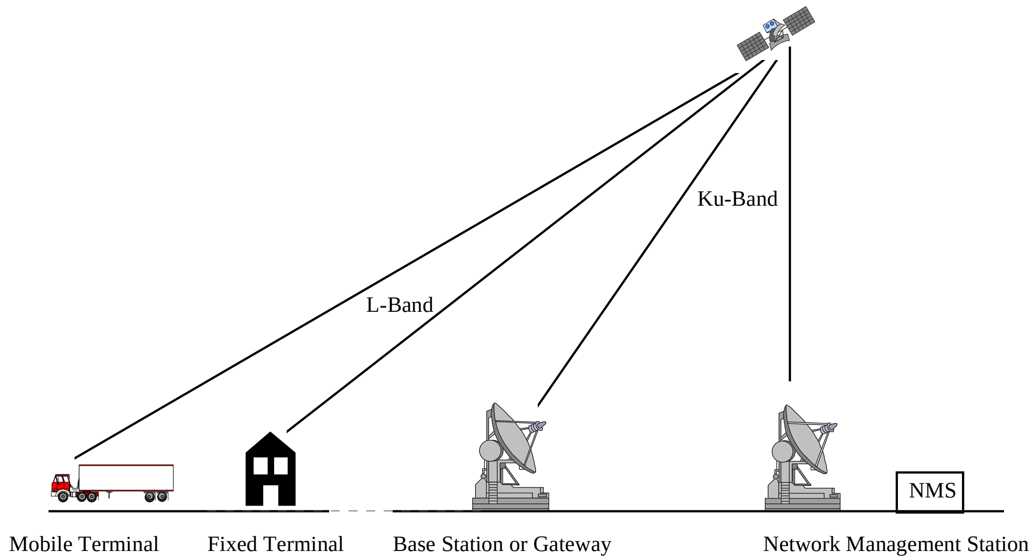


Figure 7.5-20 VSAT Network Configuration

7.5.1.1.3.5.4 Positioning Satellites

Many of the ITS applications depend on, or can profit from, accurate knowledge of the user's whereabouts. Ignoring for the moment privacy concerns, it is important to discuss here available position determination systems. Briefly, the most commonly used satellite-based systems are discussed, GPS and Russia's GLONASS, as well as Differential GPS (DGPS), a hybrid satellite-terrestrial service the Coast Guard is developing for public use in coastal areas and in the Great Lakes.

Please note that there are quite a few terrestrial-based positioning systems. A few companies are already building equipment to provide DGPS using various correction signals. Most of these developments, however, are still cloaked in mystery, given that the techniques are proprietary, with patents pending, and most of the time still at the prototype stage. Thus, these proposals will not therefore be discussed, only their underlying principles.

7.5.1.1.3.5.4.1 Satellite Navigation

The idea behind satellite navigation is both simple and ancient. The satellites, under control of precise and stable frequency references, transmit timing signals and data on their positions to the earth. A receiver measures the transit time of the signal, and deciphers the data. If the receiver clock were synchronized with the satellite clocks, measurements for range to three different satellites at known locations would allow a user to compute a 3-D position. The process is called *multilateration*. Since the receiver clock is not synchronized with that of the satellites, the transit time measurement has a common, unknown bias reflecting this difference. The biased range measurements are called *pseudoranges*. The measurement of transit time from a fourth satellite is then needed to solve the problem. Given four measurements, four unknowns can be solved, (x, y, z), and the receiver clock bias.

Having four satellites in view is only a necessary condition to compute a 3-D position estimate. The quality of that estimate depends upon two factors: 1) the spatial distribution of the satellites in view relative to the user, and 2) the quality of the pseudorange measurements. The first factor is referred to as *satellite geometry* and is characterized by a parameter called *dilution of precision* (DOP). Basically, the more spread out the satellites, the lower the DOP, and the better the position estimate. The quality of the pseudorange measurements is characterized by their rms error. Several sources of error affect the range measurements: errors in the predicted ephemeris of the satellites, instabilities in the satellite and receiver clocks, un-modeled ionospheric and tropospheric propagation delays, multipath, and receiver noise. The collective effect of these errors is referred to as *user range error* (URE). The rms of the position error is expressed simply as $\sigma_{\text{Position Error}} = \text{DOP} * \sigma_{\text{URE}}$.

For a satellite navigation system to be usable globally, all users must have in view at least four satellites with a good geometry, and the receiver URE must be such that the resulting position estimate meets the user's requirements.

7.5.1.1.3.5.4.2   GPS

The planning of GPS began in the early seventies, and the first satellite was launched in 1978. The system is owned and operated by the DOD, but offers partial capabilities to the public.

GPS is a MEO system, at 26,560 km, consisting of 21 satellites, with 3 operational spares in 6 orbital planes (see Figure 7.5-21), and is fully operational. The system transmits at two frequencies in the L-band (L1, 1575.42 MHz; L2, 1227.6 MHz) using CDMA. Only the coarse acquisition (CA) code transmitted on L1 is available for civil use. In accordance with the current policy of the U.S. DoD, the signal available from GPS is actually a purposefully degraded version of the CA code. The signal degradation is achieved by dithering the satellite clock frequency, and by providing only a coarse description of the satellite ephemeris. This policy, known as *selective availability*, effectively raises the value of the URE by a factor of four or more (σ_{URE} is in the range 25 to 40 m when measured with selective availability, versus approximately 7 m without), and remains a source of controversy among the civil users. The Claimed Precision for civilian use at present is 100m Horizontal, 140m Vertical.

The U.S. has pledged to maintain the GPS Standard Positioning Service, when operational, for a period of ten years without any direct user fees. It has also been announced recently that selective availability (SA) will be discarded to permit higher accuracy civilian use at some time between the years 2000 and 2005.

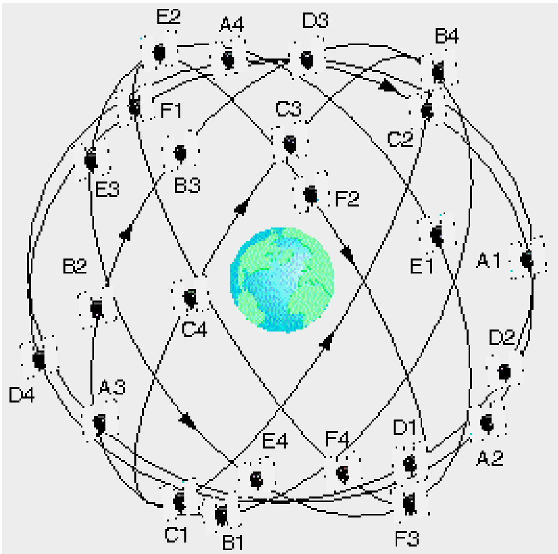


Figure 7.5-21 GPS Constellation

7.5.1.1.3.5.4.3 GLONASS

Russia's GLONASS consists of a series of 24 MEO satellites in 3 orbital planes (see Figure 7.5-22) at 25,510 km providing navigational and accurate global positioning services (claimed precision: Horizontal = 100m; Vertical = 150m). The first GLONASS was launched in December 1980. The constellation remains sparsely populated (twelve active satellites on average for the past few years), and political and economic difficulties in Russia continue to be a source of uncertainty about its future.

GLONASS uses FDMA in the 1602 - 1615.5 MHz band. The service interferes with the radio astronomy band (1610.6-1613.8 MHz), and with the recently allocated mobile satellite service at 1610-1626.5 MHz. An L1 and L2 organization, with CA code for civilian use was adopted - similar to GPS. Although GLONASS officially disavowed a selective availability-like feature (σ_{URE} = 10 m), its positioning specifications are almost identical to those of GPS.

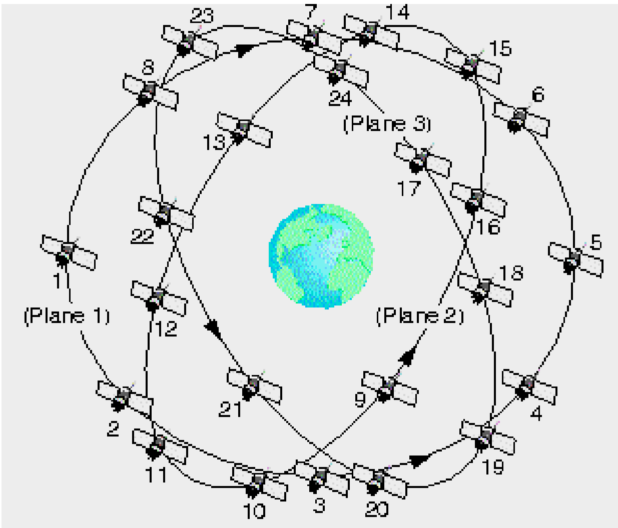


Figure 7.5-22 GLONASS Constellation

7.5.1.1.3.5.4.4 Differential GPS

Differential GPS (DGPS) is the regular GPS with an additional correction (differential) signal added. This correction improves the accuracy of the GPS and can be broadcast over any authorized communication channel. DGPS receivers collect navigational information signals from all satellites in view, plus differential corrections from a DGPS station in the area. (Many DGPS receivers consist of two units: a GPS receiver, with a data port for DGPS corrections directly connected to a radio receiver.)

The Coast Guard is developing a DGPS service for public use in harbor and harbor approach areas, as well as in the Great Lakes, most of Alaska, Hawaii, and Puerto Rico. DGPS uses pseudorange corrections broadcast over the existing network of marine radio beacons. The Coast Guard plans to complete the system and declare it operational in 1996.

7.5.1.1.3.6 Assessment for ITS

Summarizing now the technology assessment of satellite systems, it can be safely stated that the proposed and already deployed systems guarantee a wealth of choices for the provision of those ITS services that can not be provided by cheaper, more effective means, like two-way cellular. The user must moderate any optimistic expectations about service availability, given the huge investments required by most of the proposed systems in the face of market uncertainties, as well as their complexity and deployment risk.

7.5.1.1.4 Meteor Burst Communications

The meteor burst (or meteor scatter) channel, known as the "poor man's satellite channel", relies on the ionized trails of meteors as reflectors to achieve long range packet data communications. It was found that useful ionized meteor trails occur at an altitude of about 80-120 km above the earth's surface. Trails with useful electron densities for reflecting radio signals in the range of 40 to 50 MHz were found to be plentiful enough to provide communications over a range of roughly 2000 km. The minimum range limitation was found to be 400 km, as determined by the scattering geometry and electron density. The intermittent nature of the channel has to do with the random distribution of the meteors of interest which shows a strong diurnal variation (peaking at 6:00 local time, and with a distinct minimum at 18:00), and follows the Poisson law. Ionized trails were found to have a lifetime of only a few tenths of a second, creating the need for rapid exchange of information (thus the term "burst communications"). Due to the unique characteristics of the propagation mechanism (see Figures 7.5-23 and 7.5-24), Meteor Burst Communications relies on an inherent spatial multiplexing to reduce the contention in a network with potentially more than ten thousand units.

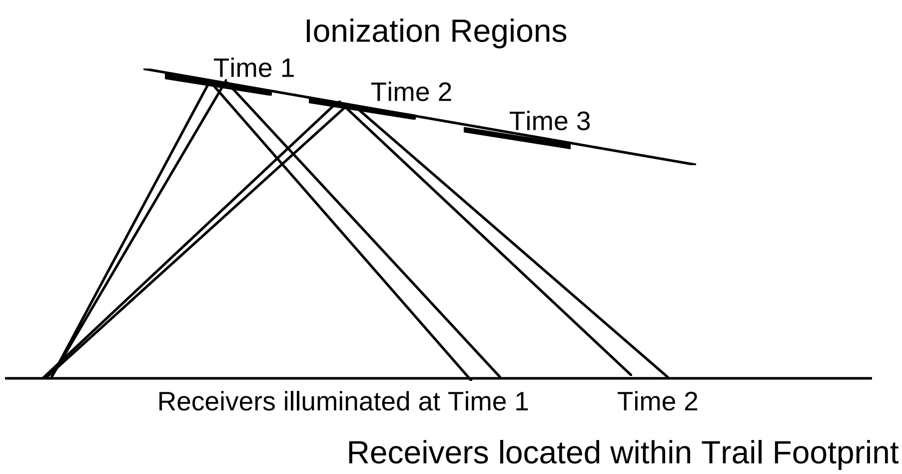


Figure 7.5-23 Motion of Ground Illumination Region due to Trail Formation and Decay

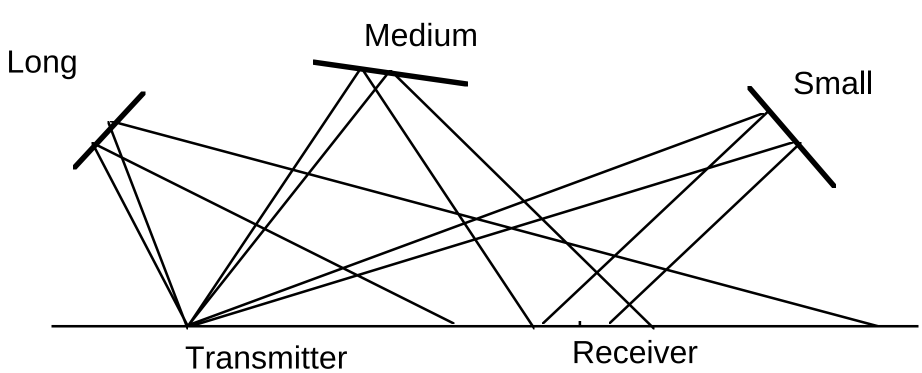


Figure 7.5-24 Effect of Trail Location on Size of Footprint

A system with the characteristics described above seems appropriate for communicating with remote, usually rural, sparsely populated areas, when there is no need for immediate, urgent communications. The coverage of conventional UHF cellular systems is too small for cost effective seamless coverage in very rural areas, especially away from major interstate highways. On the other hand, satellite service is very expensive to install and operate. Meteor Burst technology costs approximately 1/5 that of satellite systems, and the long term life cycle costs savings can not be underestimated (meteors are in essence free natural satellites, always available). Furthermore, since Meteor Burst operates in the low VHF band, the cost of the vehicle radio equipment is approximately half that of corresponding satellite equipment.

Examples of ITS services that a Meteor Burst system could potentially support are wide area Automatic Vehicle Location (AVL), and remote (long haul) Fleet Management. Surveys of potential users indicate that when out on the open road, position information every 10 to 15 minutes with short message capabilities is adequate for significant productivity enhancement. A Meteor Burst tracking system can fill the gap in the conventional cellular system where in remote areas the density of vehicles (and fixed users) cannot justify the base station infrastructure.

A Meteor Burst system could provide seamless coverage of the continental U.S. with as few as 100 base stations. However, noise levels in urban areas are too high for Meteor Burst usage. There, cellular coverage would have to be considered, pointing to the possibility of dual MB-cellular systems.

Several Meteor Burst systems have already been installed and proven effective:

- In the 1950’s, Canada installed the JANET system between Toronto and Port Arthur for simple point to point teletype communications.
- Also in the 1950’s, SRI, under contract from the U.S. Air Force, operated a test link from Palo Alto, CA to Bozeman, Montana, primarily for propagation research.
- The 60’s saw the first operational military MB communication system deployed in Europe, called COMET, operated by the NATO SHAPE technical center, providing communication from The Hague, Netherlands, to southern France, again to transmit conventional teletype messages.
- In the late 70’s, the Alaska SNOTEL (for SNOwpack TELemetry) system was installed to provide meteorological information from remote locations throughout Alaska.
- The Alaska National Guard recently installed a MB system that ties headquarters to remote locations throughout the state.
- A MB system has been installed between Sondstrom AB and Thole AB, Greenland.
- MB was selected for the Small Mobile ICBM (SICBM) program to provide primary communication under almost all conditions between mobile launch control centers and up to 1000 mobile launchers randomly dispersed over a wide area.
- Currently NORAD is testing a C^3 MB network that will connect the continental US, Alaska, and Canada.

As for commercial systems, a few experiments have been successful, namely one in the Portland, OR area where a long haul Fleet Management system has been deployed, taking advantage of the MB beyond line of sight communication capabilities.

As a conclusion, MB, although requiring a dedicated system, seems to be a cheap but still effective alternative to expensive satellite systems. In any circumstance, it cannot provide overall seamless coverage, thus requiring terrestrial cell-based coverage in urban and suburban areas in a dual MB-cellular system configuration.

7.5.1.1.5 Broadcast Systems

In the area of ITS broadcasting there are presently as many as three different high data rate FM subcarrier systems in contention for national acceptance, while RBDS is already standardized (and available) for lower data rates.

Although we will focus primarily on FM subcarrier systems, other broadcast techniques will also be considered to determine their applicability to the ITS services. These technologies vary considerably from the simple, such as HAR, to the more advanced like DAB and transmission within the TV vertical blanking period, or to using a whole SAP sub-channel. We will address also the most promising of these other technologies.

The level of detail of the analysis will be determined by the anticipated ITS role. As applicable, the capacity of the above systems will be determined, as well as the information update rates allowed.

7.5.1.1.5.1 Operational Environment

The typical environments that broadcast systems will operate in include rural, urban, suburban and inter-urban areas. The received signal will experience propagation effects such as blockage and multipath, and the success of a broadcast system will depend on its effectiveness in defeating those effects.

The propagation anomalies are primarily dependent on the operational environment, such as the type of the natural and man made structures, e.g., hills and buildings. Furthermore, the climate, the vegetation, as well as the materials of the obstacles will also affect the propagation environment. The other variable that changes the propagation environment is the driving conditions. For example, when driving in the city there will be frequent blockage periods due to buildings, hence system performance will be a function of the driving speeds, and would be quite different for speeds that range from 0 to 70 mph.

Broadcast propagation environment, and the ability of the broadcast systems to mitigate its effects will be a key parameter in identifying the appropriate ITS services that can be supported using a particular communication technology. For example, there will be broadcast systems that will transmit messages at regular intervals, such as bus schedules and weather forecasts, and others that will transmit only at specific times (e.g. hourly news). Therefore, the loss of information due to blockage and multipath will be of a lesser significance for some services and of a greater significance for others.

By definition, broadcast systems are not suited for two-way communication. One can only envision their use in very specific applications of ITS (e.g., transmitting traffic status information both on the freeway system and on surface streets - a value added service that may be of interest to some broadcasters). This would require, however, coordination with (or by) the control centers, and the definition of strict receiver standards to minimize the cost associated with the display of information.

Moreover, as already stated, the most critical performance limitation of Subcarrier Authorization (SCA) arises from multipath, or fading in general. Unfortunately, in the ITS environment multipath is unavoidable if one wishes to employ simple, cheap antennas (e.g., whip or monopole antennas). Under mobile conditions, it is not possible, without incurring unacceptable receiver costs, to try to compensate for, or nullify, the multipath effects. Thus, the broadcast system must either be designed such that it accounts for the degradation caused by the multipath, or by explicitly taking into account that sometimes the receiver will not be able to properly receive the information.

A possible operational solution would be to continuously repeat the traffic status information, updating it on the run. If a vehicle is unable to receive traffic information for a while due to specific propagation conditions, it would rely on the last successfully received status report, which would be updated as soon as reliable reception resumes.

Another possible (possibly simultaneous) solution would be to provide alternative sources of information (other radio stations) providing the same traffic information, conveniently offset in time. This would necessitate a more complex (costly) receiver that would automatically switch from a “bad” to a “good” station.

7.5.1.1.5.2 Evaluation Approach

The goal of this technical evaluation is to analyze the capabilities of the existing and projected broadcast technologies in the context of the National ITS architecture. The analysis will utilize the requirements of the ITS services and communication links that are suited for one-way wireless dissemination, and their critical attributes, such as message sizes, information rates, frequency of use,, etc. The results of the ITS broadcast data loading analysis of Section 5.2 will be applied in the evaluation.

