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MP 2000-044

Broadband Wireless, Integrated Services, and Their Application to Intelligent Transportation Systems

June 2000

Keith Biesecker

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Center for Telecommunications and Advanced Technology
McLean, Virginia

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ABSTRACT

This paper introduces some of the newer broadband wireless communications alternatives and describes how they could be used to provide high-speed connections between fixed, transportable, and mobile facilities. We also describe the new integrated service technologies – devices used to bundle voice, data, and video services for transmission over a single link. In this case, it's a broadband wireless link.

Together, the new broadband wireless and integrated service technologies can be used to provide efficient, cost effective, and flexible multi-service provisioning. We introduce this concept and discuss its potential for Intelligent Transportation Systems (ITS).

Suggested Keywords: broadband, wireless, integrated service platform, multi-service access device (MSAD), integrated access device (IAD), Intelligent Transportation Systems (ITS)

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EXECUTIVE SUMMARY

Introduction

Companies, agencies, and individuals are increasingly seeking "anywhere" voice, data, and video services; consequently, the demand for high-speed (or broadband) wireless communications is growing rapidly. Developing nearly as fast as the demand for these untethered services is the desire to integrate them so that multiple communications resources are not required.

This paper introduces some of the newer broadband wireless communications alternatives and describes how they could be used to provide high-speed connections between fixed, transportable, and mobile facilities. We also describe the new integrated service technologies – devices used to bundle voice, data, and video services for transmission over a single link. In this case, it's a broadband wireless link.

Together, the new broadband wireless and integrated service technologies can be used to provide efficient, cost effective, and flexible multi-service provisioning. We introduce this concept and discuss its potential for Intelligent Transportation Systems (ITS).

Our study is being conducted in two phases: an initial research effort, and a supplemental phase to develop a concept prototype. This paper documents the first phase of our study.

The Concept

Consider the ability to provide real-time voice, data, and video in support of the following operations:

- Back-up communications between traffic management centers
- Temporary communications between transit management centers and special event coordinators and/or portable kiosks
- Emergency communications between incident management centers and public safety units in the field

These are not exactly novel ideas, but consider the ability to establish such communication nearly "anywhere", and to permanently provide <u>all</u> of these services for less than the annual cost of a single data circuit[1].

This idea represents the basis for applying newer broadband wireless technologies to the integrated service platform. The general concept involves two aspects: integrating the services, and providing the wireless connectivity.

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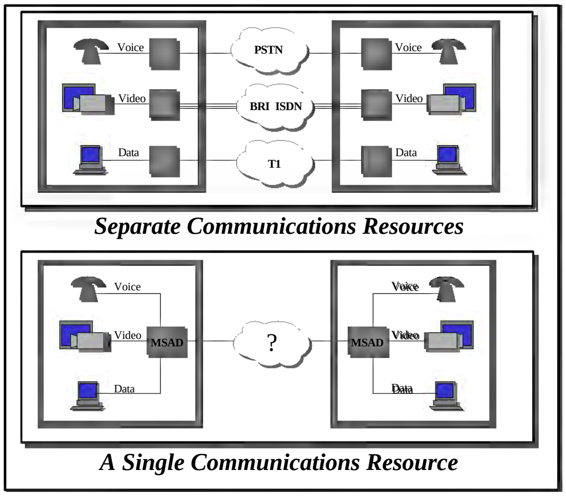
[1] As of January 2000, leasing a T1 circuit from Bell South involved non-recurring costs (NRC) of approximately $1025 and monthly recurring costs (MRC) of about $565. For one year alone, this circuit would cost over $ 7800. Some of the solutions presented in this document (with significantly more capacity and configured to support voice, data, and video services) can have NRCs on the order of $7500, and <u>no</u> MRCs.

❶ Integrating Services

Typically, several types of equipment and different transmission facilities must be patched together in order to construct an integrated service network (e.g., voice over a PSTN, data services over T1, and video teleconferencing over ISDN). Each of these services requires separate communications resources – separate equipment, separate transmission facilities, etc.



Alternatively, one can build an integrated platform by bundling services for transmission over a single facility. This bundling can be accomplish by a relatively new type of equipment – a Multi-Service Access Device (MSAD), or Integrated Access Device (IAD).

Aside from the obvious savings from bundling services, an integrated service platform requires less technical support, less maintenance, and less administration. It also eases the network management function.

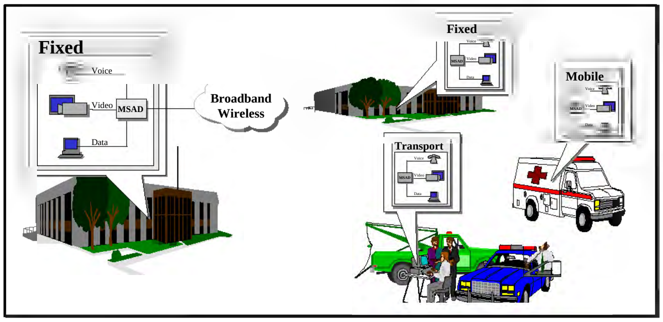
❷ Wireless Connectivity

Several companies now use wireline communications (e.g., fiber optics) to support an integrated service platform. However, we consider the wireless alternative. Wireless communication offers the flexibility to enable the "anywhere" concept.

While communication can not literally be established "anywhere", it can be established in many different locations. The coverage, as well as mobility and other performance parameters, depend on the specific wireless technology. Each presents different ways to connect fixed, transportable, and/or mobile subsystems.

Broadband wireless refers to those communications technologies that use larger (or broader) portions of the radio frequency (RF) spectrum. This spectrum is needed to achieve higher data rates, which are in turn required to adequately provide for the integrated services. For the purpose of this effort, and to limit the scope of the task, broadband will refer to those technologies that can support bi-directional data rates of at least 384 kbps.

MSADs efficiently integrate services, and broadband wireless provides high-speed and flexible connectivity. Together, these technologies can provide more services, between more locations, with less cost. And these trends will continue as the technologies develop.



Markets and Applications

The last decade has seen enormous growth in wireless communications. According to the consulting firm Ernst & Young, by 2008 wireless will surpass wireline as the dominant method of telecommunications worldwide[2]. While voice services were the driving factor this past decade, the next decade's growth will be fueled by the demand for high-speed data and video services. This will subsequently increase the demand for broadband wireless.

Federal Communications Commission (FCC) Chairman William Kennard recently expressed that the "central focus" of many of the Commission's policies is to create more wireless spectrum so that carriers can develop broadband services. A recent report from telecommunications research consulting company The Strategis Group predicts that fixed broadband wireless revenues will increase at a 418% compound annual rate over the next five years.

In addition, most telecommunications companies and local exchange carriers are beginning to offer integrated voice, data, and video services – a trend being fueled by not only the growing demands for Internet access and multimedia, but also the decreasing revenue from voice-only services. Analysts predict that these "bundled" services will soon become a major source of revenue for the large carriers.

Why is this market information relevant? It indicates the level of private sector interest and the level of government support. Both impact development of broadband wireless and integrated service technologies, which subsequently impacts the ways in which one can support ITS.

In addition to the general applications of these technologies (e.g., mobile and thin-client computing, interactive video and video teleconferencing, Internet/intranet access and virtual private networking), we present specific transportation-related applications. Some currently use broadband wireless. Others do not, but could.

Within the framework of the National ITS Architecture, broadband wireless and integrated service technologies provide a viable means for exchanging information between many different ITS subsystems.

- For Center-Center communications, this would involve traffic video feeds, analog and digital voice services, LAN extension (for exchange of documents, imagery, etc.). It might also include newer applications such as IP-based video teleconferencing and real-time multimedia collaboration.
- For Center-Traveler communications, this exchange would involve multimedia ATIS (e.g., real-time voice, data, and video for traffic reporting, yellow pages information, and/or emergency assistance).