The analysis will address the following issues and parameters:

1. Data rate for high and low data rate broadcast systems. Includes overhead for error correction and multipath mitigation (coding, interleaving, repeat broadcasting, etc.).
2. Message delivery delay.
3. Modulation techniques.
4. Coding and interleaving techniques for defeating channel errors.
5. Approach for mitigating mobile channel effects (e.g., multipath) These techniques include: (1) complex coding and interleaving, (2) combined modulation and coding, and (3) simple coding and interleaving with a repeated transmission algorithm.
6. The capacity of the broadcast system as a function of the message sizes and update frequency. The capacity and update frequency are inversely proportional, for a fixed information rate (i.e., as the requirement for the update frequency increases the effective capacity of the broadcast system decreases).
7. The data processing in the mobile units. It is an important consideration when evaluating the services that can be supported using broadcast techniques. This capability will allow broadcasting only the minimum amount of data (e.g., broadcasting compressed traffic information, instead of detailed information).
8. System coverage will be a function of the broadcast tower locations, and will also depend on the deployment strategy. The systems can use one or multiple frequencies for broadcasting. There are two options when using multiple stations (frequencies): (1) The stations can broadcast the same information with staggered repeat, which reduces message delivery delay at the cost of lost capacity; or (2) the stations can broadcast different information, therefore maximizing capacity.
9. System reliability. The effective broadcast data rate is reduced due to the reliability factor, as a result of system failures and propagation effects (e.g., blockage, multipath, etc.). A reliability factor of K% (e.g., 90% effective throughput) will be included in the analysis.
10. Addressing capabilities; the capability of addressing specific customers.
11. Interface issues: open versus proprietary interfaces.
12. Deployment cost.

In what follows the above issues will be addressed in some detail. Furthermore, the proposed and operating systems will be described and their specifications will be summarized. The analysis will include field test results, when applicable. The field test results address issues related to deployment strategies, implementation, cost, candidate services, available hardware and terminals, and service provision.

7.5.1.1.5.3 FM Subcarrier

In Europe, the spectrum allocation for FM stations is 150 kHz, while in North America it is 200 kHz. The international CCIR standard allows a subcarrier frequency of 53 to 75 kHz, while the North American standard allows for 53 to 99 kHz.

In recent years the FCC allowed for the opening of the FM baseband to 99 kHz, and relaxed the technical usage rules. This stirred up great interest in new services via SCA, e.g., teleprinter newscasting, computer data transmission, and paging. SCA allows for the use of the spectrum not occupied by the FM-stereo channel, provided certain conditions of non-interference with the audio channel are met. Deregulation has removed all restrictions on allowable modulations.

Figure 7.5-25 illustrates the FM baseband and subcarrier spectrum. Each FM station is allocated a 200 kHz bandwidth for transmitting the FM signal. In Figure 7.5-25, the baseband bandwidth between 53 and 100 kHz is not used for transmitting a stereo music signal, and can be used for broadcasting auxiliary programs and data. FM stations have the authority under their license to broadcast auxiliary programs and data without further permission from the FCC.

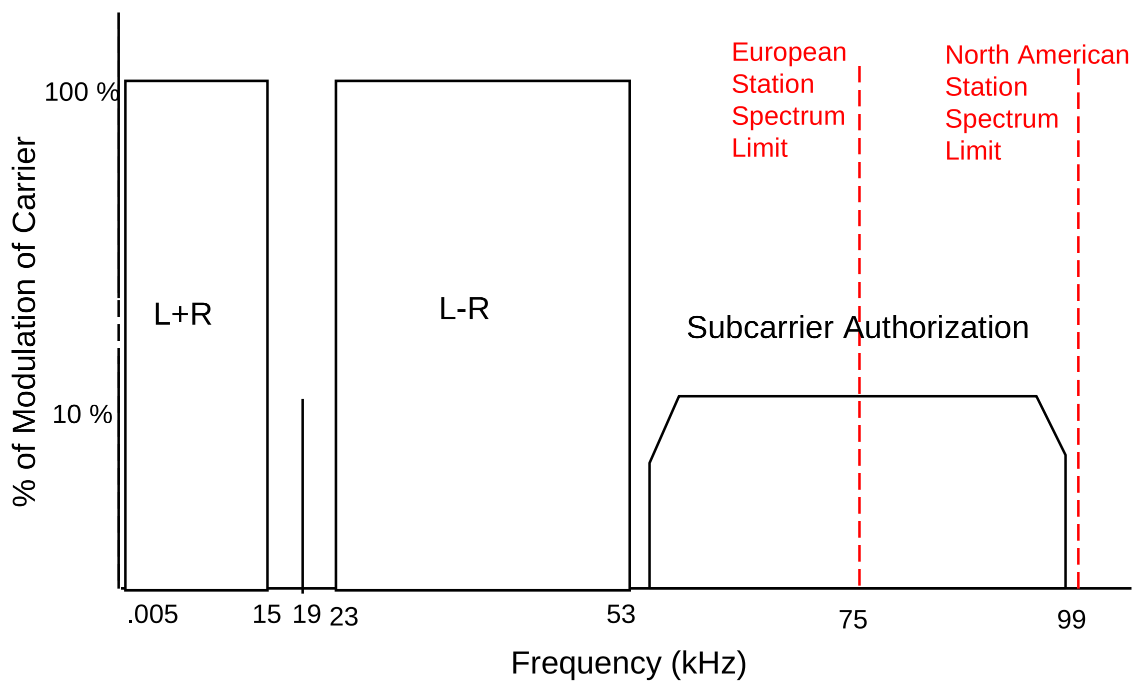


Figure 7.5-25 FM Spectrum Allocation in North America and Europe

The U.S. has adopted the international standard for transmitting low data rate using the FM subcarrier at the baseband frequency of 57 kHz (this is at three times the FM pilot of 19 kHz). This system is referred to as the Radio Broadcast Data System (RBDS). As a result, in order to insure co-existence of RBDS with high speed FM subcarrier systems, they are restricted to using the spectrum above 60 kHz (see Figure 7.5-26).

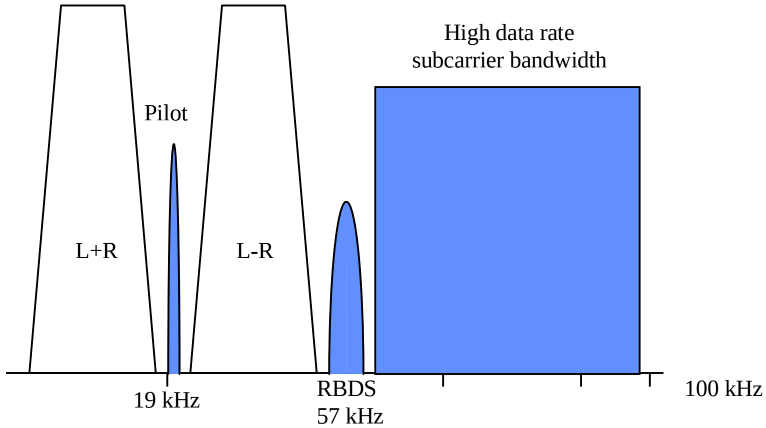


Figure 7.5-26 FM Baseband Spectrum (Not to scale)

The two most important problems inherent to FM subcarrier operation are *crosstalk* and the "birdies" effect. *Crosstalk* is the effect on the FM subcarrier channel of interference from the FM stereo channel, and it almost entirely determines the noise performance of the FM subcarrier. It is obviously determinant when operating a data FM subcarrier channel. The so called "birdies" which appear in the main FM stereo channel are interference caused by the FM subcarrier channel(s). They consist of high frequency audio whistles, typically 5–10 kHz, that are frequency modulated by the FM subcarrier material. This problem is solved in practice by the use of a PLL FM receiver for the case of a standard FM subcarrier channel side by side with the main FM stereo channel.

Any proposed system must prove non-interference with the main FM stereo channel, as well as other FM subcarrier channels.

7.5.1.1.5.3.1 Proposed and Existing FM Subcarrier Systems

There are a number of broadcast systems that are operational or have been proposed. The main difference between these systems is in their modulation techniques and the approach for mitigating the multipath and other mobile propagation problems, such as multipath and blockage. These systems use two distinct techniques for combating the propagation impairments. In the first approach, complex coding and modulation formats are used, as in MITRE's STIC and NHK's DARC system. The second approach uses time and frequency diversity, for example multiple FM stations are used for frequently (e.g. twice every few minutes) broadcasting the same message. In the second approach the terminal captures the signal from the strongest broadcast station; SEIKO's HSDS uses this scheme. These high data rate systems are described in greater detail in the subsections to follow.

We begin with RBDS, the U.S. version of the European RDS standard. R(B)DS provides low data rate service and is used, especially in Europe, to transmit traffic information without affecting the FM stereo signal.

7.5.1.1.5.3.1.1 RBDS and RDS-TMC

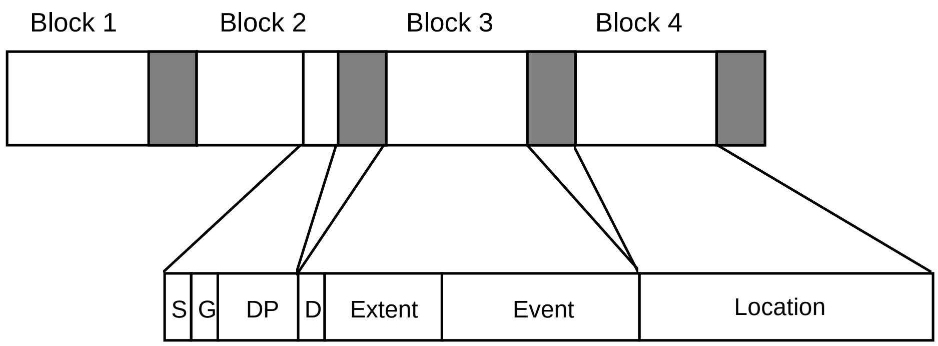
The Radio Data System (RDS) is an FM subcarrier standard first available in Europe and now gaining acceptance in the US under the acronym RBDS. RBDS uses bi-phase shift keying (BPSK) modulation format for transmitting at a data rate of 1187.2 bps, occupying the bandwidth from 53.5 to 59.4 kHz. The effective information rate for RBDS is about 300 bps, considering the overhead of coding and interleaving.

Broadcast traffic messages already provide a valuable information service to motorists throughout Europe. RDS enables traffic messages to be carried digitally and silently by a Traffic Message Channel (TMC), without necessarily interrupting/affecting the audio program.

The ALERT (Advice and Problem Location for European Road Traffic) C message coding protocol was a major product of DRIVE, the European R&D Road Transport Informatics (RTI, European version of ITS) program, and defines the standard for RDS-TMC throughout Europe. TMC messages are language-independent, and can be presented in the language of the user's choice. ALERT adopts a standard European list of traffic events (including weather) descriptions.

The ALERT protocol covers event-oriented driver information messages. Provision has been made for the subsequent definition of other applications, such as status-oriented route guidance and public transport information, as well as for alternative communications media such as AM broadcast data systems, GSM, and digital audio broadcast (DAB).

RDS-TMC information is conveyed in Type 8A RDS data groups (see Figure 7.5-27). Each standard message, as well as all system messages comprise only one group. (One Type 8A RDS data group carries 35 bits of information. Each block carries 16 bits of information, plus a check word and offset information.) Optional information can be added to standard messages up to a maximum length of five RDS data groups. Short messages have also been allowed using a half-group message sequence (in general, two distinct short messages, or the same repeated, are transmitted in one RDS data group). Standard RDS-TMC messages provide the following five basic items of explicit broadcast information: event description, location, extent, duration, and diversion advice.



S - Short Message Identifier
G - Single Group Standard Message Identifier
DP - Duration and Persistence
D - Diversion

Figure 7.5-27 Single Group Standard RDS Message

ALERT C uses location coding strategies which adopt hierarchical principles of structuring the location database in accordance with the European Broadcast Union (EBU) Broadcast for Motorists functional recommendations – the international, national, regional, and local levels are considered.

RDS-TMC messages are transmitted in a cycle whose duration is dynamically adjustable in steps of one minute from 1 to 15 minutes, or in a continuously varying "cycle" length manner. A new cycle information message must be broadcast whenever the cycle parameters change. Messages may be inserted several times into each cycle. This serves to reduce "acquisition" time, and improve the reception reliability of urgent messages.

Message priority was another issue where the EBU Guidelines on Broadcasts for Motorists have been followed, distinguishing mainly between strategic and tactical information. By definition, strategic information is of value for trip planning and route selection in the medium term, and tactical information is likely to be of relevance for immediate local diversions around current traffic problems. The following range of broadcast message priorities are considered:

- Highest Priority -- for immediate broadcast, interrupting ongoing RDS-TMC message cycles, and being repeated frequently;
- Tactical Information -- for non-delayed broadcast through early insertion into RDS-TMC message cycles, with frequent repeats;
- Strategic Information -- broadcast at fixed intervals according to RDS-TMC channel capacity; and
- Background Information -- broadcast less frequently, when channel capacity permits.

From the above, necessarily brief description of the RDS-TMC system, we see that it is a very versatile, well thought of broadcasting protocol, whose limitations are its inherent one-way characteristics, and the low data rate of 1187.5 bps.

7.5.1.1.5.3.1.2 Modulation Sciences' SCA

In this section, we analyze the system proposed by Modulation Sciences, Inc.[10], one of the companies involved in FM subcarrier. **Error! Reference source not found.** shows the proposed use of spectrum. The basic SCA channel audio response is 50 Hz to 5 kHz, with 0-20 Hz sometimes available for low speed telemetry applications. Restricting the maximum modulation frequency to 5 kHz guarantees a bandwidth of 20 kHz for the SCA channel (in fact, the SCA channel bandwidth is only 14 kHz since the outer 3 kHz fall bellow the -25 dB threshold established by the FCC — that is why the upper SCA channel could be centered about 92 kHz). The lower SCA channel is compatible with the European standards, while the upper SCA channel can only be used in North America. (The two-SCA channel structure shown does not necessarily imply that one could not use the whole 53-99 kHz band to transmit data.)

The established use of SCA has been in stationary applications. The problems identified in this section limit SCA performance even in the stationary environment. Under mobile conditions, where the propagation conditions are significantly more severe, more problems and limitations will certainly develop.

[10]Eric Small, "Data SCA: Some Real World Experiences"; Eric Small, "Making SCA work in the Real World", Modulation Sciences, Inc.

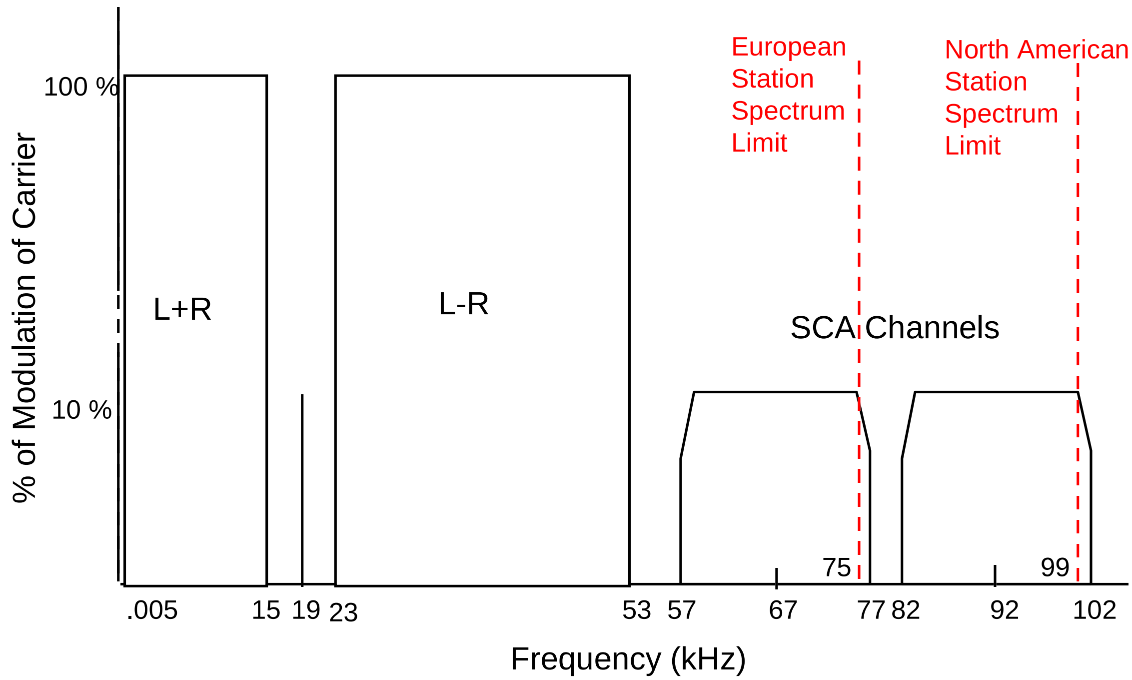


Figure 7.5-28 SCA FM Spectrum

7.5.1.1.5.3.1.2.1 Data SCA

Two types of data modulation have been considered for data SCA transmission, namely Direct and Indirect Data Modulation. In Indirect Data Modulation, also known as Compatible Modulation, the signal that goes into the SCA generator is a sequence of audio tones (AFSK). The advantage of this type of modulation is that standard (i.e., no-data) SCA generators can be used unmodified; thus cheap and easy to use generators are available. Disadvantages are the slow data rates that can be accommodated (less than 1200 bps), and the relatively expensive demodulator required to turn the audio back into data.

By switching the phase of an audio tone instead of its frequency, higher data rates can be achieved, but the cost of the receiver demodulator rises very rapidly with data rate, and, conversely, the tolerance of the system to interference (crosstalk) drops quickly. The advantage of this technique is that it employs the same technology used to send data via the telephone network; thus hardware is generally available, and is well understood. Usually data rates are bellow 9.6 kbps.

Direct Data Modulation takes advantage of something available to the FM subcarrier user, namely the subcarrier itself. The SCA subcarrier (at 67 or 92 kHz) is available for direct manipulation by the broadcaster. Instead of varying the frequency of an audio tone that in turn modulates the SCA subcarrier, the carrier itself is modulated. Higher data rates can be achieved with less bandwidth, and the receiver demodulators are cheap too.

Direct Data Modulation uses either MFSK, varying the frequency of the carrier itself, or MPSK, varying the carrier's phase. MPSK, however, requires a phase reference. Luckily, in FM stereo, an ideal external phase reference already exists: the 19 kHz pilot. A data rate of up to 46 kbps can be achieved with MPSK, occupying the entire SCA portion of the FM channel, from 53 to 99 kHz, but requiring a relatively expensive receiver. As a comparison, Modulation Sciences' Data Sidekick system achieves 4800 bps at a measured BER of 10^{-7} for fixed links under "good" weather conditions.

In fact, the first and foremost problem of SCA, the one that limits the data rate, is multipath. Under fixed conditions, using appropriate antennas allows mitigation of the multipath to assure almost always a given BER. The biggest problem, even then, remains that of “equalizing” or “zeroing” late/undesirable reflections. (Especially in urban environments, the reflection coefficient in masonry varies widely, as much as 25 dB, depending upon its surface being wet or dry.)

7.5.1.1.5.3.1.3 SEIKO’s High Speed FM Subcarrier Data System (HSDS)

SEIKO® Telecommunication Systems, Inc. (STS) has developed a flexible High Speed FM subcarrier Data System, known as HSDS, with a capability for world wide operation. HSDS is a fully developed one-way system providing messaging and information services (e.g., personal messaging, traffic information, time of day, news, weather, sports, business, and emergency information). The system has been deployed by STS under the Receptor™ trade mark in a number of cities (Portland, OR in 1990; Seattle-Tacoma, WA in 1992; Los Angeles, San Francisco, CA in 1995; a few East Coast cities in 1996). Coverage maps for some of these areas are shown in Figures 7.5-29 and 7.5-30.