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[2] "The 3G Force", http://www.redherring.com/mag/issue69/news-threegee.html (December 1999)

- For Center-Roadside or Center-Vehicle (transportable) communications, it would involve similar voice, data, and video services for emergency roadside assistance, remote medical triage, etc.

With different system designs, similar applications can be supported directly between vehicle, roadside, and/or traveler subsystems (i.e., without a center facility).

Integrated Service Platforms and the Multi-Service Access Device (MSAD)

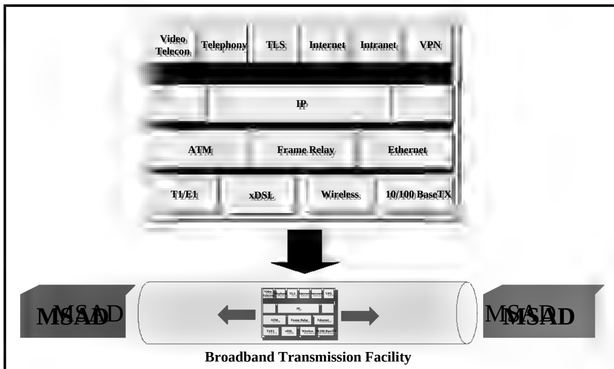
The ability to integrate services is no longer limited to the major carriers and their complex networks. With the MSAD, bundled services can now be afforded by the smaller provider as well, whether commercial provider, private company, or public agency.

MSADs can support:

- Dial tone (POTS, PSTN access, FAX)
- Corporate PBX or key system access
- High-speed Internet access
- Corporate intranet access and virtual private networking (VPN)
- Video teleconferencing
- Collaborative multimedia

These devices combine the functions of various communications equipment that would typically be needed to construct a multi-service network. This includes: routers, bridges, channel/digital service units (CSU/DSU), digital access cross-connect systems (DACS), private branch exchanges (PBX), DSL access multiplexers (DSLAM), asynchronous transfer mode (ATM) switches, subscriber management devices, etc.

The integrated functions allow the MSAD to combine multiple traffic types, effectively separating services from transmission technologies. The integrated traffic may be an ATM or Frame Relay virtual circuit, an IP/Ethernet flow, etc., but it rides over a single transmission facility. This could be an existing T1 or DSL connection. Alternatively, it might be one of the newer broadband wireless technologies.



Multiple Traffic Types over a Single Transmission Facility

The resulting integrated service platforms are practical alternatives to traditional multi-service networks. By using broadband wireless to support these platforms, one adds the benefits of mobility and rapid deployment.

Broadband Wireless Technologies

There are several older broadband technologies, both wireline and wireless. Within this document, we review many of the newer wireless technologies. Some are relatively inexpensive and use unlicensed spectrum; others require more expensive implementations that depend on licensed spectrum. The coverage, architecture, mobility, and various performance parameters will depend on the specific technology.

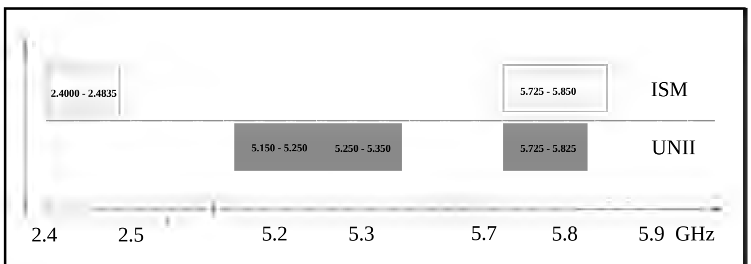
For each wireless technology or service, we address issues such as:

- Spectrum and Licensing (if applicable)
- Architecture
- Performance (e.g., data rates)
- Standards
- Existing Products, Services, and/or Systems

We also discuss costs, security, related technical innovations, system enhancements, like/similar technologies, etc.

<u>Unlicensed Spectrum Technologies</u>

Most of the unlicensed spectrum technologies presented in this document were designed to operate under Part 15 of the FCC rules and regulations. There are several Part 15 frequency bands in which to operate, but we limit our discussions to the 2.4 GHz and 5.8 GHz industrial, scientific, and medical (ISM) bands and the new 5.3 GHz and 5.8 GHz Unlicensed National Information Infrastructure (UNII) bands. Most development in broadband wireless is occurring in these areas.



2.4 GHz ISM and 5GHz ISM & UNII Bands

Of those technologies using 2.4 GHz ISM, we review the following:

- Wireless Local Area Network (WLAN) Technologies: One standard currently underpins much of the development in this market – **IEEE 802.11b**. We also address the **OpenAir** WLAN standard.

- Other Wireless Networking Standards: We briefly discuss **Bluetooth**, a technology providing basis for a new IEEE 802.15 personal area network (PAN) standard. We also address the **HomeRF** standard.

- Proprietary Wireless Networking: There are several proprietary networking technologies that operate at 2.4 GHz. Service providers offering wireless “last mile” connectivity have now formed the largest market for such equipment.

Technologies using either the 5 GHz ISM and UNII bands include:

- WLAN Technologies: The 802.11b standard has put wireless LANs on a rough parity with wireline Ethernet. However, new 5 GHz WLAN technologies will offer even better performance with data rates exceeding 50 Mbps and quality-of-service (QoS) features that can adequately support isochronous services such as voice and video. We focus on **IEEE 802.11a** and the **four HIPERLAN** standards.

- Proprietary Wireless Networking: The 5 GHz unlicensed spectrum is primarily used for outdoor long-range systems (i.e., miles not feet). While not many operational systems currently use this spectrum, proprietary technologies constitute the most rapidly evolving type of equipment in these bands.

In addition to Part 15 devices, we review two other unlicensed broadband technologies: free space optics and ulta-wideband (UWB) radio.

- **Free space optics** have been around for years, but most were used for point-to-point systems and were not particularly designed for distributed networks. However, advancements in optical systems (e.g. multiplexing techniques, optical switching, automatic tracking, and power control) have significantly improved wireless optical networking.

- **UWB** radio is currently an experimental technology for short-range radar applications. However, UWB-based communications equipment, such as that used for local area networking, might be in the foreseeable future.

Unlicensed Spectrum Technologies	Data Rates (per channel)	Max Range [1] indoor [1]	outdoor [2]
2.4 GHz ISM Band			
IEEE 802.11b	1 - 11 Mbps	~300 - 400 ft	2-20+ mi
OpenAir	0.8 - 1.6 Mbps	~300 - 400 ft	3-20+ mi
HomeRF	1-2 Mbps	~100 ft	-
Bluetooth	< 0.5 Mbps	~ 30 ft	-
Proprietary Technologies	~ 1 - 11 Mbps	~100 - 500 ft	2-20+ mi
5 GHz ISM and/or UNII Bands			
IEEE 802.11a	6 - 54 Mbps	~200 ft	35+ mi
HIPERLAN I	24 Mbps	~200 ft	35+ mi
HIPERLAN II	6 - 54 Mbps	~200 ft	35+ mi
HIPERAccess	~20 Mbps	-	-
Proprietary Technologies	6 - 100+ Mbps	-	35+ mi
Free Space Optics	155 - 1000 Mbps	-	0.1 - 1.25 mi
Ultra Wideband (UWB) Radio	20 - 100 Mbps	?	?

[1] Nominal maximum indoor ranges
[2] Using supplemental antenna systems

Unlicensed Spectrum Technologies

Note: Table does not represent all the unlicensed spectrum technologies addressed in this document; nor is it completely indicative of the technologies' potential.