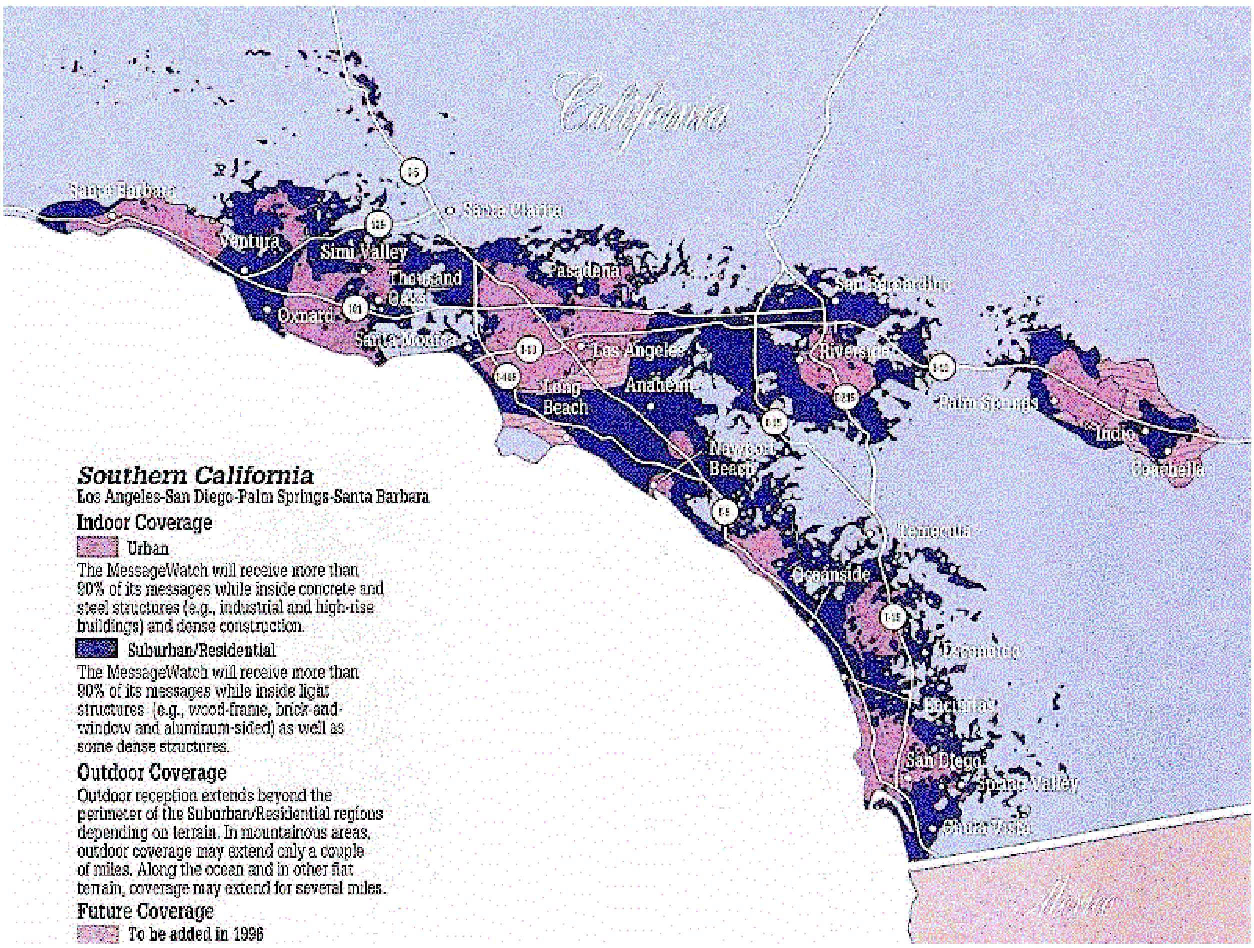


Figure 7.5-29 HSDS Coverage in the Southern California Area for Wrist-Watch Receiver (-29 dBi antenna)

The philosophy of the system design and operations is:

- The information is cyclically repeated at a rate of a few transmissions every 2-3 minutes. Therefore, if a user misses the information the first time due to blockage or error he/she will eventually receive it on the succeeding transmissions.
- The complexity of the handset is low. This has been achieved by using simple modulation and coding schemes, and using space, time and frequency diversity for mitigating multipath.

The HSDS utilizes existing FM radio broadcasting infrastructure, currently available IC's and transmission equipment, making it relatively inexpensive to deploy. By design it permits very small receivers: alphanumeric display wrist-watch receivers (SEIKO® Receptor™ MessageWatch™ which sells for $75-150), and pocket pagers. Receivers with duty cycles varying from 100% to less than 0.01% provide flexibility to select message delay, data throughput, and battery life.

The HSDS can operate as a stand alone single station system, or as multiple systems operating independently in a geographical area with each system including multiple stations. Multiple stations are accommodated by frequency agile receivers, time offset message transmission in each station, and transmitted lists of stations surrounding each station (three FM stations provide coverage for 1.2 million people in Portland, OR; seven FM stations provide a coverage area with 2.6 million people in Seattle-Tacoma, WA).

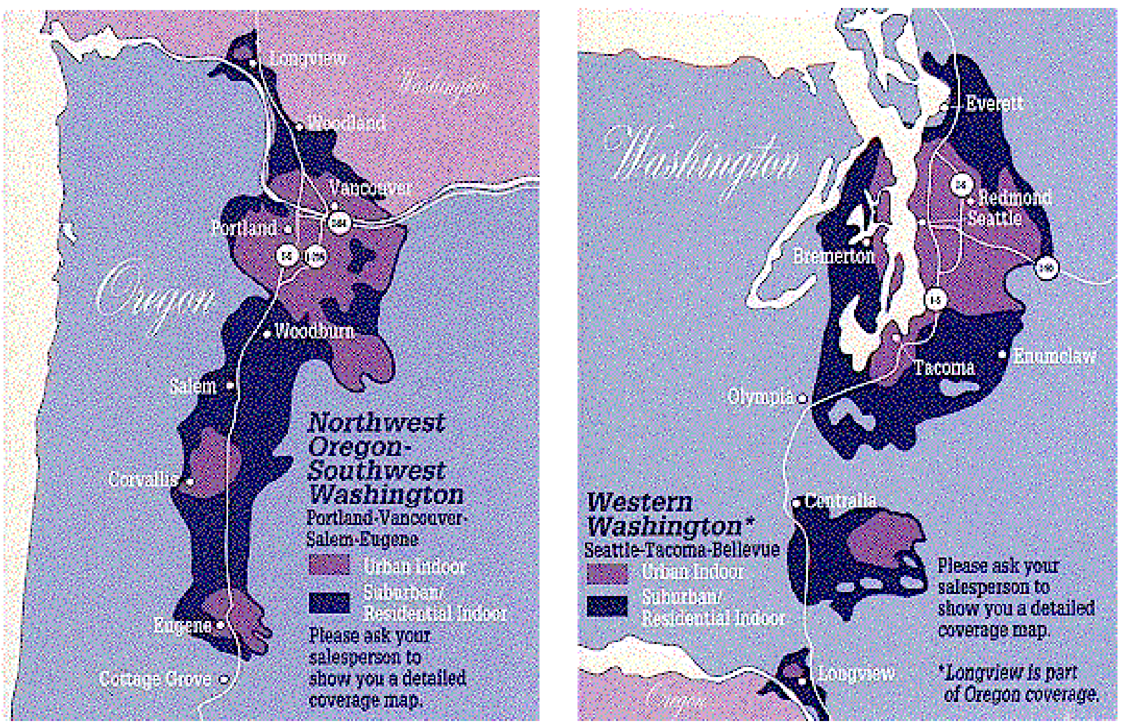


Figure 7.5-30 HSDS Coverage in the Portland, OR, and Seattle, WA, Areas for Wrist-Watch Receiver (-29 dBi antenna)

7.5.1.1.5.3.1.3.1 HSDS Technical Specifications

The HSDS system is time division multiplexed. Time is subdivided into a system of master frames, sub-frames and time slots. Each slot contains a packet of information. In multiple station systems, each station's transmissions are synchronized to UTC ensuring synchronization between stations. The synchronized and time offset stations provide an opportunity to change the tuned frequency and make subsequent attempts to receive packets on other available frequencies.

Each receiver is assigned a set of slots as times for monitoring transmissions. (Multiple receivers may share time slots, due to the random nature of expected communications.) Each slot is numbered and each packet contains the slot number to permit rapid location of assigned time slots.

The error correction scheme is flexible, the methods used varying with the application. The method used for wrist-watch reception is designed to correct a short burst of errors associated with random noise or automotive ignition noise. The standard CCITT 16 bit CRC is typically added as a component of each packet, and minimizes the chances of "missed" packets.

HSDS' modulation/encoding provides high data rate, narrow bandwidth with high spectral efficiency (1 bit/s/Hz), and negligible impact on the main audio channel, or on any existing RBDS subcarrier. The HSDS modulation is DSB SC AM with duobinary encoding[11]; the data rate is 19 kbps in a 19 kHz bandwidth centered at 66.5 (=3.5 x 19) kHz. The HSDS signal is modulated as a subcarrier ranging from 5% to 20% -- typically at 10% on commercial FM radio stations. Sharp transmission filter skirts cause extremely little impact on the main audio channel in no multipath conditions; generation of a randomized data stream reduces the impact of multipath. The narrow bandwidth of HSDS allows for compatibility with RDS operation world wide. Furthermore, from Figure 7.5-31, HSDS allows for use of subcarriers above 76 kHz in the US, and compatibility with European spectral allocation.

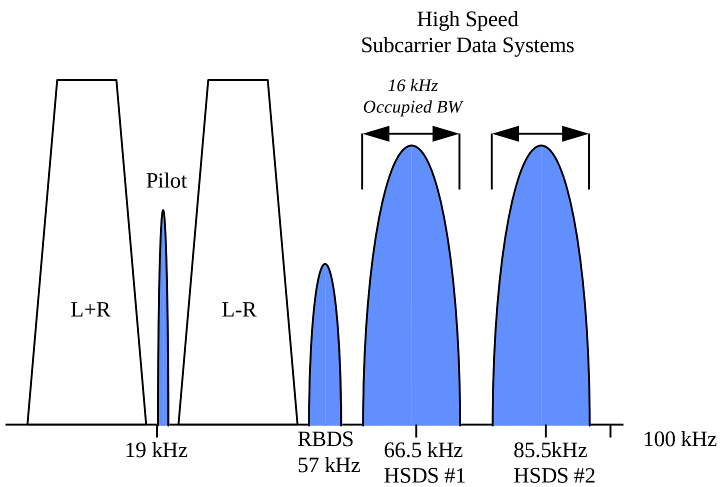


Figure 7.5-31 FM Baseband Spectrum usage for Seiko's HSDS System

The effective information rate for HSDS system is 7500 bps (considering coding and repeat transmission overhead). The HSDS system transmits 72 packets of data per second, where each packet of data contains 104 bits of information. To reduce the impact (interference) on the audio channel, HSDS uses sharp skirt filters in addition to randomizing the data using PN sequences. As a result the data looks like random noise. A typical packet of data is first Encoded, then Randomized, and finally Interleaved .

SEIKO's HSDS system multiplexes data streams of varying bandwidths. As the transmission begins, bandwidth is dynamically assigned and subscribing receivers are alerted to the service. This bandwidth is

[11] A. Lender, "The Duobinary Technique for High Speed Data Transmission", AIEE Trans. Commun. Electronics, 1963.

then freed at the conclusion of the data stream transmission. Multiple data streams may be carried concurrently with small packet-oriented transmissions (such as paging and messaging).

7.5.1.1.5.3.1.3.2 Multipath and Shadowing Mitigation Strategy

Robust wireless systems require methods to address multipath and shadowing. Some systems attempt to address these issues with extensive error correcting schemes. While these techniques are useful for the moving receiver, they become ineffective when the receiver is stopped in an extremely low signal strength area, or moving very slowly through multipath nulls. Diversity techniques are frequently used to combat fading effects.

HSDS addresses multipath and shadowing with a combination of frequency, space, and time diversity, and message numbering. Frequency diversity is achieved through frequency agile receivers (87.5-108 MHz). Space diversity (multiple station systems) provides paths from two or more directions reducing the size of shadowed areas, and the possibility of missed messages.

Time diversity can be provided in two ways: multiple transmissions on the same station, and delayed transmission between stations. Duplicated messages are rejected via comparison with the transmitted message number. Multiple transmissions of information several minutes apart are utilized for wrist mobile applications.

7.5.1.1.5.3.1.3.3 HSDS versus RDS-TMC

A comparison with RDS-TMC, in particular with the RDS-ALERT C protocol, is warranted. From Table 7.5-10, we see that there is indeed a big difference in data rate in favor of HSDS. On the other hand, the cycle length is fixed for HSDS, although as we have seen, messages can be repeated within a cycle. In any case, HSDS seems to be a promising alternative to RDS-TMC.

Table 7.5-10 Comparison of HSDS and RDS-TMC

	Center Frequency (kHz)	Bandwidth (kHz)	Raw Data Rate (bps)	Cycle Length
RDS-ALERT	57	4.8	1187.5	**Variable**
HSDS	66.5	19	19000	**Fixed**

Although HSDS requires a reasonably inexpensive infrastructure, and relatively inexpensive, small receivers, it is still a proprietary one-way system. Nevertheless, it appears to be a promising substitute for lower rate R(B)DS systems.

7.5.1.1.5.3.1.4 MITRE's Subcarrier Traffic Information Channel (STIC)

In early 1992 FHWA sponsored a research and development project for developing a high data rate subcarrier technology. MITRE/FHWA developed a high data rate subcarrier data system, and implemented a proof-of-concept prototype. The system is called Subcarrier Traffic Information system (STIC). STIC uses a complex data, and modulation format for defeating the multipath and other propagation effects. The prototype of the STIC receiver was tested in the Fayetteville, NC. The results of this trial were not available at the time of this writing.

7.5.1.1.5.3.1.4.1 Technical Specifications

Figure 7.5-32 illustrates STIC's baseband spectrum.

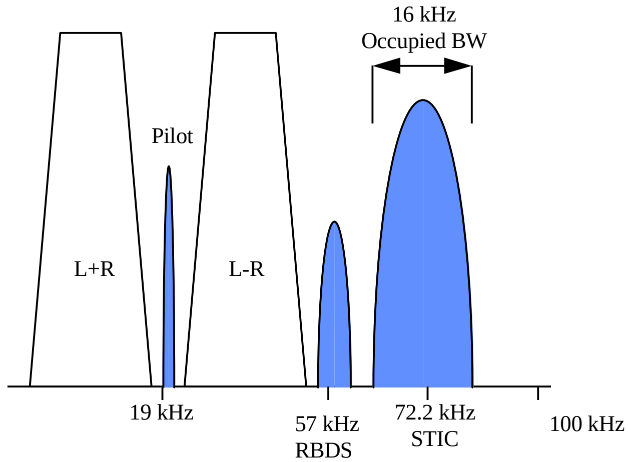


Figure 7.5-32 FM Baseband Spectrum Usage for MITRE's STIC System

The STIC data format first uses convolutional encoding, and interleaving. The interleaved data blocks are further processed by appending to each block 4 channel state estimation bits. This data is then BCH encoded and followed by the $\pi/4$ DQPSK modulator. The modulated signal is further filtered using the square root raised cosine filer with a roll-off factor of 0.68.

The parameters of the interleaver and coding are designed based on the propagation data in the FM band (100 MHz). The achievable information rate is 8 kbps, this is for a typical BER of 10^{-5} . The raw symbol rate for STIC is 18.8 kbps.

The propagation parameters are a key element in selecting the parameters of the STIC waveform, such as the interleaver size, number of channel state bits, and encoding techniques. The typical values that have been considered for the evaluation phase are:

- Delay = 3×10^{-6} sec.
- Doppler spread of 8 Hz (at 55 mph for the 100 MHz band)

The complexity of the receiver will depend on the above parameters. STIC mitigates the propagation effects by using the channel state information to estimate the quality of the received data, thereby enhancing the decoding algorithm.

7.5.1.1.5.3.1.5 NHK's Data Radio Channel (DARC) System

The Digital DJ Inc. and NHK of Japan are partners in developing the FM Subcarrier Information Services (FMSIS) for US applications. This system uses the data radio channel (DARC) technology developed by NHK Laboratories for broadcasting 16 kbps data using the FM subcarrier. DARC uses the level controlled minimum shift keying (L-MSK) modulation format, which is a variation of MSK. This modulation format has proven to be robust in a multi-path environment.

The level of the multipath in an FM subcarrier digital data system is related to the magnitude of the stereo sound level. At low stereo sound signal levels the multipath levels will be negligible when using low injection levels for the data signal. However, in the presence of higher stereo sound levels, injection levels of 10% are required. By using L-MSK, which increases the injection level only during an increase in the sound level, the digital signals are transmitted efficiently under multipath conditions. Furthermore, DARC employs two dimensional CRC coding to correct channel and burst errors.

7.5.1.1.5.3.1.5.1 DARC Technical Specifications

The FMSIS, using the DARC modulation format, places the digital data at 76 kHz baseband frequency, at a data rate of 16 kbps. This results in an occupied bandwidth of about 32 kHz. DARC's effective information rate, after error correction, is about 8 kbps or about 1,000 alphanumeric characters per second. The system is designed to co-exist with the low data rate RBDS system (Figure 7.5-33). The reliability of the system (% of correct reception) is improved by repeat broadcasting at a rate of 2 to 3 times every few minutes.

The receiver for the DARC system uses a chip set, developed by SANYO, for (1) filtering, (2) L-MSK demodulation, and (3) synchronization and decoding. The receivers will incorporate the chip sets to decode the received data and display the information using LCD panels.

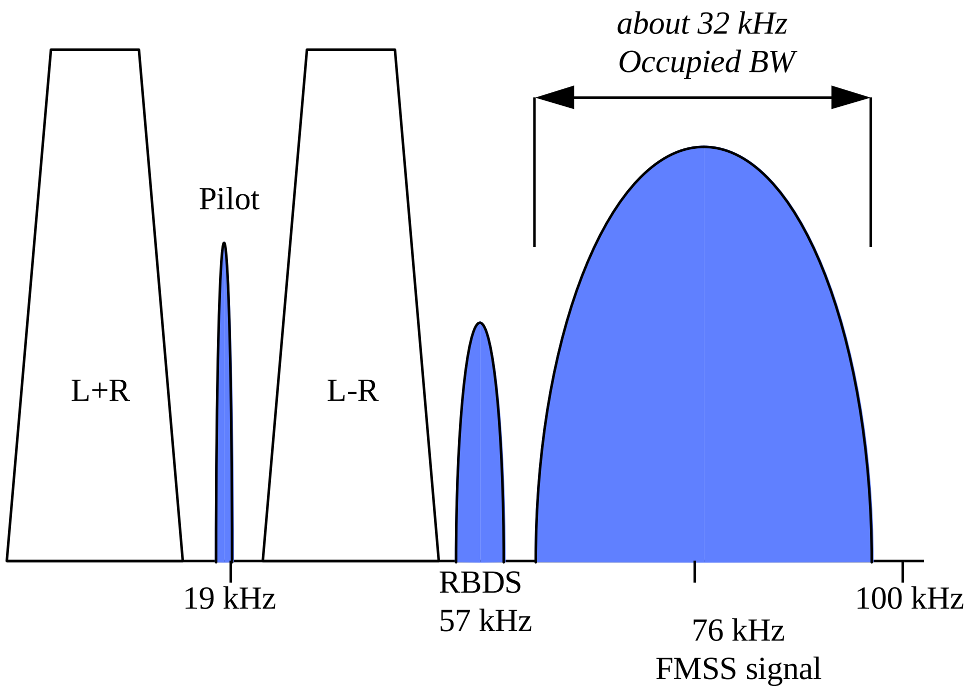


Figure 7.5-33 FM Baseband Spectrum Usage for NHK's DARC System

7.5.1.1.5.3.1.5.2 Field Test Results

In September of 1993 the DARC system was tested in Tokyo, using first generation receivers. The participants included both auto and radio receiver manufacturers. The trial included propagation test under (1) multipath conditions, (2) normal road, and (3) highway conditions. The results of this test presented the system bit-error-rate, and were used to estimate the system reliability (% of correct reception), under various conditions. The reported results claim reliability of 90 to 95% that can be obtained when using multiple repeat techniques.

In summary, DARC resorts to a more complex mobile unit, and lower per transmitter capacity to provide gains in reliability.

7.5.1.1.5.3.2 Evaluation Results and Conclusions

7.5.1.1.5.3.2.1 Capacity Analysis Results

The capacity of the broadcast systems is analyzed in the context of the ITS Architecture using the data loading analysis in Chapter 6 supported by Appendix F. The summary of these results is depicted in Table 7.5-10. The results present the aggregate information rate for traffic information services, travel information services and transit information services. The aggregate information rate is further evaluated for a growth rate of 10, 20 and 30 percent. The growth rate includes the increase in the number of links and the increase in the required update rates.