Licensed Spectrum Technologies

As indicated by the billions of dollars spent in recent auctions, licensed spectrum technologies are expected to become a valuable commodity. We review many of the new broadband services/technologies, including:

- Local Multipoint Distribution Service (**LMDS**): a high-speed, wireless networking technology/service that operates in the 28-31 GHz range.
- Multichannel Multipoint Distribution Service (**MMDS**): a 2-3 GHz technology/service to provide wide-area, high-speed, wireless networking.
- Wireless Communication Service (**WCS**): a 2 GHz technology/service that may be used for fixed or mobile communication.
- General Wireless Communication Service (**GWCS**): a 5 GHz technology/service also intended for fixed or mobile communication, including ground-to-air services.
- Broadband Personal Communication Service (**Broadband PCS**): Broadband PCS systems operate within both the 1900 MHz PCS bands and the 800 MHz digital cellular bands. We focus on use of the PCS spectrum. We also address both fixed and mobile systems, including second generation (**2G**), enhanced second generation (**2.5G**), and third generation (**3G**) PCS.
- Satellite Services: Satellite systems provide the means to extend services to underdeveloped urban areas as well as the suburban and rural markets. We review the **Teledesic** and **SkyBridge** broadband LEO systems, as well as a new broadband GEO system called **SkyDSL**.
- Digital Television (DTV): **DTV** is unique to our study. It is the only technology we review that is intended for broadcast only communication. However, this technology offers public safety and transportation agencies an effective (and possibly inexpensive) means of disseminating broadband multimedia.

Licensed Spectrum Technologies	Data Rates (per channel)	Range
Local Multipoint Distribution Service (LMDS)	~ 155 Mbps	~ 3.5 mi
Multichannel Multipoint Distribution Service (MMDS)	~ 37 Mbps	~ 30 mi
Wireless Communication Service (WCS)	~ 30 Mbps	~ 30 mi
General Wireless Communication Service (GWCS)	~ 30 Mbps	~ 30 mi
Broadband Personal Communication Service (Broadband PCS)		
Mobile Systems	0.144 - 2.048 Mbps*	~ 3 - 5 mi
Fixed Systems	~ 2+ Mbps	~ 3 - 7 mi
Satellite Service		
Teledesic	2 - 64 Mbps	global
SkyBridge	2 - 100 Mbps	global
SkyDSL	0.500 Mbps	North America
Digital Television (DTV) Alternative	19 Mbps	1 - 30 mi

Licensed Spectrum Technologies

Note: Table does not represent all the licensed spectrum technologies/services addressed in this document; nor is it completely indicative of the technologies' potential.

Conclusions

Phase I: Researching Broadband Wireless and the Integrated Service Platform

With significant advances in capacity and reliability, broadband wireless technologies now offer strong alternatives to wireline solutions. They also support the "anywhere" aspect of multimedia service provisioning. And as opposed to conventional broadband wireless, most are (or will soon be) more widely available, offer greater flexibility (i.e., better coverage for more users), offer better performance (e.g., larger data rates, enhanced quality-of-service), and are less expensive.

Additionally, most wireless systems are usually deployed in less time and with less cost than wireline alternatives – whether by public or private service provider. Some are also capable of rapid deployment (within days or even hours) in emergency situations.

In this initial phase, we have reviewed over fifty new broadband wireless technologies. However, by the time this document is published, many changes will have occurred, and new technologies will have emerged. The industry is extremely dynamic and must be followed continuously.

The transition to integrated services is also underway, and with the development of the MSAD, this capability is no longer restricted to the major carriers. In relatively inexpensive fashion, the MSAD can bundle voice, data, and video services for transmission over a single link. MSADs efficiently integrate the services; broadband wireless provides the high-speed and flexible connectivity.

For ITS, these technologies present several ways to rapidly exchange information between fixed, transportable, and mobile units, supporting any number of applications. Broadband wireless has already begun to appear in the transportation and public safety domains, particularly traveler information, traffic management, emergency/incident management, and law-enforcement. As ITS develops, the numbers and types of transportation-related applications will grow. The ability to support these applications with the developing broadband wireless and integrated service technologies could provide significant technical and financial benefits.

Phase II: Concept Prototyping

The second phase of our study will focus on a concept prototype. An appendix to this document provides preliminary details on the prototyping effort, including: the general prototype design, the potential test-bed location(s), and the demonstration and evaluation process.

Phase II began with the completion of this report, and the prototype should be operational by the end of the calendar year (2000). When our limited assessment is complete, we will document in further detail the prototype design and functionality, the test location and facilities, and the assessment methodology and results. We will also address other issues, concerns, questions, and problems that arise during phase II activities.

SECTION 1

INTRODUCTION

Companies, agencies, and individuals are increasingly seeking “anywhere” voice, data, and video services; consequently, the demand for high-speed (or broadband) wireless communications is growing rapidly. Developing nearly as fast as the demand for these untethered services is the desire to integrate them so that multiple communications resources are not required.

There have been several advancements toward both of these goals. However, broadband wireless and integrated service technologies are rapidly evolving and remain largely unknown to the transportation community, and research is needed to further establish their application within ITS. Mitretek is conducting such efforts in support of the Federal Highway Administration (FHWA).

1.1 PURPOSE

This paper introduces some of the newer broadband wireless communications alternatives and describes how they could be used to provide high-speed connections between fixed, transportable, and mobile facilities. We also describe the concept of a multi-service access device (MSAD) – equipment used to integrate voice, data, and video services for transmission over a single link, in this case a broadband wireless link.

Together, broadband wireless and integrated service technologies can be used to efficiently provide multimedia throughout the wireless coverage area, whether this is several hundred feet or several miles. We explain this concept in general and later elaborate on the idea by introducing concept prototypes.

Most importantly, we discuss how this concept can be used to support transportation-related applications. This includes the applications supporting traveler information, traffic management, incident/emergency management, and public safety operations.

1.2 SCOPE

Our study is being conducted in two phases: an initial research effort, and a supplemental phase to develop a concept prototype. This paper documents the first phase of our study.

After establishing the concept of using broadband wireless to support integrated services, we discuss general applications (i.e., the horizontal market). We then discuss applications of interest to the ITS program, both general and specific.

For the purpose of this study, and to limit the scope of the task, broadband communications technologies are defined as those that can support bi-directional data rates of at least 384 kbps. We review only wireless communications alternatives, since they provide the mobility and flexibility needed for “anywhere” services. However, because of the need to provide connectivity in different environments (local, wide-area, fixed, mobile, etc.), we discuss many different alternatives. Some of these use licensed spectrum (e.g., Local Multipoint Distribution Service (LMDS)), and others take advantage of license-free spectrum, such as the wireless LAN technologies. Only the newer broadband wireless technologies are observed; they are often as fast (if not faster), more flexible, and less costly than conventional technologies. They are also becoming more widely available.

There are variations on the MSAD, but their function and utility are nearly identical. These devices also operate independent of location. Therefore, we describe in general the role of this equipment and do not address the slight differences in available products.

After addressing the enabling technologies (i.e., broadband wireless and MSAD), we introduce a prototype that will be built to demonstrate the concept. Prototype development (phase II) began with the completion of this report.

1.3 ORGANIZATION

This document is divided into five additional sections and one appendix:

- Section 2 introduces the concept of applying broadband wireless to the integrated service platform.
- Section 3 presents existing markets for these technologies and introduces applications within the ITS domain.
- Section 4 describes the function of the MSAD – establishing an integrated service platform.
- Section 5 introduces several new broadband wireless technologies.
- Section 6 offers brief conclusions from this first phase of the effort.
- Appendix A presents a concept prototype.

SECTION 2

THE CONCEPT

Consider the ability to provide real-time voice, data, and video services in support of the following operations:

- Back-up communications between traffic management centers
- Temporary communications between transit management centers and special event coordinators and/or portable kiosks
- Emergency communications between incident management centers and public safety units in the field

These are not exactly novel ideas, but consider the ability to establish such communication nearly "anywhere", and to permanently provide all of these services for less than the annual cost of a single data circuit[1].

This idea represents the basis for applying newer broadband wireless technologies to the integrated service platform. The general concept involves two aspects: integrating the services, and providing the wireless connectivity.

2.1 INTEGRATED SERVICES

Figure 2-1 illustrates common methods for provisioning voice, data, and video services. Voice is provided over the public switched telephone network (PSTN), data services (e.g., corporate intranet) use T1 connections, and video teleconferencing is available over multiple Integrated Services Digital Network (ISDN) lines. Each of these services requires separate communications resources – separate equipment, separate transmission medium, etc.

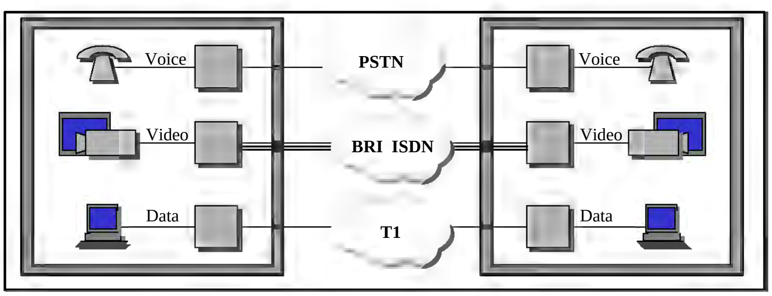


Figure 2-1. Separate Communications Resources for Different Services

[1] As of January 2000, leasing a T1 circuit from Bell South involved non-recurring costs (NRC) of approximately $1025 and monthly recurring costs (MRC) of about $565. For one year alone, this circuit would cost over $ 7800. Some of the solutions presented in this document (with significantly more capacity and configured to support voice, data, and video services) can have NRCs on the order of $7500, and no MRCs.

Alternatively, one could establish an integrated platform by bundling services for transmission over a single link, as shown in Figure 2-2. Recent development of the Multi-Service Access Device (MSAD), also referred to as the Integrated Access Device (IAD), allow one to do this effectively and in relatively inexpensive fashion.

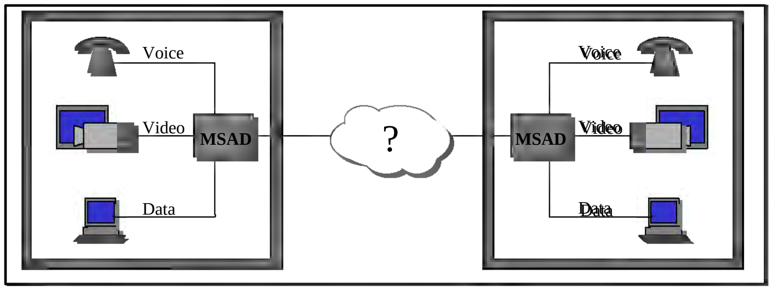


Figure 2-2. A Single Communications Resource for Different Services

Aside from the obvious savings from bundling services, the integrated service platforms require less technical support, less maintenance, and less administration. They also ease the network management function.

Figure 2-2 only illustrates the concept of integrated services and the MSAD. Additional information is provided in Section 4.

2.2 BROADBAND WIRELESS

Several companies currently use wireline communications (e.g., fiber optic systems) to support an integrated service platform. However, we consider the wireless alternative. Wireless communication offers flexibility in the physical location of system end-points – the “anywhere” concept. These locations are not truly anywhere, but anywhere within the range of a particular wireless system.

Broadband wireless refers to those communications technologies that use larger (or broader) portions of the radio frequency (RF) spectrum. This spectrum is needed to achieve higher data rates, which are in turn required to adequately provide for the integrated services. For the purpose of this effort, broadband will refer to those technologies that can support bi-directional data rates in excess of 384 kbps.

Wireless communications are traditionally identified as belonging within one of many RF service allocations: fixed, mobile, land mobile, satellite, mobile satellite, etc. These designations do not necessarily define or limit the application as one might infer. For this study, we refer to “fixed communications solutions” as those that can be used between any stationary end-points. These include transportable end-points – nodes that can be moved but are intended to communicate only while stationary.

We refer to "mobile communications solutions" as those that can be used between end-points while at least one of them is in motion – a mobile end-point. Motion is subjective, and we will discuss the degree of mobility as we address each individual wireless technology.

Additionally, the fixed and mobile communications solutions can be implemented in point-to-point, point-to-multipoint, or multi-point-to-multipoint architectures. Each is best suited for specific types of connections. Often hybrids are used to create a solution that can reach the entire market.

The different communications solutions and architectures create several configurations. We consider the following:

- Fixed communications, Point-to-point
- Fixed communications, Point-to-multipoint
- Fixed communications, Multipoint-to-multipoint
- Mobile communications, Point-to-multipoint

Point-to-point architectures are formed by two radios in direct communication with each other. This is the simplest architecture, but it is also the least scaleable. Point-to-point is well suited for high-speed dedicated links, such as high-speed backhaul connections or large corporate interconnections.

Point-to-multipoint architectures are formed between a base station radio (a hub) and multiple remote end-points. They allow coverage over a broader area, but each end-point must still be within range and line of sight (LOS) of the base station.

Multipoint-to-multipoint architectures are formed by a mesh of radio links. Each node in the network becomes part of the infrastructure and will route data through the network to its destination

Each of these configurations is illustrated below. Each presents several ways to connect fixed, transportable, and/or mobile end-points.

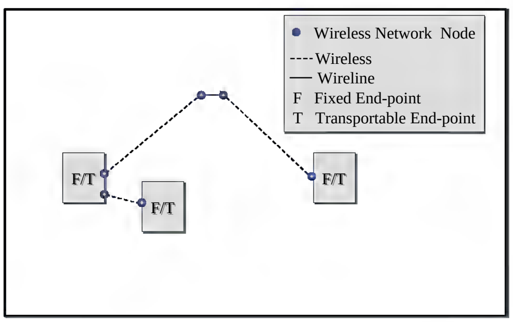


Figure 2-3. Fixed Point-to-point

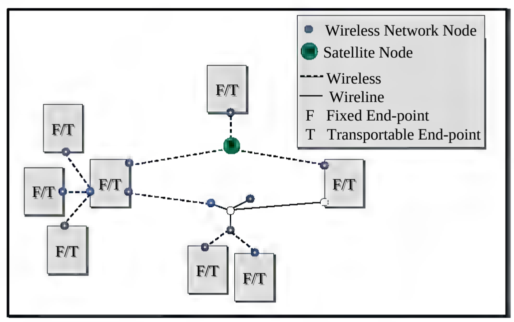


Figure 2-4. Fixed Point-to-multipoint

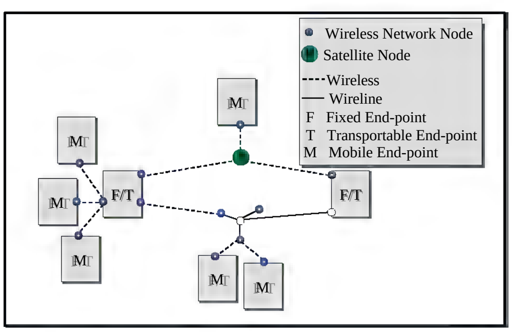


Figure 2-5. Mobile Point-to-multipoint

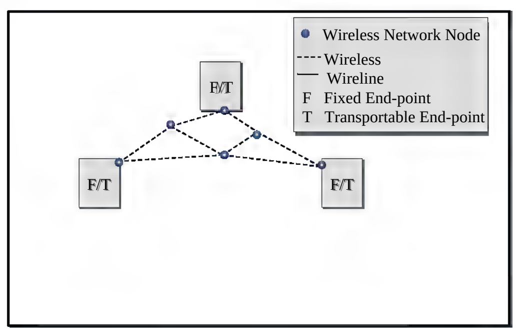


Figure 2-6. Fixed Multipoint-to-multipoint

Until recently, the availability of broadband wireless was severely limited, and the costs of using such resources were exorbitant. The older technologies (primarily terrestrial microwave and satellite transmissions) offered a mediocre, if any, solution. However, many new broadband wireless alternatives are less expensive and more widely available, as would be expected with any technology in demand. New broadband wireless technologies also offer greater flexibility and better performance.