Table 7.5-10 presents the capacity of the high data rate FM subcarrier systems, viz., HSDS, DARC, and STIC, using a single and dual broadcasting channel. The capacity for these systems is evaluated at the three reliability factors of 100, 90, and 70 percent. The reliability factor accounts for the propagation impairments, such as holes in the coverage, multipath, blockage, etc. These results are presented assuming a single station operation, i.e., that if more than one station is used they do not supplement each other to increase reliability.

From Table 7.5-10, it is observed that the high data rate FM broadcast systems can meet the capacity requirements of the proposed ITS services which are presented in Section 6. Since the RBDS system and high data rate systems can co-exist, if desired, the RBDS system can also be used to support either a limited number of services or lower information update rates.

Table 7.5-10 ITS Required Information Rates and Broadcast Systems Capacity

ITS Services	Information rate per ITS service (bps)	Increase in information rate due to demand			High data rate broadcast system capacity effective information rate					
					single channel at a reliability factor of			dual channel at a reliability factor of		
		10%	20%	30%	100%	90 %	70 %	100 %	90 %	70 %
Traffic information services	1,366	1,502	1,639	1,775						
Transit services	1,536	1,690	1,843	1,997						
Traveler Information Services	2,750	3,025	3,300	3,575						
Total Broadcast Information Rate	5,651	6,217	6,782	7,347	7,500	6,750	5,250	15,000	13,500	10,500

7.5.1.1.5.3.2.2 Coverage and Deployment Issues

The first approach to propagation mitigation uses multiple broadcast stations (i.e., multiple frequency bands), for transmitting the same information. Evidently the location of the FM towers in this case is of primary importance in optimizing the coverage area. The potential increase in the coverage area will result in an effective lower system capacity, since the same message will be broadcast from multiple stations. In this approach, the receivers will have the capability of tuning to multiple stations and selecting the strongest signal.

In the second approach, the broadcast system uses coding and modulation techniques for multipath rejection (STIC, DARC). Therefore, in general one FM station will be utilized per geographic area, to offer a certain set of services. However, these systems require receivers of higher complexity, compared to the first approach. In the complex mobile receiver approach the broadcast coverage could possibly be less than the first case, depending on the operational environment.

From the above discussion, the coverage and deployment, which are interrelated, depend on:

- The propagation environment – is one or multiple stations needed to meet the coverage requirements?
- The required capacity – are multiple stations needed to meet the capacity requirements?
- Available broadcast systems (number of the available FM subcarrier systems).

The coverage area can be determined and optimized by selecting the broadcast technology (i.e., RBDS, HSDS, STIC or DARC) that will best meet the capacity requirements and best fit urban propagation conditions.

7.5.1.1.5.3.2.3 Interface Issues

The core of the FM subcarrier broadcast systems is the algorithm required for demodulation, encoding and multipath mitigation, and the hardware/firmware that it requires. The broadcast system developers have been integrating the receivers into a set of LSI chips for compact implementation. The issues that are involved in using broadcast systems include: (1) interface standards for inter-operability and nationwide compatibility, (2) licensing agreements for using the specific broadcast technology i.e., hardware and software, and (3) system integration, i.e., hardware interface with ITS user terminals

With the exception of the low data rate RBDS system that has an open and standard interface, all high data rate systems have proprietary interfaces (Table 7.5-11)

7.5.1.1.5.3.2.4 Conclusions

Table 7.5-11 outlines the broadcast technologies' attributes. The high data rate FM subcarrier technologies that were analyzed in this document will meet the capacity requirements of the ITS data flows proposed for broadcast communication services.

The above analysis has also discussed the issues related to the coverage, interfaces, and national inter-operability. All high data rate systems that are discussed in this document (HSDS, STIC, and DARC) use proprietary hardware and interfaces, whereas RBDS uses a standard open interface. Using a system with a proprietary interface will impact the national inter-operability for the ITS services. The main issue in using a proprietary system will be the licensing agreements for the specific technology and hardware.

Table 7.5-11 Summary of the Broadcast System Specifications

Broadcast System	Status / Technology Maturity	Interface issues	Implementation	Special Features & Tech. for combating channels effects (e.g., multipath)	Data Rate	Inf. Rate
RBDS	Operational / Commercial	Open	Commercial		1187 bps	300 bps
STIC	Prototype/ Ready for deployment	Proprietary, licenced for free in U.S.	Prototype	Uses coding, interleaving & correlation techniques.	18.8 kbps	7.6 kbps
DARC	Operational / Commercial	Proprietary	Commercial		19 kbps	8 kbps
SEIKO, HSDS	Operational / Commercial (Oregon, LA, Seattle)	Proprietary	Commercial	Freq. and time diversity: scans for 7 Station, multiple transmission of the message, time offset between stations	19 kbps	7.5 kbps

Note: RBDS can co-exist with High Speed FM subcarrier systems.

The main issue in deploying FM subcarrier systems will be the need for standardizing the interface with ITS and achieving inter-operability between competing proprietary systems. Work is ongoing to standardize the high speed FM subcarrier systems. The work involves independent assessment of the three high speed systems, STIC, HSDS, and DARC, including their protocols and interfaces, by EIA at the NASA Lewis Research Center.

A subset of the ITS services that will not require high data rate can be broadcast using RBDS. Since RBDS has been standardized, those ITS services could easily achieve national inter-operability.

7.5.1.1.5.4 Digital Radio Broadcasting (DRB)

The 1992 World Administrative Radio Conference (WARC-92) decided the world-wide allocation for Digital Radio Broadcasting (DRB) in L-Band.

DRB will replace both FM and AM stations. For FM stations, the plan should accommodate DRB facilities which will provide for replacement of their existing coverage and have the potential to expand to the highest class of FM station. For wide-coverage AM stations, the objective is to accommodate stereophonic DRB facilities equivalent to the highest class of FM station. For limited coverage AM stations, the objective is initially to replace existing coverage, with potential to expand to the highest class FM station. (Coverage should be based on service in more than 90% of locations, 90% of the time for mobile reception.)

Industry Canada already announced the publication of a Draft Allotment Plan for Terrestrial Digital Radio Broadcasting (DRB) for stations operating within the 1452 to 1492 MHz frequency band (L-band) using the EUREKA 147 (DAB) system, following WARC-92's allocation of that band to DRB. (Canada introduced that proposal at WARC-92.) The 40 MHz of available spectrum was divided into 23 DRB channels. Each DRB channel can accommodate up to five CD-quality stereophonic programs and ancillary data. Up to five existing AM and/or FM broadcasters are grouped together to share the same transmitting facility.

A future DRB satellite component was also considered, and is anticipated for 2003-2005. In contrast, neither FM, at 88-108 M, nor AM, at 0.525-1.705 MHz are suitable for satellite signals.

7.5.1.1.5.4.1 Digital Audio Broadcasting (DAB)

Digital Audio Broadcasting (DAB), sometimes also called Data and Audio Broadcasting, uses innovative digital signal processing techniques for channel coding and modulation (COFDM) and audio compression (ISO/MPEG Layer 2). These techniques were chosen to ensure superb reception of CD-quality sound and various data services with mobile, fixed and portable receivers. Extensive tests have proven the validity of the DAB system, even under the most difficult reception conditions, e.g. in urban or mountainous areas with significant multipath effects and doppler shifts.

The DAB system is a wide-band digital transmission technology developed by the Eureka-147 DAB consortium. In cooperation with the EBU and ETSI, the standard of this new system has been finalized and recently accepted. This standard is now officially available and is known as ETS 300 401.

DAB offers the following features:

- mobile reception of audio in CD quality
- insensitivity to interference
- ease of operation
- efficient use of bandwidth

- low transmitter power
- opportunities for data, video and multimedia
- pay radio (Addressable radio)
- picture radio
- teletext, newsletters, narrowcasting

The DAB system has been proposed for adoption in Canada as an eventual replacement for existing AM and FM analog sound broadcasting.

Limited licenses have been issued in both Canada and Europe to broadcasters who wish to experiment using the digital transmission system by simulcasting their AM or FM broadcasts. The age of digital radio started with the launch of regular DAB services by Danmarks Radio (DR) in Denmark on 1 September 1995, followed by the BBC in the UK and by the SR in Sweden, both on 27 September 1995. DAB-based radio broadcasting will officially start in the year 1997 in Germany and Belgium; France, The Netherlands, and Australia are also planning their migration.

Satellite provisioning of DAB is under consideration in Europe and in Canada. Recently, BBC Research and Development, in collaboration with Telecomunicaciones de Mexico and the Instituto Mexicano de Comunicaciones, carried out successful satellite reception tests on Eureka DAB in the suburbs of Mexico City, using channels in the L-band provided by the Solidaridad 2 satellite. High–quality audio transmissions were successfully received from the satellite by both a fixed receiver and in a moving vehicle. This was the first test of mobile satellite reception using the Eureka 147 system.

Digital Radio Research Inc. (DRRI), a non-profit, research and development joint initiative of the Canadian Broadcasting Corporation and leading private broadcasting organizations, with financial support from the Canadian government, is conducting technical feasibility studies on the Archimedes mediaStar project, a satellite-based communication system using DAB technology. The proposed system, described as an "electronic multi-media kiosk", will use six HEO satellites in highly elliptical polar orbits to transmit wide-area audio and data services to mobile and fixed receivers in Europe, North America and East Asia.

7.5.1.1.5.4.1.1 DAB versus RDS

RDS, as we discussed before, is capable of offering some very useful features. However, there are two major differences between RDS and DAB which are important. Firstly, when compared with DAB, there is a very tight limit on the capacity offered by RDS. In France, for example, where TDF operates a paging service via RDS, Radio France is already unable to transmit the basic RDS features in conformity with the RDS specification guidelines, simply because so much capacity is used for the paging service. TDF already uses 70 % of the total capacity for paging alone. DAB, on the other hand, offers a much greater capacity for data services, and greater flexibility to trade off one application against another, not only data versus data, but also data versus audio. Secondly, only DAB can provide durability and reliability of transmission and can eliminate the multipath problems that plague FM reception in the car. This is the main advantage of DAB.

7.5.1.1.5.4.1.2 Deploying DAB in the U.S.

A note of caution is needed concerning the deployment of DAB in the U.S. At present in the U.S., L-band is used by licensed aeronautical telemetry and not available even for testing, let alone the establishment of a permanent set of frequencies for DAB. Even though spectrum is available in the U.S.

in S-band (2,300 MHz), if the U.S. established a Eureka system[12], the standard would likely be out of step with the rest of the world. How this would affect the tuner manufacturers of the world is difficult to judge. It could mean that a separate band be installed in each tuner destined for the U.S. market, without the usual transportability between Europe and U.S. that exists with standard AM/FM.

7.5.1.1.5.4.2 In-Band, On-Channel (IBOC) System

Since the Eureka concept was first introduced, alternatives have been suggested. The U.S. has fought against the use of L-band -- it was recognized that the inception of DAB on L-band would mean that 500 million radios would instantly become obsolete. In the view of many, the establishment of L-Band digital radio stations would result in the creation of a third radio band (in addition to AM and FM), a new band whose better-sounding stations would attract revenue away from conventional AM and FM broadcasters, which are already having problems generating sufficient profits in the crowded U.S. radio market. (This possibility is completely avoided by the Canadian government-industry plan to move all Canadian AM and FM stations to the L-Band.)

Competitors of DAB are basically six In-Band, On-Channel (IBOC) proposals whose objective is to produce cost effective, backward-compatible systems that can return the investment in the existing structure.

IBOC DRB has, however, not proven to be a solid competitor to DAB. In fact, in the U.S., DAB underwent testing by the Electronic Industries Association (EIA) and the National Radio Systems Committee (NRSC), and was declared a clear winner. Independent laboratory tests have confirmed that Eureka 147/DAB is the only digital radio technology capable of delivering CD-quality audio without interference to other stations. Test results indicate that proposed IBOC systems cause unacceptable degradation of AM and FM signals on adjacent frequencies as well as the host frequency. IBOC systems also experienced problems with adjacent digital signals interfering with each other in the crowded bands.

AM offers DRB the often overlooked advantage of favorable and extensive radio propagation characteristics. AM also offers DRB a readily available network of broadcasting facilities, including directional and nondirectional antenna towers and arrays, in place and operational at this time. The potential for delivering IBOC DRB in the AM band is too often dismissed due to potential technical challenges such as limited allocation bandwidth, interference due to market saturation and antenna pattern bandwidth considerations. However, USA Digital Radio, a company founded by U.S. broadcasters, has taken the position that both the infrastructure and the heritage of the AM broadcast industry are of a value that justifies meeting the technical challenges necessary to make AM IBOC DRB practical and realizable.

7.5.1.1.6 Wide Area Beacon "Solution" to Wide Area Wireless

While it is true that beacons are more oriented towards short-range types of services and applications, the partition of ITS user services between wide-area and short-range wireless communication is not uniquely determined by (technical) system requirements. The purpose of this section is to discuss an alternative architecture in which some or all of the services in the first category are provided by short-range wireless communication between vehicles and roadside beacons (i.e., wide area coverage by means of widespread deployment of roadside beacons). The analysis is primarily from a technical and feasibility standpoint. The salient findings are discussed here and further details are provided in Appendix G.

[12] DAB can function anywhere in the 30-3,000 MHz band.

7.5.1.1.6.1 Coverage, Availability, Delay

Since all beacons in a given area use the same frequency, siting is constrained by the need to eliminate interference. For example, in Hughes' VRC system, receiver sensitivity is set to limit the effective range to about 200 feet. For acceptable interference levels, the minimum separation between beacons in the absence of obstructions is about 1/3 mile. This leads to the deployment shown below using cross-hatched circles. In an urban or suburban setting, however, the obstruction caused by buildings located on a rectangular street grid allows the siting of additional beacons without interference. Typically, the number of beacons can be doubled by locating the additional beacons (shown as dotted circles) equidistant from the original ones. We are thus led to postulate the idealized full deployment shown in Figure 7.5-34.

This coverage could be increased if frequency reuse were implemented, since beacons operating at different frequencies could be interspersed among those shown above. Such a system would then be no different from a full fledged micro-cellular system-- and would be prohibitively expensive for any dedicated set of users. Such a hypothetical situation, however, would defeat the essence of DSRC, which is based on very simple, inexpensive user equipment without sophisticated frequency agility. Thus, it will not be considered.

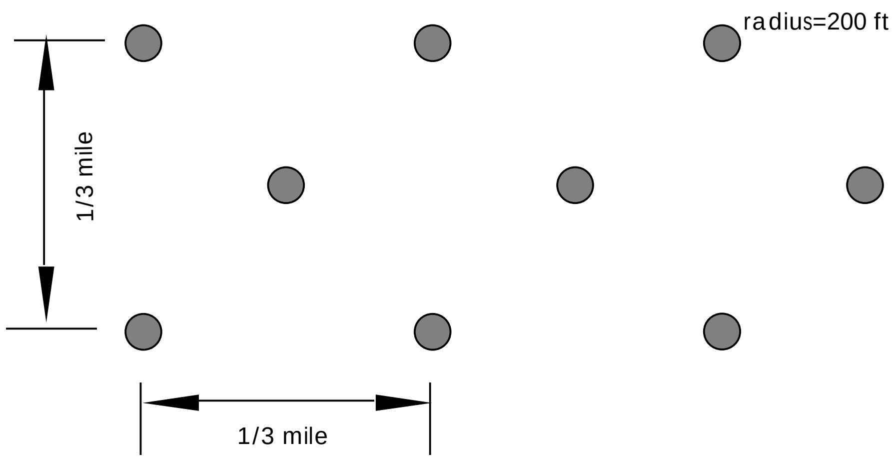


Figure 7.5-34 Full Deployment of a Beacon System

In the deployment shown in Figure 7.5-34, there are eighteen beacons per square mile, implying that literally tens of beacons will have to be deployed in the area covered by only one cellular base station. The postulated full deployment would greatly increase the number of devices which must be installed along roadways and connected via wired communication networks relative to a cellular-type solution, thus increasing the initial cost of such a system as well its maintenance.

For illustration purposes, the Urbansville scenario is examined. The Urbansville region covers 800 square miles. The postulated deployment requires a total of 14,400 readers. For comparison, 2560 intersection controllers and 111 ramp meter controllers are thought to be necessary.

Another key aspect of the indicated deployment is the small fraction of the total area actually within communication range of a beacon, which can be appreciated from Figure 7.5-34. That fraction is just $18\pi (200)^2 / 5280^2 = 0.081$ (= 8.1%). However, given that the vehicles move essentially on surface streets and highways, it is more meaningful to compute the percentage of "linear" coverage, i.e., the fraction of the roadway length covered by the beacons. The fraction is slightly higher at (200 * 0.3)/ (1609.3/3) = 0.112

(= 11.2%). This immediately points out to the fact that only a small, similar percentage of the vehicles will be within range of such a fully deployed system. These small coverage factors also mean that time-constrained wide area ITS applications cannot be accommodated with such a system.

One of the serious drawbacks of wide area wireless communication using beacons is transmission delays which occur while a vehicle is located in a dead zone between beacons. This is, of course, most significant for vehicles which are traveling slowly or are stationary for some period of time as illustrated in Figure 7.5-35.

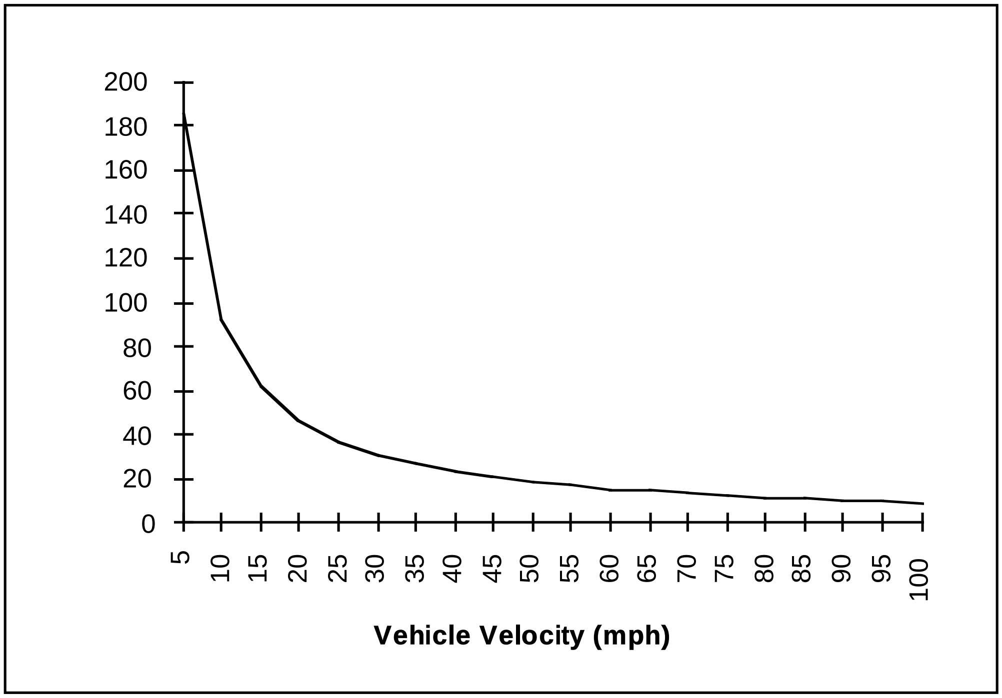


Figure 7.5-35 Dead Zone Crossing Times

For example, a vehicle traveling 10 mph requires 93 seconds to traverse the 1360 foot dead zone between beacons. Another more impressive result is that at 19 mph, the average freeway speed in the LA area during rush hour, the time to traverse the dead zone is still around 50 seconds. It is clear that such a beacon system cannot meet transmission time requirements for many ITS services.

Another drawback of a beacon system is the complexity required to carry out two-way communications between the TMC and vehicles which move from one beacon to another during the exchange. The time a moving vehicle will remain in the coverage area of a beacon is plotted in Figure 7.5-36.