Additionally, most wireless systems are usually deployed in less time and with less cost than wireline alternatives – whether by public or private service provider. Some are also capable of rapid deployment (within days or even hours) in emergency situations.

While communication can not be established "anywhere", it can be established in many different locations. The coverage, as well as mobility and other performance parameters, depend on the specific broadband wireless technology. We present this information in Section 5.

2.3 APPLYING BROADBAND WIRELESS TO THE INTEGRATED SERVICE PLATFORM

MSADs efficiently integrate services, and wireless broadband provides high-speed and flexible connectivity. Together, as illustrated in Figure 2-7, these technologies can provide more services, between more locations, with less cost. And these trends will continue as the technologies develop.

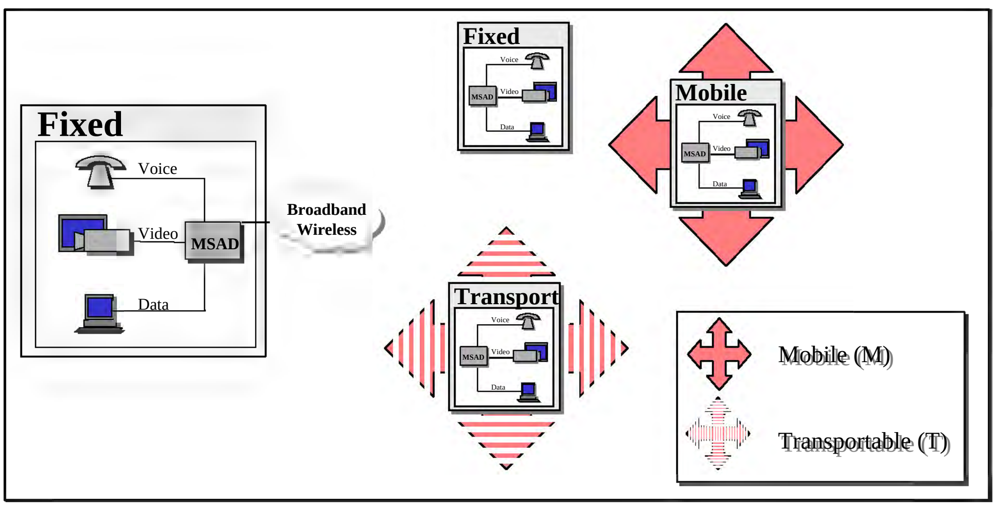


Figure 2-7. "Anywhere" Integrated Services

In the following section, we discuss the application of these integrated technologies. In Appendix A, we introduce a prototype that will demonstrate the concept.

SECTION 3

MARKETS AND APPLICATIONS

After briefly addressing the potential of broadband wireless, this section introduces some general applications (i.e., the horizontal market) and some developing vertical markets. We also present some specific transportation-related applications involving public safety, traffic management, and advanced traveler information. Finally, we identify information flows within the National ITS Architecture that could be supported by broadband wireless alternatives, particularly when applied to the integrated service platform.

3.1 THE BROADBAND WIRELESS MARKET

The last decade has seen enormous growth in wireless communications. According to the consulting firm Ernst & Young, by 2008 wireless will surpass wireline as the dominant method of telecommunications worldwide[1]. While voice services were the driving factor this past decade, the next decade's growth will be fueled by the demand for high-speed data and video services. This will subsequently increase the demand for broadband wireless.

Whether for commercial or consumer use, broadband wireless offers a competitive alternative to wireline solutions. Creating a wireless infrastructure is simply cheaper and faster than digging up streets to lay copper or fiber; moreover, it promises to bypass the problem of the typically narrowband "last mile". With significant advances in capacity and reliability, along with lower prices, wireless technologies are now looking like strong broadband alternatives to digital subscriber line (DSL) and cable modems. Federal Communications Commission (FCC) Chairman William Kennard recently expressed that the "central focus" of many of the Commission's policies is to create more wireless spectrum so that carriers can develop broadband services.

A recent report from telecommunications research consulting company The Strategis Group predicts that fixed broadband wireless revenues will increase at a 418% compound annual rate over the next five years. By 2003, they forecast that no less than 34% of US households and 45% of US businesses will be serviceable by broadband wireless networks. The group's report entitled: " US Wireless Broadband: LMDS, MMDS and Unlicensed Spectrum," estimates that fixed broadband wireless revenues will reach $3.4 Billion in 2003 (and these projections don't account for companies such as WinStar, an LMDS-like service provider, or PCS systems designed to support mobile users)[2].

Why is this market information relevant? It indicates the level of private sector interest and the level of government support. Both impact the development of broadband wireless, which subsequently impacts the ways in which one can support ITS and transportation-related applications.

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[1] "The 3G Force", http://www.redherring.com/mag/issue69/news-threegee.html (December 1999)

[2] Stokell, Ian, "US Wireless Broadband To Soar - Strategis Report", Newsbytes, http://www.newsbytes.com/pubNews/99/140343.html (December 1999)

3.2 GENERAL APPLICATIONS AND DEVELOPING VERTICAL MARKETS

With the development of broadband wireless, we can expect to see an explosion of users seeking “anywhere” access to information. This access primarily involves the Internet and/or various intranets.

- Internet: The Internet is a rapidly developing public network that connects millions of computers and over 200 million users worldwide. There are many ways to access the Internet, the most common of which is through a commercial or private Internet Service Provider (ISP).

  Interwireless, a wireless ISP established in 1998, offers Internet connections at speeds of up to 15Mbps for most of Los Angeles, Santa Clarita, Ventura, Newbury Park, and the entire San Fernando Valley.

  Cyber Internet Services in Salem, OR, has assembled a wireless network with the capacity thus far to link more than 70 percent of the city's commerce to the Internet.

- Intranet: Intranets are networks belonging to an organization, usually a corporation, accessible only by the organization's members, employees, or others with authorization. Secure intranets (e.g., a virtual private network (VPN)) are now one of the fastest-growing segments of the Internet since they are much less expensive to build and manage than private networks.

  Microserv Computer Technologies Inc. is currently using wireless LAN-based technologies to set up wireless VPNs for business customers throughout Idaho Falls, ID.

Having established high-speed network access – in this case wireless – one has the ability to support a variety of broadband applications (i.e., those applications requiring high-speed communication to adequately perform their intended function). Some of the more popular broadband applications include:

- Mobile computing
- Thin-client computing (i.e., users run applications on remote computing systems)
- Video teleconferencing and video telephony
- Video on-demand and interactive video
- Real-time large file transfer (e.g., a multimedia document)

Additionally, many narrowband applications (i.e., those requiring only low-speed connections) could be supported simultaneously by bundling services and using broadband communications. These applications include:

- Voice telephony
- E-mail
- E-commerce
- Voice over IP (VoIP) (i.e., packetized voice)

- Streaming media (i.e., packetized audio/video)
- Collaborative multimedia involving packetized voice, data, and video

In other words, most any broadband application found in the wireline domain, can be supported in the wireless domain. In either case, the ability to support the applications will depend on the availability of a broadband infrastructure. In Section 5, we address this issue as it relates to wireless systems.

Some industries realized the potential of broadband wireless years ago and are currently using the technologies to support their day-to-day operations. These vertical markets include:

- Manufacturing
- Healthcare and telemedicine
- Education (including distance education/learning)
- Retail
- Wearhousing
- Distribution
- Telecommuting
- Home networking
- Public network access (from transit terminals, airports, hotels, etc.)

More significantly, broadband wireless has begun to appear in the **transportation** and **public safety** domains.

3.3 TRANSPORTATION-RELATED APPLICATIONS

In this subsection, we present specific transportation-related applications that currently use broadband wireless. We also identify transportation-related applications for which narrowband (i.e., low-speed) wireless technologies are being used (and could be enhanced with broadband) as well as applications that use no wireless technology at all (but could).

EXISTING BROADBAND WIRELESS

The following applications currently incorporate broadband wireless. However, their performance could be enhanced with some of the newer broadband wireless technologies.

- **Traveler Information**

  Commercial Vehicles: PNV Inc., an information service provider for the commercial trucking industry, recently announced that they have begun to deploy "PNV B-Connected". PNV B-Connected is a wireless service extension of the company's existing national network that enables truck drivers, industry suppliers, and travelers to gain access to the Internet, e-mail, multimedia traveler information, etc.

The service will be available via the company's network of 268 truck stop sites along the nation's interstate highways. Users will be able to connect anywhere within a 0.5 mile radius of a site, whether at in the parking lot, restaurant, etc.

In February of this year, truckstop operators were told by consultants for the National Association of Truckstops and Travel Plazas (NATSO) that fleets may soon be able to communicate with their drivers not only by voice but by video as well. Drivers and operators were also told they would be able to transfer information (e.g., data, images) that affects their daily work activities. NATSO urged truckstop operators to prepare for the shift in communications methods.

- **Traveler Information, Traffic Management**

  Vehicle-to-roadside: This past January, the Test-bed Center for Interoperability (an R&D Center operated by the California State Department of Transportation (Caltrans)) hosted a successful demonstration of mobile video streaming and file transfer. Wireless nodes – one along the roadside and another in the test vehicle – exchanged information at data rates of up to 30 Mbps. Tests were successful with the vehicle traveling at speeds of up to 70 mph.

  The system uses a new wireless LAN-based technology that we address in Section 5. While performance, reliability, and other operational parameters have yet to be verified, the implications for vehicle-to-roadside applications are encouraging.

- **Traffic Management**

  Video Surveillance: Caltrans uses wireless-enabled cameras for remote surveillance of the San Francisco Bay Bridge. The concept system began with four camera units, but an additional 50 units might be installed as part of a complete surveillance system. The maximum range supported by the existing wireless units is 8 miles – from the entrance on the San Francisco side of the bridge to the Caltrans building. A similar system is being considered for the Sacramento area.

- **Traffic Management**

  Vehicle Detection: This past November, Odetics ITS introduced a broadband wireless-enabled camera as part of its vehicle detection systems. Additionally, the system has the ability to return surveillance video from remote locations (i.e., send the vehicle detection video to a central control facility).

- **Emergency Management**

  Mobile Triage: Southwest Research Institute (SwRI) developed the LifeLink System for the San Antonio District of the Texas Department of Transportation (TxDOT). The purpose of this system is to provide audio/video conferencing and vital statistic data telemetry between ambulance crews and physicians in hospitals. It allows early assessment and treatment in the field, including while the ambulance is en-route. Unlicensed band wireless equipment is used to make the connection between the ambulance and roadside access points. Communication between roadside and the hospital is then provided by TxDOT's fiber-optic network.

- **Law Enforcement**

  Crime Information Databases: The Trumbel County, OH, Sheriffs Office is experimenting with broadband wireless technologies (wireless LAN-based) to provide connectivity between patrol cars and various municipal facilities. The intent is to allow officers in the field to communicate with local office workstations, which in turn have access to data, images, fingerprints, etc. available from local, state, and/or National Crime Information Center (NCIC) databases.

EXISTING NARROWBAND WIRELESS

There are many new wireless information services for the traveling public. Most of these are supported by narrowband systems (and adequately so). However, as in other markets, the demand for data-intesive applications will grow – more information at faster speeds. The following transportation-related applications represent those that could be enhanced with broadband wireless. The original function would not necessarily change, only the amount and type of information, and the rate at which this information is provided.

- **Incident/Emergency Management, Law Enforcement**

  ALERT: Advanced Law Enforcement & Response Technology (ALERT) was developed by the Texas Transportation Institute (TTI) to support mobile platform requirements of the first responder. To date, the technology has been used primarily to support law enforcement. However, it could also be used to support EMS and fire crews. Law enforcement vehicles are currently equipped with wireless communications systems that provide access to remote sources of traffic and investigation information, but these are narrow-band (low-speed) systems. Incorporating broadband wireless could augment services provided between remote command centers and the field.

- **Incident/Emergency Management**

  Municipal Databases: The town of Cupertino, CA, has begun a project to interconnect all government agencies, including public safety, to a micro-cellular data network (a Metricom network). They intend to provide public safety agencies with greater access to city databases and allow them to submit information (e.g., images, reports) about fire and crime scenes.

- **Traveler Information**

  Mobile Office: Omnipoint Communications recently debuted their Wireless Advanced Vehicle Equipment (WAVE) system as an option in the 2000 Lincoln Navigator. Intended to establish the mobile office environment, this system can provide Internet access, intranet access, e-mail, remote monitoring, entertainment, and other emergency services. WAVE uses Global System for Mobile Communications (GSM) wireless networks, which are currently narrowband (low-speed) cellular networks but will eventually be improved to support broadband.

- **Traveler Information**

  Traffic and Weather: In January, TransCore, the transportation group of Science Applications International Corporation (SAIC), released its first real-time traffic and weather application that uses wireless technology. AIRTIS, their advanced traveler information system, provides traffic and weather services as well as Internet access for business and personal use. The service is currently offered over narrowband mobile satellite links.

- **Traveler Information**

  ".com" Providers: Traffic411.com , one of many new ".com" providers, recently demonstrated the ability to provide real-time traffic advisories (audio/video traffic reports) to commuters via wireless phones and palm-size PCs. Using PacketVideo's streaming media software, they are able to provide this information over several different narrowband systems, including the existing cellular phone systems. This type of information (i.e., packetized) could easily be bundled with other IP-based traffic and transmitted over broadband wireless links.

NO WIRELESS

The following applications do not currently use broadband wireless technologies. However, they might benefit from ability of technologies to expand coverage or enhance system performance.

- **Traveler Information**

  National Parks: A recent joint venture between the U.S. Departments of Transportation and the Interior is aimed to bring safety, mobility, and access benefits to the National Parks. An Advanced Traveler Information System (ATIS) will give travelers real-time information on parking availability, public transportation, weather, etc. This ATIS could be supported by wireless broadband with minimal disturbance to the parkland.

- **Traveler Information**

  VDOT: Over the next year, the Virginia Department of Transportation (VDOT) will roll out its new ATIS, offering traffic news that reflects real-time conditions from interstates and major arterial roadways. In addition to getting information over the phone, the Web, and the radio, one will also have access to kiosks in public venues (e.g., shopping malls, transit terminals, etc.). These kiosks can be supported by broadband wireless to provide enhanced services, such as live video, in addition to text messages.

- **Law Enforcement**

  Wired Broadband Network Extensions: Montgomery County, MD, recently began to deploy its next generation broadband communications infrastructure, a wireline infrastructure called "FiberNet". This network will interconnect hundreds of government sites including public safety divisions, health care facilities, and the educational teaching and administrative infrastructure. Additional agencies could quickly and efficiently be added with broadband wireless network extensions.