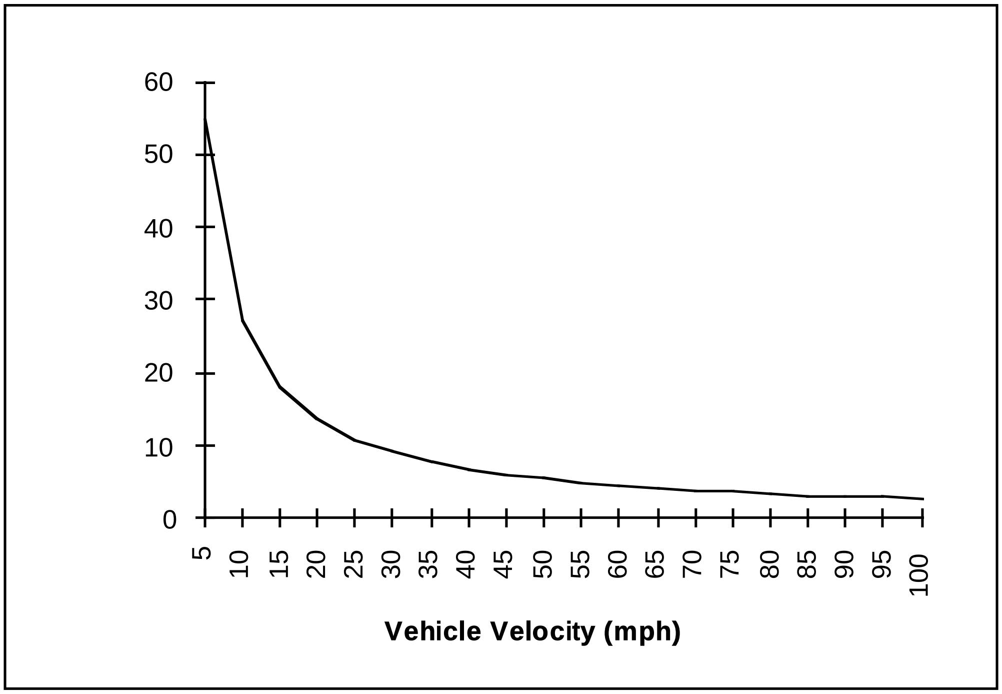


Figure 7.5-36 Beacon Coverage Crossing Time

For example, a vehicle traveling at 60 mph will traverse beacon coverage (400 feet) in 4.6 seconds. For many traffic types, a query from the vehicle will elicit a response from either the TMC or a third-party provider. In many cases, the response will not be available until after the vehicle has left the coverage range of the beacon. Therefore, the TMC must direct its response to multiple neighboring beacons (see Appendix G). Compensating for location uncertainty will increase processing at the TMC or service provider and message storage at the beacons. In order to minimize wireless traffic, the beacon-to-vehicle communication protocol should restrict transmission of such responses to the first reader which establishes contact with the vehicle and transmits the response.

7.5.1.1.6.2 Deployment Issues

A wide area beacon solution would imply extending the role of beacons from that of providing roadside-to-vehicle communications to that of providing wide-area communications.

Discussions of beacon system installation by government agencies versus using private cellular systems implicitly commingle two issues which in fact are quite distinct. The first issue is to compare the cost and technical merits of a “cellular” versus a “beacon” solution. The second issue is whether government agencies should allocate spectrum and fund the deployment of equipment to meet the needs of ITS for wireless data communications.

The fact that, currently, private operators are using “cellular” and that the government is focusing on “beacons” is not the result of an indissoluble link between these institutions and the methods they are using. It merely reflects the fact that engineers and planners on both sides have been solving different problems. Cellular operators have to serve high volume paying customers everywhere using crowded spectrum, while current beacon systems serve low volume, typically non-paying customers in sporadic spots. The different solutions adopted by each side reflect perfectly rational responses to different constraints, rather than any deep rooted differences in design methods. If beacons were economical for providing universal wireless coverage, there is little doubt that the private sector would have deployed them. Conversely, if elevated antennas covering large areas were the best way to operate toll systems today, it would be surprising if this was not indeed the approach taken by the government.

An examination that separates the merits of government support of ITS communications from the merits of beacons provides the following conclusions:

1) Government support does not appear needed to stimulate wireless data provision. The government may help wireless in general by allowing use of its property to install antennas. Private sector participants are the most likely to bring to end users the benefits of the lowest cost approaches through technological innovation spurred by competition.

2) Beacons are not appropriate for high volume, continuous coverage service such as the wireless data services required by ITS. The beacon's disadvantages in such applications are their inefficient use of bandwidth (with current modulation technologies), the high number needed for deployment to match low U.S. population densities, the gaps in coverage due to simplistic frequency reuse, and finally the need to start from ground zero compared to installed cellular systems whose costs are shared by many users.

3) Using beacons for wide area coverage does not appear economic now. If using beacons later becomes the most economic approach to providing wide area wireless data, then the private sector can be expected to provide that solution too. There does not appear to be a need for the government to fund wide scale installation of beacons at this point.

7.5.1.2 Short Range ITS Communications

7.5.1.2.1 Communications Between Vehicle and Roadside

There are three candidate technologies for the short range wireless communication link between the vehicle and the roadside, i.e., u2 links. These are active RF, passive (modulated backscatter) RF, and infrared. This section presents some of the technical features of these technologies. Although each of the underlying technologies is capable of a wide range of technical performance, this comparison will be restricted to the specific features which have been commercially implemented, and to varying degrees, incorporated into standards for each technology. This is consistent with the Joint Team's approach to standardization which is to emphasize adoption of standards for existing technologies rather than introduce new infrastructure.

A number of vendors have produced or are proposing active RF DSRC equipment. These systems are generally proprietary and not inter-operable. Of these, the Hughes' VRC system seems to be among the most advanced technically and also seems to be the subject of a well-advanced standardization process. Among the applicable standards are a draft version of the *Electronic Toll and Traffic Management (ETTM) User Requirements for Future National Inter-operability* prepared by the ETTM User Group of the Standards and Protocols Committee of ITS America, and a draft *Standard for Dedicated, Short Range Two-Way Vehicle to Roadside Communications Equipment* being prepared by the ASTM. The Hughes' VRC system is described, and some aspects of its performance are analyzed in the beacon analysis presented in Appendix G. Some specifications for this system are listed in Table 7.5-12 for comparison with the other beacon technologies.

Table 7.5-12 Beacon Systems Specifications

System	Maximum Range	Data Rate	Transmit Block Size	Tag Data Storage
Active RF	200 ft	550 kbps	512 bits	not known
Passive RF	75 to 100 ft (with extended range reader)*	300 kbps (600 kbps optional)	128 bits	20 frames of 128 bits
Infrared	not known	125 kbps	256 bytes (forward), 128 bytes (reverse)	not known

* exact range depends on antenna gain and power setting

Passive RF beacon systems produced by Amtech have achieved a significant number of permanent installations in the U.S. and worldwide, primarily for toll collection. Recently, a partnership named Intellitag Products, jointly owned by Amtech and Motorola, has introduced an upgraded product line which is claimed to be compatible with the previous Amtech products. It is also claimed that operation is compliant with the open protocol detailed in the *AVI Compatibility Specifications* in Title 21 of the California State Code of Regulations. Some specifications for this product line are also listed in Table 7.5-13 for comparison with the other beacon technologies. Some other features are of interest. Transmit frequency is programmable in 1 MHz steps from 902 to 928 MHz. This feature aids non-interfering operation of readers in adjacent lanes, since they can transmit at different frequencies. In addition, external synchronization signals can be supplied to the readers so that they transmit at different times. Note however, that this reduces overall throughput. Transmit power level is programmable in 1 dB increments from 50 to 500 mW.

Infrared beacons developed by Siemens form part of the ALI-SCOUT dynamic route guidance and interactive transport management system. This system has undergone trials in Europe (the LISB project in Berlin) and is currently being tested in Michigan (the FAST-TRAC project). The beacons transmit a sequence of up to 40 blocks of data of duration 17.5 ms, each containing 256 bytes of data. The beacon is "silent" for an interval of 11 ms following each data block to allow vehicle tags to respond with a single block of data. The vehicle tag's data block is 8.5 ms in duration and contains only 128 bytes. Although the vehicle tags implement a simple randomization mechanism to select which interval to respond in, destructive collisions will occur when multiple vehicles are within range of the reader. When the reader successfully receives a data block from a tag, it acknowledges reception in its next data block.

From a purely technical standpoint active RF beacons have a number of advantages over passive RF beacons. Among these are:

- The use of an active tag inherently gives greater range for the same reader transmit power and antenna gain. This facilitates covering traffic in multiple lanes with a single reader.
- The use of TDMA with reservation slotted-Aloha access protocol allows simultaneous handling of a larger population of vehicle tags. This also facilitates covering traffic in multiple lanes with a single reader.
- The larger packets (512 bits versus 128 bits) used in active RF give more flexibility for applications which may require greater data transfer than electronic toll collection.

On the other hand, passive RF systems offer the advantage of lower cost tags. In fact, tags are available which obtain all of their power from the received RF signal and hence require neither a self-contained battery or connection to the vehicle electrical system.

At this point in time, limited data is available on the performance of infrared beacons, therefore it is difficult to compare them with either of the RF technologies.

The foregoing technical comparison suggests that active beacons are superior to passive beacons. However, in comparing beacon technologies for use in the ITS communication architecture we must keep in mind the particular functions which have been allocated to the u2 communications link. The proper basis for comparison is the degree to which the beacon technologies fulfill the requirements of these functions.

In the Joint Team architecture, the applications served by the u2 interface are toll collection, parking fee collection, CVO in-motion inspection, and pre-clearance and in-vehicle signing. All of the technologies should be capable of successful deployment in situations where vehicles are restricted to lanes and one reader is deployed per lane. This will certainly be the case for parking fee collection and will probably be the case for toll collection due to the need to handle both equipped and non-equipped vehicles. For these applications there is no basis for prescribing one technology over another, so the architecture should start by accommodating all emerging standards and allow the marketplace to drive deployment. Since passive RF systems already have many proven installations, and also offer lowest cost tags, it is likely that they will capture a significant share of the market. Hence, they cannot be dismissed in favor of higher performance beacons.

In the remaining applications, CVO in-motion inspection and pre-clearance and in-vehicle signing, it may not be desirable to restrict vehicles to particular lanes. In these cases it appears that the technical advantages of active RF technology will provide superior performance. In this case it seems likely that they will capture a significant share of the market. Again, the architecture should accommodate the emerging standards for active RF technology.

In the scenario described above, both passive and active RF beacons are seen to capture somewhat distinct market segments. The role of infra-red beacons is harder to predict. In one sense this is not ideal, since two standards must be supported. On the other hand, the existence of only two standards would be a great improvement over the current situation in which many vendors provide non-inter-operable systems. To eventually achieve national interoperability, which would be very advantageous for the set of services considered here, a single common standard will need to emerge, perhaps spurred along with encouragement from the FHWA.

7.5.1.2.2 Vehicle-to-Vehicle Communications

VtoVC requires a high data rate, and a bursty, usually line-of-sight transmission with high reliability between vehicles. It is still in the research stage, both in the U.S. and in Europe. Solutions in the U.S. tend to stay in the low GHz bands (e.g., 1 and 2 GHz band spread spectrum systems, and some 5 GHz band TDMA systems). The European solution of choice seems to be the 60 GHz band, where the H_2O absorption phenomenon does not affect, and on the contrary facilitates, the short range communications involved.

It is in the AVSS and AHS areas that V2VC plays an important role, although the feasibility and practicality of using VtoVC for AVSS purposes has been questioned by many. The clearest example is Intersection Collision Avoidance, one of the 29 user services. It does not easily lend itself to VtoVC implementation-- reasons are the interaction with pedestrians, and the need to set the detection threshold to keep the number of false alarms within an acceptable range (and this is a theoretical, fundamental limit that has to be dealt with).

The most ambitious ideas, however, have to do with an intrinsically European concept of “co-operative driving”. Essentially, the vehicles would broadcast to their neighborhood their status, any upstream information of interest such as, road conditions, incident reports, etc. How this information would be obtained is another question. (Perhaps from the involved vehicles.) Mainly, vehicles would broadcast information regarding their intentions (e.g., passing, veering right/left). The essential questions, that fortunately we do not have to answer (that is left in the capable hands of the AHS Consortium), are: how will the vehicles make sense of the barrage of information impinging on them? How to prioritize them? How to make sure they get any information deemed important, especially if they come to rely on it?

In order for these external warnings to be effective, the target vehicles have to be properly equipped (which raises the issue of compatibility at a national level), and a minimum penetration realized before any benefits will be observed. That threshold is obviously very difficult to predict.

In AHS, Vehicle-to-Vehicle communications are essential to the concept of platoons, groups of vehicles on the same highway traveling in the same direction in near proximity, where the stability of the platoons is conditioned on all the vehicles knowing exactly what all other elements of the platoon, and especially the leading vehicle, are doing (speed, acceleration). Vehicle-to-Vehicle communications are even more important to enable the formation and break-up of platoons. So, AHS is not likely without Vehicle-to-Vehicle communications, and will only be possible for so equipped vehicles.

In spite of the fact that through ISTEA Congress has mandated the US DoT to develop an operational AHS test track by 1997, little has been done in the area concerning Vehicle-to-Vehicle communications. To the Team's knowledge, only one trial has been performed in the U.S. involving Vehicle-to-Vehicle communications. The test was performed by PATH (U.C. Berkeley) involving four vehicles provided by Ford Motor Company, each equipped with an Integrated Platoon Control System (IPCS) unit consisting of (off-the-shelf) model 386 PC, a spread spectrum communication system, radar system, sensors, and actuators. The radar system was provided by VORAD Safety Systems, Inc., San Diego, CA.

The control algorithm running on the PC requires data to be transmitted from one vehicle to another. A communication system was designed consisting of a roof-mounted antenna, a PROXIM digital transceiver, and a Metacomp communication interface board. The communication was half-duplex at the rate of 122 kbps in synchronous mode. The frequency used was in the 902-928 MHz band, approved by the FCC for unlicensed low-power use. Using the radio link, the speed and acceleration measurements of the lead vehicle were transmitted to the following vehicle(s) every 55 ms (18 Hz update rate). The controller in the following vehicle used these measurements to calculate the proper action to keep constant headway depending on the lead vehicle's motion.

The small size of the trial, and the fact that the communication between vehicles occurred without interferers (some kind of round-robin method was used to time the transmission of the different vehicles so that each was appropriately staggered, never to coincide with another vehicle transmission), makes this too ideal a trial even to be a proof of concept. However, the experience demonstrated that constant-spacing vehicle-follower longitudinal control can be implemented on a small group of vehicles with reasonable accuracy and ride quality, by using a combination of ranging sensors and vehicle-to-vehicle communication, together with a sophisticated non-linear control law.

In parallel, PATH (U.C. Berkeley) is working to define the communication requirements for AVCS, involving both vehicle-to-vehicle and vehicle-to-roadside links. Under consideration is the information needed for vehicle control, the reliability requirements, and the physical means for implementing the communication links, with particular attention to narrowband radio communication approaches that make efficient use of spectrum. On the other hand, PATH (USC) has investigated an integrated spread spectrum communication system combining vehicle-to-vehicle and vehicle-to-roadside communications. PATH is also involved in a comparative evaluation study of the performance of vehicle-to-vehicle communication systems, based on a technical performance specification under development.

In Europe, and under the aegis of the RACE Program, theoretical work has been proceeding in the area of vehicle-to-vehicle communications in the 6 and 60 GHz bands[13]. Pure TDMA schemes are under investigation for this application; this in spite of the fact that a common slot synchronization is a major problem since there is no master station providing synchronization information. However, local synchronization may be sufficient given that there is no reason why far away (few miles) vehicles must be synchronized — this implies the capability of mutual synchronization between vehicles.

In Japan no work is being done, to the Team’s knowledge, in the vehicle-to-vehicle communication area, the effort being concentrated in the vehicle-to-roadside area. In fact, some analysts reason that given dense enough a coverage (which, as observed in the Beacon analysis, is not possible without some kind of frequency reuse or without some kind of multiple access mechanism like CDMA or TDMA), vehicle-to-vehicle communication could be accomplished through the infrastructure (*i.e.*, vehicle-to-vehicle-via-infrastructure or vehicle-to-infrastructure-to-vehicle).

In summary, for systems to be deployed well into the 21st century (possibly late 2020’s), little has been done, and even less can be guessed at what will be available for deployment at that time. Never the less, it is essential to probe into the problems likely to arise in the complex environments of surface streets and highways of the future and the future technologies required for automated highways.

Quoting Prof. Shladover[14], much of the most research-intensive effort needed to bring AVCS to deployment will have to be in the development of enabling technologies. These have to do with the subsystems or components that need to be combined to produce fully functional systems. In most cases, the enabling technologies are applicable across a range of functional areas, and are certainly not exclusive to AVCS. However, in many cases the performance and reliability requirements for AVCS exceed those for other functions (wide emphasis on safety in AVSS). Below is a list, by no means exhaustive, of technologies where some progress is being done.

- Ranging Systems
- Other Sensors
- Integrated Computer Control and Data Acquisition Systems

7.5.2 Wireline Communications

Wireline network options include the use of private networks, public shared networks, or a mixture of the two. Examples of private network technologies are twisted pair cables, FDDI over fiber optic rings, SONET fiber optic networks, and ATM over SONET networks. Examples of public shared network options are the leasing of telco-offered services such as leased analog lines, frame relay, ISDN, metropolitan ethernet, and Internet. A third wireline network option is that of a mixed network, where existing communications infrastructure can be utilized to the greatest extent possible, and possibly upgraded to carry any increased data load. The addition of CCTV in particular can overload the backbone of an existing network.

The decision to specify a private network is probably not motivated by technological reasons because the desired data bandwidth can be supplied through the use of public shared networks. Much as the choice of technologies like CDPD for the wide-area u1 interface has many advantages such as cost sharing and risk reduction, shared wireline links have many similar advantages. It is certain that in the time frames studied that one or more local carriers can provide a network connectivity to fulfill the ITS requirements.

The reasons for building a private network have more to do with requirements/preference for a network built to the exact specifications of the user, and with matching the funding mechanism. If one-time capital funding is more easily obtained than monthly lease fees, then a private network appears as the best choice. In any case, there will still be an ongoing maintenance cost.

The active participation of the owners of the roadway right of ways in partnership with one or more commercial carriers may be a means of having a private network built for the ITS infrastructure at little or no cost to the local agency. In exchange for the use of the rights of way, the carriers would provide a portion of the network capacity for ITS use, and much of the maintenance cost.

For the purposes of the communication analysis, the owner of the network is not an issue, nor is the exact technology used on each link an issue. The goal was to demonstrate that the wireline data loads derived in the data loading models, both between the fixed entities in the Urbansville infrastructure model presented, and between the fixed and the mobile entities, can be carried comfortably using link technologies currently available or expected to be deployable in the time frames of interest. The candidate network technologies studied included those that are standardized (or will be in the time frames of interest) and are available in commercial quantities. To reach that goal, several network technologies were studied, and then a subset of those network technologies were incorporated into communications simulations models and performance results were determined.

The choice of a network technology for a deployed network must be based on the specific details of the infrastructure assets deployed in the specific metropolitan area. Any conclusions drawn in this analysis should not be generalized to every deployment area.

7.5.2.1 Candidate Wireline Technologies

The candidate network technologies discussed below are chosen from standardized network technologies because they consist of components available from multiple vendors. There are no added development costs, they are compatible with public shared networks, and they have been tested in various environmental conditions. The candidate private network technologies studied here include Ethernet, Fiber Distributed Data Interface (FDDI), Synchronous Optical NETwork (SONET), and Asynchronous Transfer Mode (ATM).

In addition to the network technologies listed above, the use of twisted-pair copper lines for the lowest level in a network is considered as a cost saving means of transmission. This allows the reuse of existing twisted-pair infrastructure. For new construction, the cost of fiber with optical transceivers is close to the cost of twisted pairs with modems.

Ethernet is a network technology based on a bus, primarily used in local area networks. The data rate is typically 10 Mbps, and the transmission media is coaxial cable. Access is controlled by a media access protocol (MAC) incorporating a Carrier Sensing Multiple Access with Collision Detection (CSMA/CD) scheme. The access protocols cannot accommodate networks covering a large area efficiently. To cover a metropolitan area the network must be broken down into many smaller LAN areas, which are then linked together using high-speed links. The CCTV camera load in any reasonable area would probably exceed the data capacity of ethernet, so a separate network would be required to carry the video data.