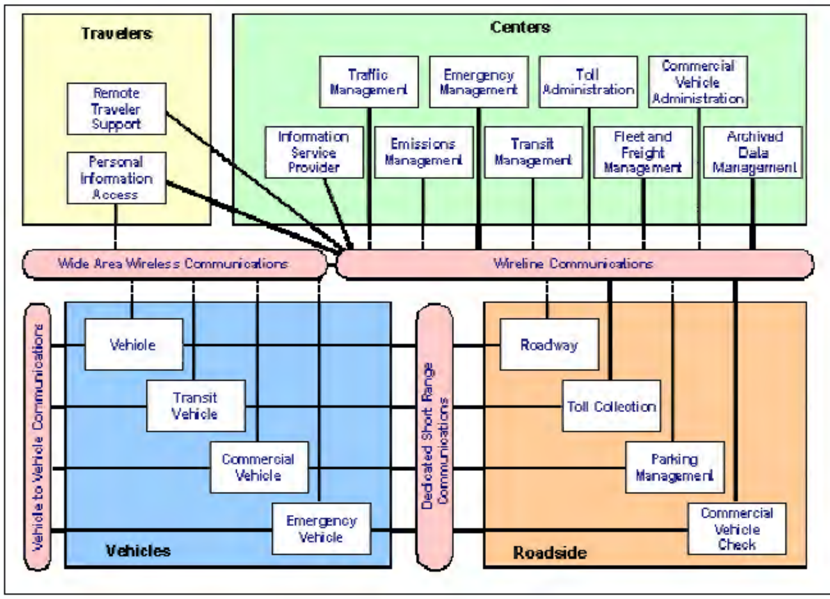
  Montgomery County is also set to outfit hundreds of police patrol cars with video cameras. In a configuration similar to that used for the LifeLink system in San Antonio, one could use broadband wireless to integrate this police video into the county-wide network for centralized monitoring.

There are many other wireless service providers and manufactures involved in the transportation domain. There are also other transportation-related applications/projects involving wireless communications; we did not intend to present them all. Our intent is to demonstrate the developing interest in broadband wireless and address the potential for additional transportation-related applications. The National ITS Architecture indicates several.

3.4 ITS APPLICATIONS

The National ITS Architecture provides a common framework for planning, defining, and integrating intelligent transportation systems. It defines the functions (e.g., gather traffic information) that are required for ITS, the physical entities or subsystems where these functions reside (e.g., a center or a vehicle), and the information flows that connect these functions and subsystems together into an integrated system.

The information passed between center-, traveler-, roadside-, and vehicle-type subsystems includes small bursty data, large data transfers, voice, and video. All supported by any number of communications systems, wireline or wireless, wide-area or short-range, as illustrated by Figure 3-1.



Centers: Provide management, administrative, and support functions for the transportation system. Each communicates with other centers to enable coordination between modes and across jurisdictions.

Roadside: Intelligent infrastructure distributed along the transportation network. Perform surveillance, information provision, and plan execution control functions. Operation is governed by center subsystems.

Traveler: Equipment used by travelers to access ITS services pre-trip and en-route. Includes elements owned and operated by the traveler (e.g., PDA) as well as those owned by information providers (e.g., a kiosk).

Vehicle: general driver information and safety systems applicable to all vehicle types. Transit, Emergency, and Commercial Vehicles add capabilities unique to these special vehicle types.

Figure 3-1. National ITS Architecture Information Flow

The Architecture's communications document suggests options for implementing various communications links and identifies the type of communication (i.e., wireline or wireless, wide-area or short range) that would most likely support each of the information flows. Wireless communication alternatives were typified by the existing cellular telephone and data networks (e.g., AMPS, CDPD, and ARDIS). While the document notes the potential of emerging wireless systems, it does not (and could not have) accounted for all the newer broadband wireless alternatives. From an architectural perspective, broadband wireless could be used to link any of the ITS subsystems.

Wireline communication alternatives were suggested for many information flows because of bandwidth requirements or perceived cost restrictions. The opinion was that "…wireline bandwidth is plentiful, and inexpensive when compared to wireless communications…". At the time this was true, but it is no longer the rule.

The second-largest transmission between Roadside Subsystems and Traffic Management Subsystems – a suggested wireline transmission – is an encoded video signal requiring a data rate of 1.5 Mbps (when using MPEG-1 video encoding). Not only could some of the newer broadband wireless systems support this load, but newer MPEG-4 encoding could reduce this load and allow the use of even lower capacity wireless systems.

Information flows between center, roadside, and travelers subsystems do not have to be supported by wireline communications. Tables 3-1 to 3-3 indicate some of the ITS National Architecture's suggested wireline information flows that could be supported by broadband wireless alternatives.

Table 3-1. Center-Traveler Information Flows

Source	Dest	Information Flow
ISP	PIAS	broadcast_information
ISP	PIAS	traveler_information
ISP	PIAS	trip_plan
ISP	PIAS	yellow_pages_information
PIAS	ISP	traveler_profile
PIAS	ISP	traveler_requst
PIAS	ISP	trip_confirmation
PIAS	ISP	trip_request
PIAS	ISP	yellow_pages_request
ISP	RTS	broadcast_information
ISP	RTS	traveler_information
ISP	RTS	trip_plan
ISP	RTS	yellow_pages_information
RTS	ISP	traveler_requst
RTS	ISP	trip_confirmation
RTS	ISP	trip_request
RTS	ISP	yellow_pages_request
TRMS	RTS	emergency_acknowledge
TRMS	RTS	secure_area_monitoring_support
TRMS	RTS	transit_fare_payment_responses
TRMS	RTS	transit_traveler_information
RTS	TRMS	emergency_notification
RTS	TRMS	secure_area_surveillance_data
RTS	TRMS	transit_information_user_request
TRMS	PIAS	personal_transit_information
PIAS	TRMS	transit_information_user_request
EM	RTS	emergancy_acknowledge

Centers	
ADMS	Archived Data Mgt Subsystem
CVAS	Commercial Vehicle Admin
EM	Emergency Management
EMMS	Emissions Management
FMS	Fleet and Freight Management
ISP	Information Service Provider
TAS	Toll Administration
TMS	Traffic Management
TRMS	Transit Management
Roadside	
CVCS	Commercial Vehicle Check
PMS	Parking Management
RS	Roadway Subsystem
TCS	Toll Collection
Traveler	
PIAS	Personal Information Access
RTS	Remote Traveler Support
Vehicle	
CVS	Commercial Vehicle Subsystem
EVS	Emergency Vehicle Subsystem
TRVS	Transit Vehicle Subsystem
VS	Vehicle Subsystem

Table 3-2. Center-Roadside Information Flows

Source	Dest	Information Flow
TMS	RS	AHS_control_information
TMS	RS	freeway_control_data
TMS	RS	roadway_information_system_data
TMS	RS	sensor_and_surveillance_control
TMS	RS	signal_control_data
TMS	RS	sensor_and_surveillance_control_data
TMS	RS	hri_control_data
RS	TMS	AHS_status
RS	TMS	environmental_conditions
RS	TMS	hov_data
RS	TMS	hri_status
RS	TMS	incident_data
RS	TMS	reversable_lane_status
RS	TMS	signal_control_status
RS	TMS	traffic_flow
RS	TMS	traffic_images

Table 3-3. Center-Center Information Flows

Source	Dest	Information Flow
EM	TMS	remote_surveillance_control
EM	TMS	remote_surveillance_control
media	ISP	external_reports
media	TMS	external_reports
TMS	EM	current_network_conditions
xxx	yyy	"most anything"

The “xxx” and “yyy” entries in table 3-3 indicate that any number of center subsystems, and their associated information flows, could be supported.