FDDI is a LAN-based network technology using a fiber optic transmission medium. It can support a data rate of 100 Mbps, and a total network cable length of 100 km. Up to 500 stations can be linked on a single network. Although a logical ring network topology is required, FDDI can support both star and ring physical topologies. Access to the ring is controlled by a token-passing scheme: A station must wait for a token before transmitting, each station repeats any frames received downstream to the next station, and if the destination address on a frame matches the station address, it is copied into the station’s buffer and a reception indicator is set in the frame status field of the message which continues downstream. The message continues downstream through the network to the originating station which then removes the message from the network. An enhancement to FDDI was standardized as FDDI II, which provides a circuit mode of operation. It allocates time slots of FDDI to isochronous channels. Up to sixteen, 1.144 Mbps channels can be allocated, with a 1 Mbps channel remaining for a token channel. Using this standard would allow constant-rate data from CCTV cameras to be transmitted on the isochronous channels with the remaining time slots available for the asynchronous (packet) data from intersection controllers and sensors.

SONET is an optical interface standard for networks that allows inter-operability between equipment manufactured by different vendors. It defines the physical interface, optical line rates, frame format, and operations, maintenance, and provisioning overhead protocol. The base rate of transmission is 51.84 Mbps, and higher rates are allowed as multiples of the base rate. At the base rate, data are transmitted in frames of 90 by 9 bytes every 125 microseconds. Higher rates are achieved by transmitting a multiple number of these frames every 125 microseconds. The first three "columns" of the 90 by 9 byte frame are reserved for overhead data, and the rest constitute the "payload" of 50.11 Mbps. The synchronous structure and byte-interleaved structure of SONET allows easy access to lower-order signals, which allows the use of lower- cost hardware to perform add/drop, cross-connect, and other bandwidth allocation techniques, eliminating the need for back-to-back multiplexing/demultiplexing. The overhead allows remote network monitoring for fault detection, remote provisioning and reconfiguration of circuits, reducing network maintenance costs. SONET networks can be configured as point-to-point or ring networks. For fault redundancy, SONET rings are frequently configured as bi-directional rings with one-half of the network capacity reserved for transmission during a fault. In the case of a cut in the two fibers (one for each direction) between two adjacent nodes on the ring, traffic is rerouted by the nodes on either side of the break, in the direction away form the break, using the reserved excess capacity of the ring.

ATM is a packet-switching technology that routes traffic based on an address contained in the packet. Packets are statistically multiplexed through a store-and-forward network, allowing multiple data streams of various data rates to flow through the network with greater instantaneous link efficiency. The technology uses short, 53-byte fixed-length packets, called cells, allowing the integration of data streams of various rates. The short cell length limits the length of time that another cell must wait before given access to the link. Cells containing video data can be given a priority over data cells, so that continuous video streams will not be interrupted. The 53-byte cell consists of a 5-byte header and 48 bytes of user data. ATM is connection oriented, and every cell travels through the network over the same path, which is specified during call setup. The cell header then contains only the information the network nodes need to relay the cell from one node to the next through the network. ATM connections exist only as sets of routing tables stored in each switch node, based on the cell header. Each ATM switch along the route rewrites the cell header with address information to be used by the next switch node along the route. Each switch node needs to do very little to route the cell through it, reducing switching delay. ATM can be used on a variety of links, and particularly SONET links for the medium-haul lengths required in a metropolitan-area deployment. The ATM concept, being based on switches routing packets, tends to favor a star configuration with a dedicated line to each user. ATM is still in the development phase, but should be considered as one of the strongest network technology candidates for the deployment time frames being considered.

7.5.2.2 Candidate Wireline Topologies

Network topologies were studied in Phase I of the National Architecture Program by the Rockwell Team (section 6.3.2.2 of *IVHS Communications Network Requirements Document*) for purposes of making preliminary determinations of the total physical length of links and data rates required on links given topological assumptions. Communications simulations were run on several fundamental candidate network designs to provide throughput and delay statistics. The goal at this point was to demonstrate that the data can be carried on the candidate networks, and to provide a rough cost for such a network.

The network connecting the sensors and intersection controllers to the TMS will be at least a two-level network, with the first network level connecting the sensors and intersection controllers to a hub in the center of each section, and the second network level connecting each of the section's hubs to the TMS. An additional network level may be added as a set of concentrators deployed throughout the sections to concentrate data over higher-rate lines to the hub. This was contained in the type-C section by clustering the intersection controllers into groups of eight, with a single connection to the hub. Concentrators were applied in the network where they can be used to decrease the overall network cost.

The use of star connectivity was studied for both levels of the network. The selection of a ring or star network configuration is largely determined by the link transmission technology selected, such as private FDDI networks, and public leased twisted pairs. Examples of some of the connectivity options and their effect on the total length of links was analyzed. The results of the simulations showed clearly that the delay on any reasonably designed wireline network was completely negligible.

7.5.2.3 Public Network Usage

The candidate shared public network technologies include leased analog lines, digital leased lines, frame relay, Integrated Services Digital Network (ISDN), metropolitan ethernet, Switched Multimegabit Data Service (SMDS), and Internet.

Portions, or all, of the communications links for the architecture can be provided by shared public network technologies. The public network technologies that can be considered to fill a large subset of communications requirements, and are available in most jurisdictions are detailed in Table 7.5-13.

Table 7.5-13 Widely Available Public Network Technologies

Link Technology	Analog leased lines	Digital leased lines	Frame Relay	ISDN	SMDS
Type of service	Dedicated circuit	Dedicated circuit	Packet switched	Circuit switched and packet	Packet switched
Transmission medium	Standard telephone line	Digital facilities	standard telephone line to four-wire T1 technology	basic rate ISDN - standard telephone lines; primary rate ISDN - four-wire T1 technology	four-wire T1, and fiber optics
Data rate	up to 28.8	2.4 Kbps, 64 Kbps, fractional T!, T1 (1.5 Mbps), T3 (4.5 Mbps), DS3 (45 Mbps)	56 Kbps up to T1	Circuit switched B channel 64 Kbps, packet D channel 16 Kbps; basic rate ISDN=2B+D, primary rate ISDN = 23B+D	T1, T3, SONET to 155 Mbps
Capabilities	point-to-point and multipoint	point-to-point and multipoint	Suitable for data only.	B channel well suited for CCTV which can be used intermittently, D channel for simultaneous data	Suitable for data only.
Comments	Universally available	High reliability	Fixed monthly charge based on data rate	Cost is usage dependent	Cost is usage dependent
Cost/month (rough estimate, based on undiscounted tariffs)		56 Kbps: $300/month; T1: $3.50/month/mile + $2500/month; DS3: $45/mile/month+ $16000/month	56 kbps: $175/month T1: $435/month	basic rate ISDN: $25/month + $0.57/kilopacket for data and $0.016/minute for B channel	

Metropolitan ethernet may be available in some jurisdictions as a service provided by CATV companies. This shared network is currently found in only a few metropolitan areas, but could be offered in many more in the future as CATV systems are upgraded with fiber-optic technology. This network technology is only applicable to the controller data, and cannot handle the CCTV data load.

Many jurisdictions will already have some form of communications network in place for the centralized control of intersection controllers. The architecture will allow the continued use of these networks if desired, with the lower-level twisted-pair links used for the intersection controller data. The addition of CCTV cameras brings the data rate requirement of the network up so that a high-speed network backbone is required. Concentrators can be placed in the network to multiplex the intersection controller links onto the high-speed backbone network, along with the CCTV data links.

7.5.2.4 Localized Use of Internet

The Internet could also potentially provide data communications, but there are security issues in its use for many of the ITS network applications.

The Internet is a collection of networks using TCP/IP protocol (Transmission Control Protocol--TCP, and the Internet Protocol--IP). Since its introduction by the Inter Networking Working Group in 1982, it has gained tremendous attention in the network communities. (The average time between new networks connecting to the Internet was ten minutes as early as July, 1993.)

In this section, we investigate the feasibility of using Internet as a communication network between the TMC and other transportation fixed entities like PS's and FMC's. In particular, we focus on the average access delay and gather packet loss statistics from the Internet.

7.5.2.4.1 Approach

The PING command was used to investigate round-trip propagation times over the Internet by sending Internet Control Message Protocol (ICMP) echo-request packets. Two series of measurements were performed, one in the LA area in February-March 1994, and a new one in the Boston area in February 1995.

The results from the LA measurements were found to be lacking since they corresponded only to periodic samples of the Internet delay, instead of registering its behavior over time (important if one wants to detect worst-case conditions). Therefore the analysis here will focus mainly on the most recent results obtained in the Boston area.

7.5.2.4.2 Internet Round-Trip Measurements

A set of seven Universities in the great Boston area, were PING'ed first for a period of 48 hours, and then for a whole week to collect round-trip information. Also selected was a small Boston organization, City Year, selected at random to "represent" organizations that in principle cannot afford, or cannot justify having dedicated high speed connections, and Digital Equipment Corporation, because although local it is located far from GTE Laboratories, and is expected to have high traffic.

Probability Density Functions (PDF's) of the observed round-trip delay were computed. All of them show considerable tails that extend to 200-400 ms, with occasional round-trip delays exceeding one second.Figure 7-5-37 shows three examples.

The worst PDF (i.e., highest average delay) will be used in Section 8 in the end-to-end delay simulation to arrive at the delay distribution for the traffic that crosses the Internet. The round-trip delay will be evenly split between the reverse and forward directions.

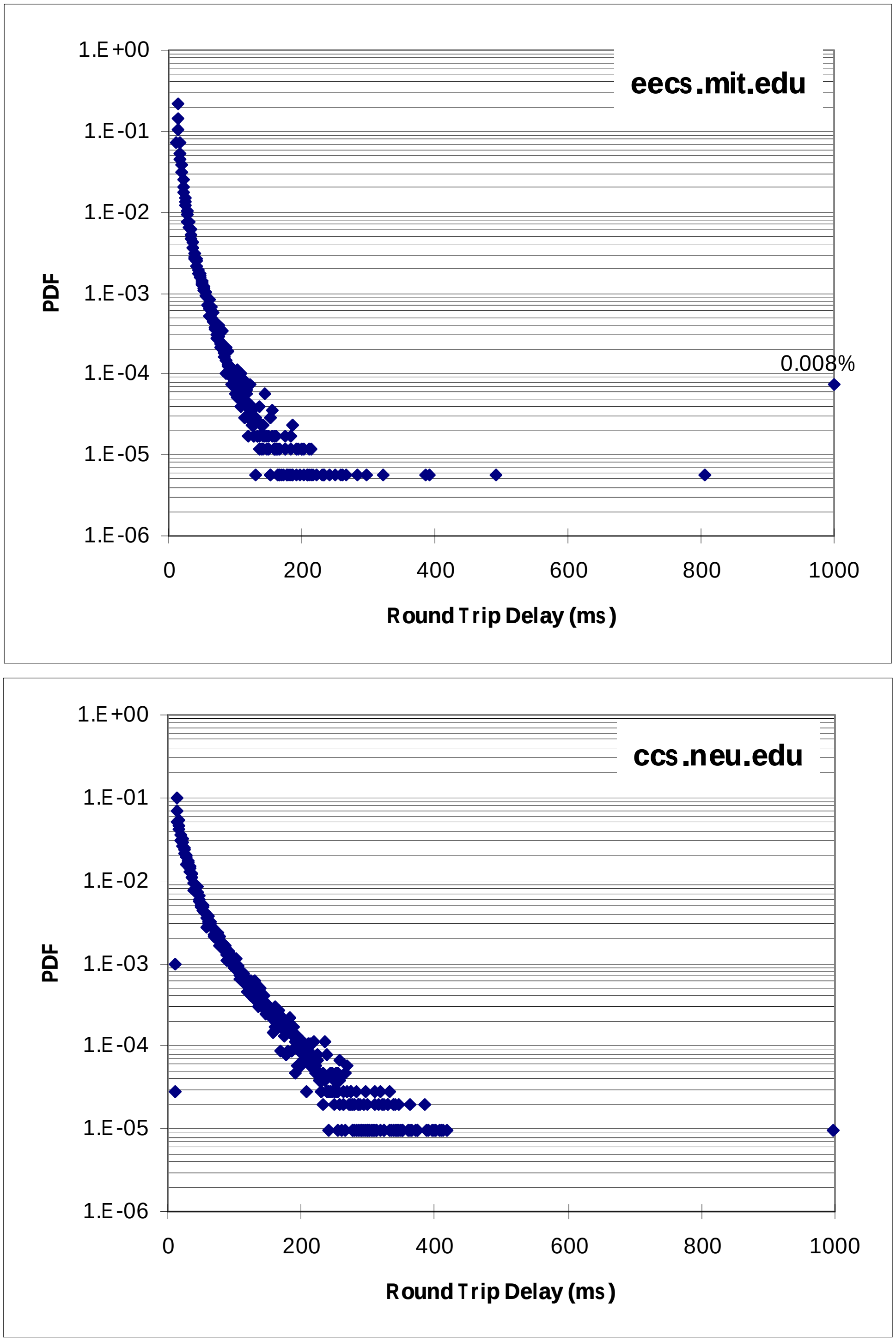


Figure 7.5-37 PDF's of the Round-Trip Delay

(Node not available 19 hours out of the 48 hours observation period)

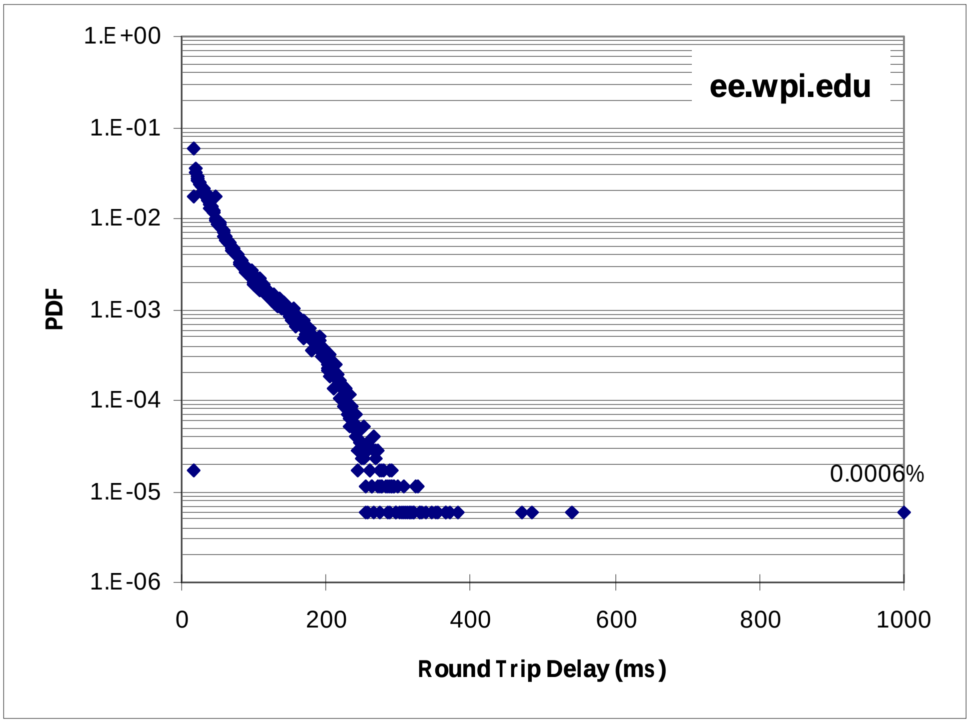


Figure 7.5-37 PDF's of the Round-Trip Delay (Cont.)

The average round-trip delay as a function of the time of day is shown in Figure 7.5-38. As expected, from GTE Laboratories to these Internet sites, two peaks are observed corresponding to the peak periods noticed in the E-mail and Internet Access characterizations: higher loads correspond to more congestion at the intermediate routers, and thus higher delays.

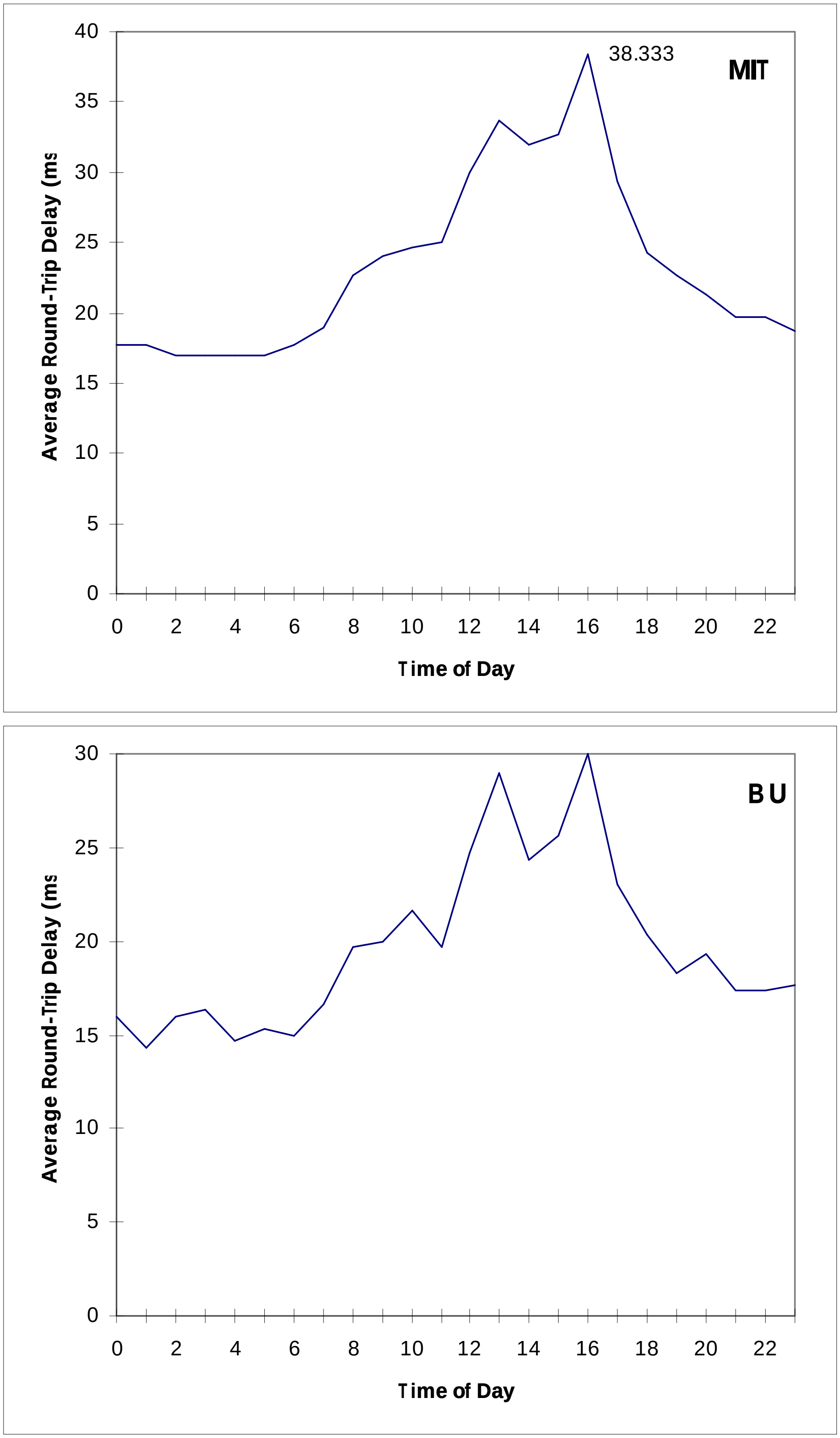
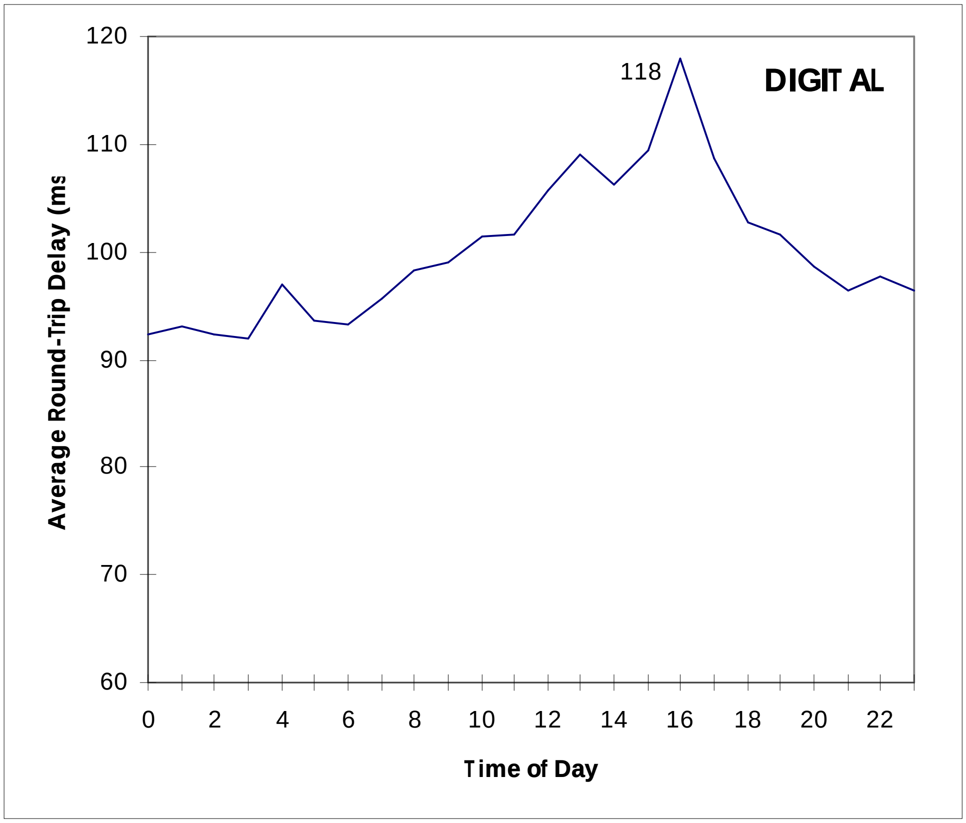


Figure 7.5-38 Average Round-Trip Delay (Period March 5-7, 1996)



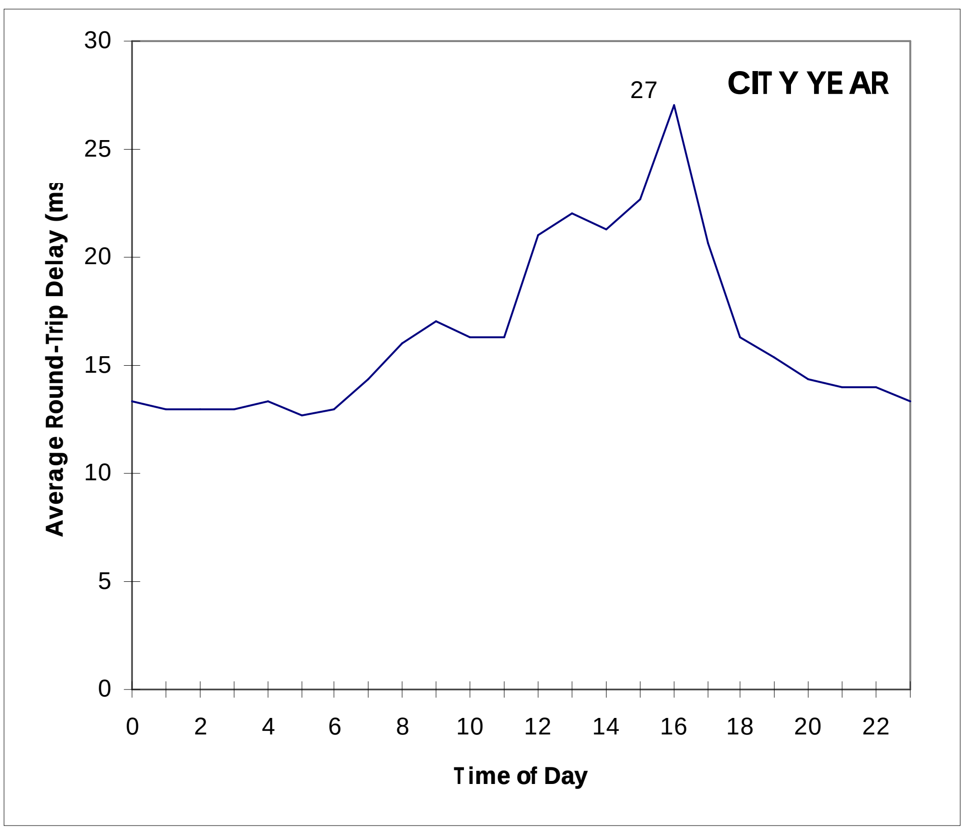
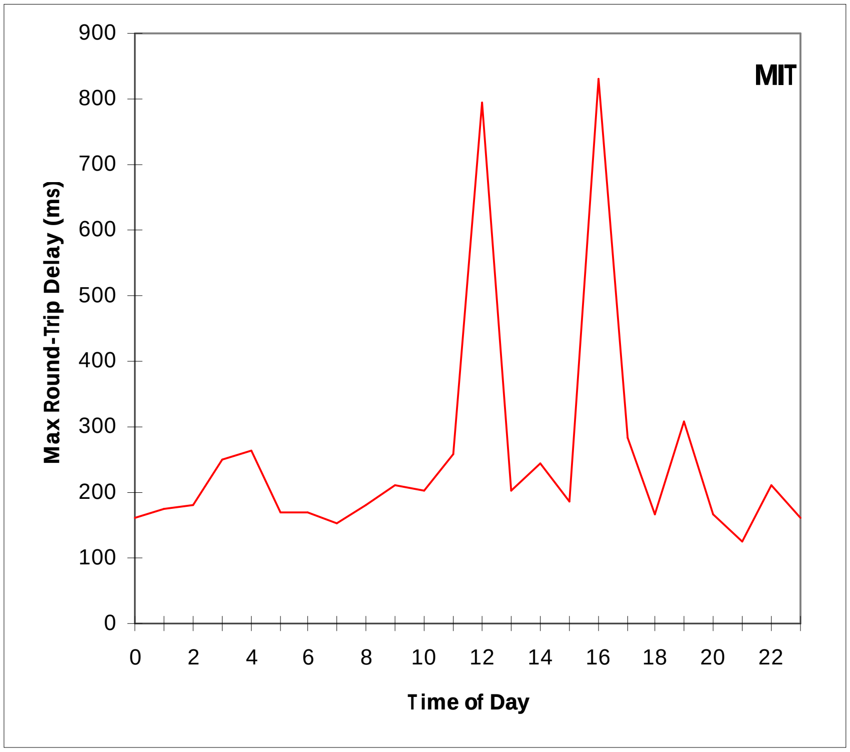


Figure 7.5-38 Average Round-Trip Delay (Period March 5-7, 1996) (Cont.)

Also instructive is the delay range. From Figure 7.5-39, it is observed that while the minimum delay stays more or less the same, the maximum hourly delay suffers large increases during the peak periods. (Long delays occur also outside these periods, but since they do not affect the average delay they must be sporadic and of short duration.)



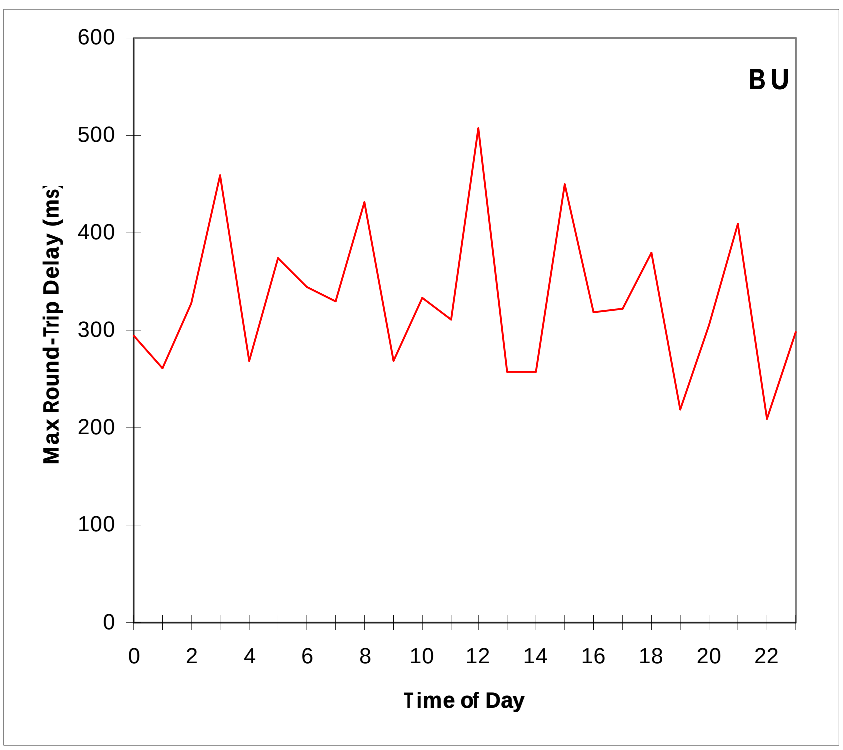
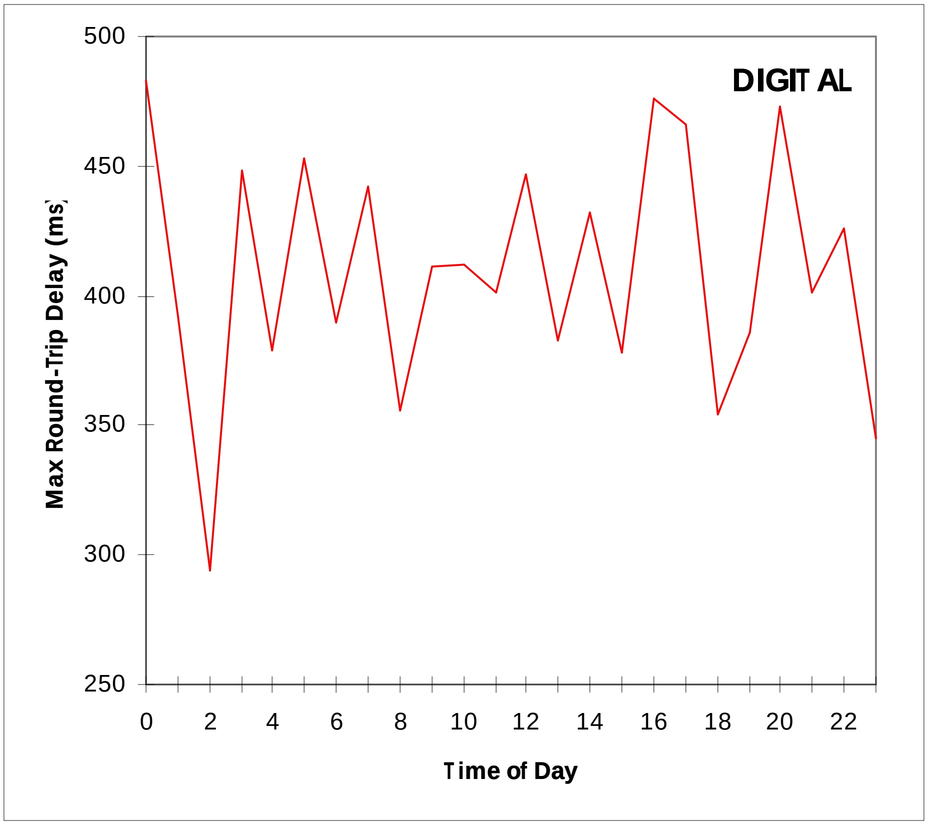


Figure 7.5-39 Example of the Range of Round-Trip Delays (Boston, March 5-7, 1996)



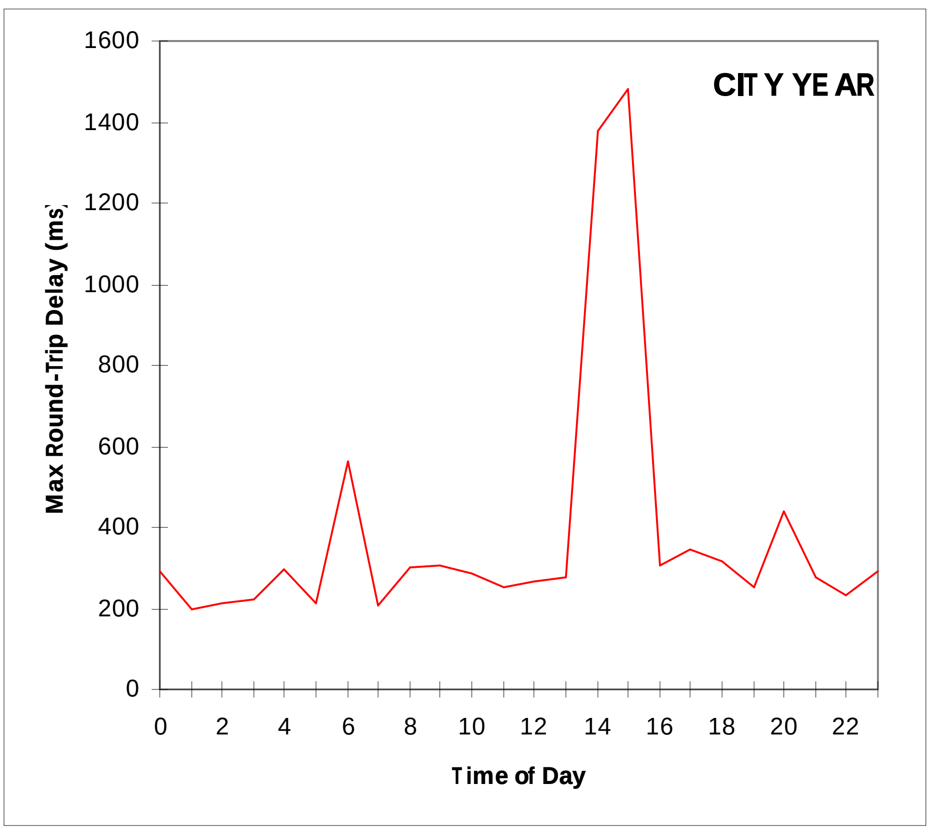


Figure 7.5-39 Example of the Range of Round-Trip Delays (Boston, March 5-7, 1996) (Cont'd)

7.5.2.4.3 Packet Loss

Equally important, from the point of view of information delivery, is packet loss. The co-operative workings of the Internet subject each packet to the perspective of being dropped at each router if the load exceeds the queues or the processing capabilities of the router (many are not dedicated routers).

During the same period March 5-7, 1996, information was collected on packet loss for the same organizations as above. The samples are shown in Figure 7.5-40. The conclusion is that the packet loss peaks in general with the round-trip delay.

The higher loads in the network imply higher loads in the routers, more difficult routing, and more likely overload of the routers. When overloaded, the routers implement a non-discriminating rejection of incoming packets to keep their load within reason, and not overflow.

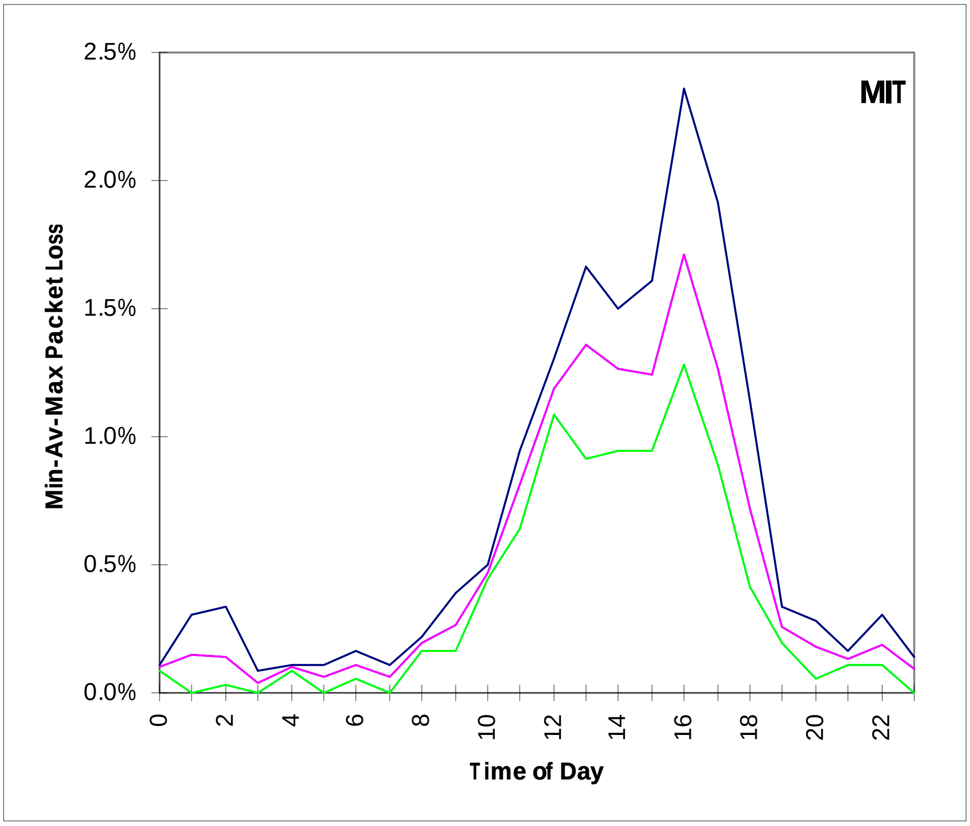


Figure 7.5-40 Minimum-Average-Maximum Packet Loss (Boston, March 5-7, 1996)

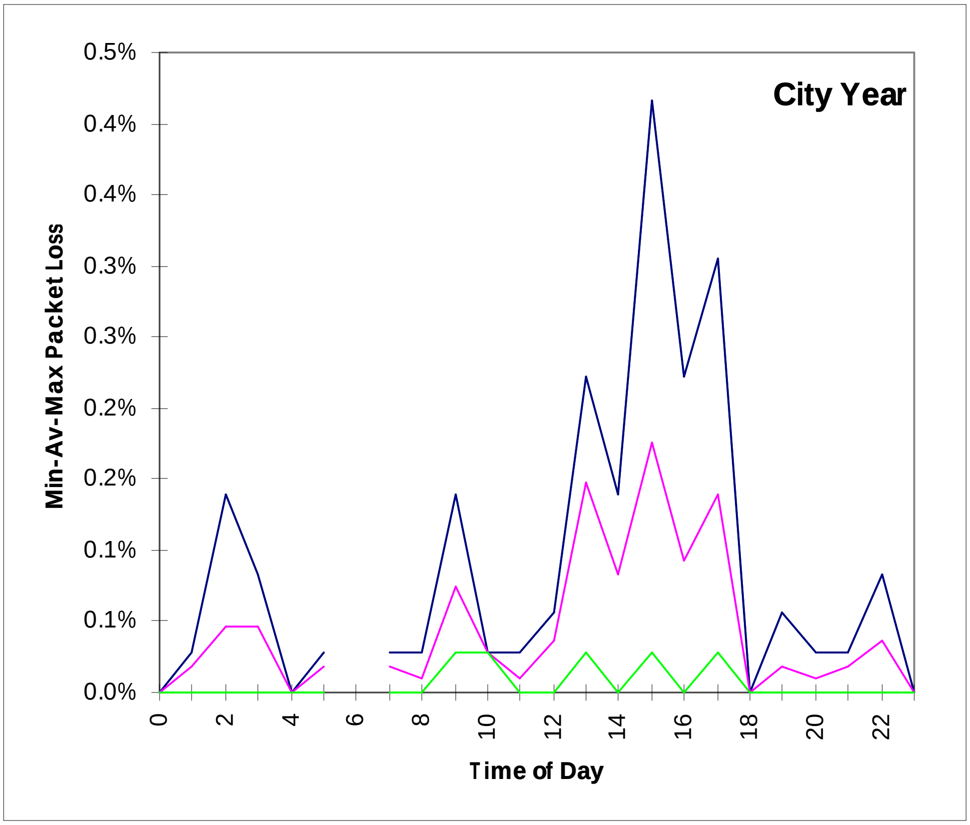


Figure 7.5-40 Minimum-Average-Maximum Packet Loss (Boston, March 5-7, 1996) (Cont'd)

7.5.2.4.4 Conclusions

Besides the privacy and security issues of communicating over the Internet, which are still far from resolved, the stochastic nature of the traffic on the Internet must be considered. The variance of the round-trip delay, as well as its average and the percentage of packet loss vary significantly over time. Thus, all those ITS applications requiring timely, consistent delivery of information should not use the Internet as a means of transferring information.

The occurrence of packet losses points also to the need of using a guaranteed delivery protocol like TCP, and restrict the use of non-guaranteed delivery protocols (like UDP) to non-essential, mostly repetitive transactions (e.g., vehicle location,and normal, i.e., non-emergency, vehicle status reports).

7.6 Technology Survey and Assessment Summary

Section 7.5 presented a very broad survey and assessment of the telecommunications technologies applicable to the ITS Architecture. The key differentiating features of these technologies are summarized in this section, as a quick reference for the convenience fo the reader. Table 7.6-1 provides an easy to read compilation of the terms and definitions used in the summary (and earlier in Section 7.5). Table 7.6-2 provides the summary comparison for terrestrial wireless data systems. Table 7.6-3 provides the summary comparison for satellite systems. A fraction of the table entries contain a "?" indicating the unavailability of information at the time of writing this proprietary information. It should be kept in mind that advanced technology evolves rapidly, so the information in the tables will need to be kept up to date in the future.

Table 7.6-1 Definition of the Entries in the Summary Tables

TERM	DESCRIPTION
SATELLITE SYSTEMS	Name of the satellite system
PARTNERSHIP	List of the companies, organizations, or individuals who are the principals and/or contributors of capital
SPECIFIC CHARACTERISTICS	
ORBIT CLASS	**Classification of the satellite orbit** **LEO -** Low Earth Orbit. Altitude is typically below 10,000 km. **Big LEO -** The term "Big" refers to the fact that the system is designed for voice and data services. The operating frequency is above 1 GHz. **Little LEO** - Little LEO's operate below 1 GHz, typically in the VHF band. Designed for data services only. **GEO -** Geosynchronous Earth Orbit. Altitude is approximately 36,000 km. Geostationary satellites having this orbit remain stationary over the same earth location. **HEO -** Highly Elliptical Orbit. Orbit has large eccentricity (continuously changing altitude) **MEO -** Medium Earth Orbit. Altitudes ranging from 3,000 km to 20,000 km. **ICO -** Intermediate Circular Orbit, as termed by the European satellite community. Same as MEO.
ALTITUDE (km)	Orbital altitude in kilometers over the surface of the earth.
NUMBER OF SATELLITES	Total number of satellites in the specified satellite system.
NUMBER OF PLANES	Number of planes used in the satellite system
ORBITAL PERIOD (minutes)	Orbital period in minutes
AVERAGE SATELLITE VISIBILITY TIME (minutes)	Average time that a satellite is visible to the user's communication equipment on earth in minutes.
MULTIPLE SATELLITE VISIBILITY	**yes** - indicates that more than one satellite is visible to the user's communication equipment on earth. **no** - indicates that only one satellites is visible to the user's communication equipment on earth.
SATELLITE DIVERSITY	**yes** - indicates that signals (carrying identical information) from two or more satellites are combined using a technique so as to improve reception for the land user. **no** - indicates that satellite diversity is not used.
MULTIPLE ACCESS TECHNIQUE	Schemes used to provide multiple users access to the network in order to minimize transmission overhead and maximize overall throuput. **Fixed-assignment channel-access**: **CDMA -** Code Division Multiple Access. **DS-SS -** Direct Sequence Spread Spectrum **FDMA** - Frequency Division Multiple Access. **FH-SS -** Frequency Hopped Spread Spectrum **SDMA -** Spacial Division Multiple Access.

TERM	DESCRIPTION
	TDMA - Time Division Multiple Access. **TDD** - Time Division Duplexing (a form of TDMA) **Multiplexing technique:** **FDM -** Frequency Division Multiplexing **TDM -** Time Division Multiplexing **Random-Access Methods**: **Dynamic Slotted ALOHA protocol** **DSMA/CD** - Digital Sense Multiple Access/ Collision Detection **Data Sense Multiple Access**
MODULATION	**BPSK or PSK -** Binary Phase Shift Keying **QFSK or 4-ary FSK-** Frequency Shift Keying with four orthogonal signals **GMSK -** Gaussian Filtered Minimum Shift Keying **QPSK -** Quadrature Phase Shift Keying **O-QPSK -** Offset Quadrature Phase Shift Keying
FREQUENCY BAND	**VHF -** Very High Frequency, 30 to 300 MHz **UHF -** Ultra High Frequency, 300 to 3000 MHz **SHF -** Super High Frequency, 3 to 30 GHz **L-band -** 390 MHz to 1.55 GHz **S-band -** 1.55 GHz to 5.2 GHz **Ka-band -** 33 GHz to 36 GHz **SMR band -** 896-901 MHz, 935- 940 MHz **Cellular band -** 824-849 MHz, 869-894 MHz **ISM -** 902-928 MHz **Narrowband PCS** – 901 to 902 Mhz, 930 to 931MHz, 940- to 941MHz **Paging -** 929-932 MHz
UPLINK FREQUENCY BAND	Allocated frequency band for transmission use from the earth user to the satellite.
DOWNLINK FREQ. BAND	Allocated frequency band for transmission use from the satellite to the earth user
DELAY CHARACTERISTICS	
Minimum mobile link one-way propagation time (ms)	Minimum one-way propagation time between mobile user and satellite in milliseconds.
Maximum mobile link one-way propagation time (ms)	Maximum one-way propagation time between mobile user and satellite in milliseconds.
SATELLITE ON-BOARD PROCESSING	**no** - indicates a “bent-pipe” or transparent transponder **yes** - indicates on-board signal regeneration before retransmission
HAND-OFF	**no** - indicates that a terminal’s call within one cell area or satellite can not be handed off to another cell or satellite as the terminal moves into this new area. **yes** - indicates that a terminal’s call can be handed off to an adjacent cell or satellite
VOICE CIRCUITS PER SATELLITE	Number of voice channels that a satellite can accommodate
COVERAGE	Geographic region in which service is provided by the system
MATURITY/ FEASIBILITY	
SCHEDULED OPERATION	Estimated date of initial service of system
PERCENTAGE OF OBTAINED FINANCE	Estimated percentage of obtained finance for the system
FCC LICENSE	**Date** indicates the estimation of when the system obtained an FCC license.
CAPABILITIES	
VOICE RATE (kbps)	Bit rate of digitized voice in kilobits per second.
DATA RATE(kbps)	Bit rate of data information. Units given in kilobits per second.
MOBILITY	
DUAL-MODE versus SINGLE MODE USER TERMINALS (land and satellite)	**Dual -** indicates that the terminal provides operating modes for both satellite and terrestrial communications. **Single -** indicates that the terminal provides only one operating mode.
HAND-HELD versus PORTABLE USER TERMINALS	**Portable** - indicates that the user terminal is a briefcase- or bag-sized self-contained unit combining antenna, battery,

TERM	DESCRIPTION
	transceiver and handset. **Hand-Held** - indicates that the user terminal is sized to a human's palm.
SYSTEM SECURITY	**Confidential Service** - a service for which the content of the user's data, traffic volumes and identities is kept confidential or private. This service prevents unwarranted extraction of information from the communication channel. **Authentication Service** - a service which ensures that the content of the user's data and any other information is genuine, unaltered, and complete. This service also ensures that the information is not an unlawful replay of information. This service prevents someone from injecting false data into the communication channel. **Encryption -** security mechanism which converts plaintext into cyphertext. Cyphertext is unintelligible except to those individuals/systems that know the secret of the decryption algorithm. An encryption service enables both confidential and authentication services.
COSTS	
SYSTEM (Million US Dollars)	Estimated cost of the full deployment of the system in Millions of US Dollars.
USER TERMINAL (US Dollars)	Estimated cost of the terminal in US Dollars.
VOICE RATE (US Dollars per minute)	Estimated cost of voice service in US Dollars per minute.
DATA RATE (US Dollars per kbyte)	Estimated cost of data service in US Dollars per kilobyte.
SERVICES	List of services made available by the system.
TARGETED APPLICATIONS	Applications for which the system was designed.

Table 7.6-2 Summary Comparison of Wireless MAN and Cell-based Land Mobile Systems

	RAM Mobile Data USA	ARDIS	GEOTEK	CDPD	"CDPDng"	SKYTEL	METRICOM	TAL
PARTNERSHIPS	RAM Broadcasting Corporation, BellSouth (originally developed by Ericsson and Swedish Telecom)	Motorola and IBM	Geotek	CDPD Forum (150 companies including cellular service providers, equipment manufacturers, software developers)	CDMA Data Group	Mobile Tele-communications Technology, Inc.	Metricom	Tetherless Access LTD.
System Characteristics								
COMMUNICATION TECHNOLOGY	SMR	SMR	ESMR	Cellular	Cellular	2-way paging	MAN	?
SWITCHING	packet	packet	packet	packet and circuit	packet and circuit	n/a	packet	
OPEN STANDARD	*Although promoted as an open architecture and a defacto standard, uses proprietary network layer protocol called MPAK.	proprietary	proprietary	yes	yes	proprietary (Motorola's ReFLEX 500 protocol)	proprietary	proprietary ?
RADIO CHANNEL ACCESS TECHNIQUE	proprietary, TDMA	proprietary, FDMA	proprietary, FHSS	Open, FDMA (packet radio overlay on AMPS)	will be open, (packet radio overlay on CDMA)	proprietary	proprietary, FHSS	proprietary, CDMA ?
MULTI-USER ACCESS TECHNIQUE	Data Sense Multiple Access	Dynamic-Slotted ALOHA	?	Broadcast in Forward direction; Digital-Sense Multiple Access/Collision Detection (DSMA/CM) in Reverse direction (packet radio overlay on AMPS)	CDMA-SS	?	?	?
MODULATION	GMSK	4-ary FSK	?	GMSK	?	BPSK/QPSK	wide ?	?
BANDWIDTH	12.5 kHz	25 kHz	?	30 kHz	?	25 kHz	wide ?	?
FREQUENCY BAND	SMR	SMR	ESMR	Cellular	Cellular	Narrrowband PCS	ISM	?
LICENSED SPECTRUM	yes	yes	yes	yes	yes	yes	no	no
NETWORK ARCHITECTURE	macro cellular	macro cellular	macro cellular	cellular	cellular	macro cellular	micro cellular with no handoffs, multihop	micro cellular, multihop
MOBILITY	vehicle speeds	vehicle speeds	??	highway speeds	highway speeds	low vehicle speeds	pedestrian speeds	pedestrian speeds
SYSTEM SECURITY	no (user provided encryption)	no (user provided encryption)	Medium (use of spread spectrum)	high (encryption algorithms)	high (encryption algorithms)	no (user provided encryption)	Medium (use of spread spectrum)	??
MATURITY OF SYSTEM	mature	mature	new	mature	future	new	new	?
SERVICES								
IP TRANSPORT	no	no	future	yes	yes	n/a	yes	yes
IP TRANSPARENT (use of gateways)	yes	yes	future	yes	yes	n/a	no	?

Table 7.6-3 Summary Comparison of Proposed Satellite Systems

SATELLITE SYSTEMS	**ORBCOMM**	**STARSYS**	**VITASAT**	**CONSTELLATION (formerly ARIES)**	**GLOBALSTAR**	**IRIDIUM**	**TELEDESIC**	**ELLIPSO**	**ICO (formerly Inmarsat-P)**	**ODYSSEY**	**INMARSAT (A,B,C,M)**	**MSAT**	**SKYCELL**
PARTNERSHIP	Orbital Sciences Corp., Teleglobe, TRW	North America Collection and Location by Satellite (NACLS), ST System	Volunteers In Technical Assistance (VITA, VITACOMM)	Constellation Communication Joint venture with TELEBRAS for the equatorial plane (ECCO)	Loral, Qualcomm	Motorola	Bill Gates of Microsoft, and Craig McCaw founder of McCaw Cellular Communications, Inc. and chairman of Teledesic	Ellipso	Multiple Government Agencies, Hughes	Teleglobe, TRW	Multiple Government Agencies (International Maritime Satellite Organization, consortium of 60 countries)	American Mobile Satellite Corp., Glentel, Inc., BCE, Spar Aerospace, Hughes, Mitsubishi, Westinghouse	American Mobile Satellite Corp. (Hughes, AT&T, MTel, Singapore Telecom
Specific Characteristics													
ORBIT CLASS	Little LEO	Little LEO	Little LEO	Big LEO	Big LEO	Big LEO	Big LEO	MEO and HEO	MEO (Intermediate Circular Orbits, ICO)	MEO	GEO	GEO	GEO
ALTITUDE (km)	775, 950-1150 depending on reference	1288	800	1018	1400	780	695-705	MEO is 8040; HEO is 7846x520	10355	10354	35786	35786	35786
NUMBER OF SATELLITES	20, 26, 36 depending on reference	24	2 to 3	48	48 plus 8 spare	66 plus 6 spare	840 plus up to 84 spare	MEO is 6; HEO is 10	10 plus 3 spare	12 plus 3 spare	Inmarsat phase 2 uses 4 satellites (since 1992) Inmarsat phase 3 uses 5 satellites (projected 1996)	2	?
NUMBER OF PLANES	3	?	?	4	8	6	21	2	2	3	?	?	?
ORBITAL PERIOD (minutes)	104.1-108.3	?	?	105	114	100	99	MEO is 280; HEO is 180	359	360	N/A	N/A	N/A
AVERAGE SATELLITE VISIBILITY TIME (minutes)	95% of time	?	?	?	8.21	5.54	1.74	?	57.8	47.27	always	always	always
DUAL SATELLITE VISIBILITY	?	?	?	?	3 or more	at poles	>= 2 most of the time	>= 2 North of 40° South	usually >= 2	>= 2	?	?	?
SATELLITE DIVERSITY	?	?	?	?	yes	no	no	yes	yes	no	?	?	?
MULTIPLE ACCESS TECHNIQUE	?	?	?	CDMA	CDMA	FDMA/ TDMA/ TDD	TDMA, SDMA, FDMA, Advanced TDMA	CDMA	TDMA	CDMA	mostly FDMA	TDMA/TDD	FDMA
MODULATION	PSK	?	?	?	QPSK	QPSK	?	O-QPSK	QPSK	QPSK	?	?	?
UPLINK FREQUENCY BAND	VHF	?	?	L-band	L-band	L-band	Ka-band	L-band	S-band	L-band	?	L-band	L-band
DOWNLINK FREQ. BAND	VHF	?	?	S-band	S-band	L-band	Ka-band	S-band	S-band	S-band	?	L-band	L-band
Delay Characteristics													
Minimum mobile link one-way	?	?	?	3.39	4.63	2.6	2.32	?	34.5	34.6	238	238	238

Table 7.6-3 Summary Comparison of Proposed Satellite Systems

SATELLITE SYSTEMS	**ORBCOMM**	**STARSYS**	**VITASAT**	**CONSTELLATION (formerly ARIES)**	**GLOBALSTAR**	**IRIDIUM**	**TELEDESIC**	**ELLIPSO**	**ICO (formerly Inmarsat-P)**	**ODYSSEY**	**INMARSAT (A,B,C,M)**	**MSAT**	**SKYCELL**
propagation time (ms)													
Maximum mobile link one-way propagation time (ms	5 sec	?	?	?	11.5	8.2	3.4	38.7	48	44.3	275	?	?
SATELLITE ON-BOARD PROCESSING	?	?	?	?	no	yes	yes	?	?	no	no	no	no
HAND-OFF	?	?	?	?	yes	yes	yes	yes, terminal not involved	yes	yes	?	?	?
VOICE CIRCUITS PER SATELLITE	?	?	?	?	2000-3000	1100 (power limited)	100,000 (16 kbps channels)	?	4500	2300	?	?	?
COVERAGE	US now, Global future	Global	Global, designed for developing countries including South America, Africa	Global	within +/- 70° latitude	Global	Global, except for 2° hole at poles; 95% of earth's surface	North of 50° South	Global	major land masses	Global	North America, Hawaii, Caribbean	North America
MATURITY/ FEASIBILITY													
SCHEDULED OPERATION	Currently Operational in US; 1996 Canada and Mexico; 1997 Europe and Latin America	1996	1996	1998	1998	1998	2001	1998	2000	2000	Operational since 1993	1996	?
PERCENTAGE OF FINANCE OBTAINED THUS FAR	~100%	?	?	~15%	~70%	~30%	?	?	58%	?	?	?	?
FCC LICENSE	late 1994	Experimental License in 1992	?	?	Jan. 1995	?	?	?	?	?	WARC '92 and WRC '95	?	1989
CAPABILITIES													
VOICE RATE (kbps)	?	?	?	4.8	adaptive 2.4/4.8/9.6	2.4/4.8	16	4.15	4.8	4.8	6.4 to 16 depending on system	?	?
DATA RATE(kbps)	2.4 uplink, 4.8 downlink	?	?	2.4	7.2 sustained throughput	2.4	16 to 2048	0.3 to 9.6	2.4	9.6	0.6, 2.4, 9.6, 64 depending on system	2.4	1.2-4.8
MOBILITY	?	?	?	?	?	?	Fixed	?	?	?	Fixed and Mobile	Fixed (Canada and Alaska); Mobile (Contiguous 48 States)	Full mobility (vehicles, ships, and airplanes)
DUAL-MODE vs. SINGLE MODE USER TERMINALS (land and satellite)	?	?	?	?	DUAL	DUAL	SINGLE	DUAL	DUAL	DUAL	DUAL (drivers for ARDIS, CDPD, GSM)	DUAL	?
HAND-HELD vs. PORTABLE USER TERMINALS	Portable and Hand-held	?	Portable	Hand-held	Hand-held	Hand-held	Portable	Hand-held	Hand-held	Hand-held	Portable	Portable	Portable

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SYSTEM SECURITY	?	?	?	?	?	?	encryption	?	?	?	?	?	authenti-cation only
COSTS													
SYSTEM (Million U.S. Dollars)	?	?	?	$1,700	$2,000	$3,700	$9,000	$750	$2,600	$1,800	?	?	?
USER TERMINAL	$100 -$400	?	$3500	?	~$750/terminal; $1000-$1200 for telephone	$2500-$3000	?	~$1000; $300 add-on to digital cellular unit	"Several Hundred"	~$300	$5000-$35,000 depending on system	$5000-$6000	?
VOICE RATE (US Dollars per minute)	?	?	?	?	$0.35-$0.55	$3.00	?	$0.50	$1-$2	$0.75 ; $24 monthly charge	$2.00-$8.00 depending on system	$2.50	Standard, $25/month, $1.49/minut Business, $175/month 200 minutes free, $0.85/minut voice, data, fax
DATA RATE (US Dollars per kbyte)	$1.00 per 100 bytes	?	$50/month for up to 100 kbytes	?	?	?	?	?	?	?	$1.00-$1.50	?	similar to voice servic costs
SERVICES	two-way messaging, RDSS	one-way data, two-way messaging	two-way messaging; store and forward with typically 90 minute message delay and as much as 12 hour delay.	voice, data, fax	Voice, data, fax, paging, short message service, RDSS	Voice, data, fax, paging, messaging, RDSS	Voice, data, fax, paging, video	Voice, data, fax, paging, messaging, RDSS	Voice, data, fax, paging	Voice, data, fax, paging, messaging, radio determination satellite services (RDSS)	voice, data, fax, e-mail, store-and-forward, alerting, position determination	voice, data, fax, dispatch radio	Voice, data, fax, location determina-tion
TARGETED APPLICATIONS	emergency comm., 2 way-mail, remote resource monitoring	emergency comm. stolen asset recovery, hazardous material tracking	Store-and-forward data	extension of the cellular network	worldwide communication	worldwide communication	ISDN to rural businesses and remote terminals (fixed)	extension of cellular network	global phone through integration with cellular services	extension of cellular network	worldwide communication	mobile office, position determination, e-mail, monitoring, voice dispatching (2-way), broadcast and multicast messaging	transporta-tion, maritime, aeronautical remote site industries