ITS information flows to be supported by wide-area wireless systems involve voice, short messaging, or non-real-time communication from centers to traveler, roadside, and vehicle subsystems. These are all relatively small amounts of information that support simple applications. The size and function of these flows was restricted due to limited wireless communication alternatives at the time (i.e., narrowband systems), but the broadband wireless alternatives permit much larger flows in real-time scenarios.

Tables 3-4 and 3-5 indicate just some of the ITS National Architecture’s suggested wireless information flows that could incorporate more information and/or be provided with less latency if supported by broadband wireless alternatives.

Table 3-4. Center-Vehicle Information Flows

Source	Dest	Information Flow
EM	EVS	emergency_dispatch_requests
EM	EVS	incident_command_information
EM	EVS	suggest_route
EVS	EM	emergency_dispatch_response
EVS	EM	emergency_vehicle_tracking_data
EVS	EM	incident_command_request
EVS	EM	incident_status
EM	VS	emergancy_acknowledge
EM	VS	emergancy_data_request
VS	EM	emergency_notification
ISP	VS	traveler_information
ISP	VS	trip_plan
ISP	VS	yellow_pages_information
VS	ISP	traveler_requst
VS	ISP	trip_confirmation
VS	ISP	trip_request
VS	ISP	vehicle_probe_data
VS	ISP	yellow_pages_request
TRMS	TRVS	driver_instructions
TRMS	TRVS	emergency_acknowledge
TRMS	TRVS	request_for_vehicle_measures
TRMS	TRVS	transit_schedule_information
TRMS	TRVS	transit_traveler_information
TRVS	TRMS	emergency_notification
TRVS	TRMS	transit_vehicle_conditions
TRVS	TRMS	transit_vehicle_location_data

Table 3-5. Center-Traveler Information Flows

Source	Dest	Information Flow
EM	PIAS	emergancy_acknowledge
PIAS	EM	emergency_notification
RTS	EM	emergency_notification

Whether to support what were originally identified as wireline flows, or to augment those identified as wireless flows, broadband wireless provides an alternative for exchanging information between ITS subsystems.

- **Center-center** information flows could be supported by any of the configurations presented in Section 2, but most likely, these would be fixed point-to-point, fixed point-to-multipoint, and fixed multipoint-to-multipoint solutions. Recall that these include fixed as well as transportable facilities (e.g., a temporary control center)

- **Center-traveler** information flows could be supported by any of the configurations presented in Section 2. An appropriate solution would depend on the mobility of the end-point(s). Fixed point-to-point, fixed point-to-multipoint, and fixed multipoint-to-multipoint alternatives could be used if the end-points were fairly immobile (e.g., an RTS or a stationary PIAS), but mobile point-to-multipoint solutions might be used if the end-point is in motion (e.g., a mobile PIAS).

- **Center-vehicle** information flows would most likely use mobile point-to-multipoint solutions. However, if the information is to be sent while the vehicle is stationary (e.g., a public safety vehicle, or EVS, at the scene of an incident), then fixed point-to-point, fixed point-to-multipoint, and fixed multipoint-to-multipoint alternatives could be used as well.

- **Center-roadside** information flows, like center-to-center information flows, could be supported by any of the configurations presented in Section 2, but most likely these would be fixed point-to-point, fixed point-to-multipoint, and fixed multipoint-to-multipoint solutions. Again, these include fixed as well as transportable facilities (e.g., a special event coordinators kiosk, etc.).

In addition to supporting individual information flows, broadband wireless can be applied to the integrated service platform allowing bundled services (i.e., the concept of this effort).

- Small data flows can be supplemented with larger data flows, voice and/or video.
- Larger data flows can be supplemented with short messaging, voice, and/or video
- Voice can be supplemented with larger data flows, short messaging, and/or video
- Video flows could be supplemented with voice as well as small and large data flows

This Section introduced a wide range of broadband applications for the transportation domain. As ITS develops, the numbers and types of such applications will grow. The ability to support these applications with the developing broadband wireless and integrated service platform technologies provides significant benefit to many transportation agencies. In the following Section, we elaborate on the function and utility of the integrated service platform. We then present a variety of broadband wireless technologies that can be used to support this platform.

SECTION 4

INTEGRATED SERVICE PLATFORMS
AND THE MULTI-SERVICE ACCESS DEVICE (MSAD)

Most telecommunications companies and local exchange carriers are beginning to offer integrated voice, data, and video services. This trend is being fueled by not only the growing demands for Internet access and multimedia communication, but also the decreasing revenue from voice-only services. Analysts predict that these “bundled” services will become a major revenue source for the large carriers (e.g., MCI WorldCom, Sprint, AT&T). Two studies,"Branding and Bundling: Business Telecom Services," and "Branding and Bundling: Consumer Telecom Services," indicate that 66 percent of businesses and 63 percent of consumers are interested in purchasing some form of bundled service.[1]

The ability to integrate services is not restricted to the major carriers and their complex networks. It can also be afforded the smaller provider as well, whether commercial provider, private company, or public agency.

4.1 INTEGRATED SERVICES

Typically, several types of equipment and different transmission facilities must be patched together in order to construct an integrated service network. Figure 4-1 illustrates common methods for provisioning voice, data, and video services. Voice is provided over the PSTN, data services use T1 or similar connections, and video teleconferencing is available over ISDN. Each of these services requires separate communications resources – separate equipment, separate transmission facilities, etc.

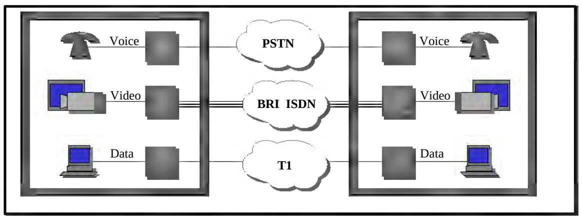


Figure 4-1. Separate Communications Resources

Alternatively, one can establish an integrated platform by bundling services for transmission over a single facility, as shown in Figure 4-2.

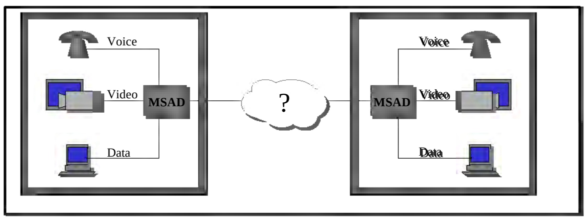


Figure 4-2. A Single Communications Resource

[1] “Strategis Group Studies Find Consumers and Businesses Favor Bundled Telecom Services”, http://www.newsbytes.com/news/00/142113.html, Newsbytes (January 2000)

This bundling of services is enabled by a Multi-Service Access Device (MSAD), or Integrated Access Device (IAD). MSADs can provide for applications such as:

- Dial tone (POTS, PSTN access, FAX)
- Corporate PBX or key system access
- High-speed Internet access
- Corporate intranet access and virtual private networks (VPNs)
- Transparent LAN services (TLS)
- Video Teleconferencing
- Collaborative multimedia
- Voice over IP (VoIP) and/or voice over ATM

Most any application can be supported.

4.2 MULTI-SERVICE ACCESS DEVICE

MSADs combine the functions of various communications equipment that would be needed to construct a multi-service network. This includes Ethernet routers and bridges, channel/digital service units (CSU/DSU), digital access cross-connect systems (DACS), private branch exchanges (PBX), DSL access multiplexers (DSLAM), asynchronous transfer mode (ATM) switches, subscriber management devices, etc.

The integrated functionality allows the MSAD to combine multiple traffic types, effectively separating services from transmission technologies, as illustrated in Figure 4-3.

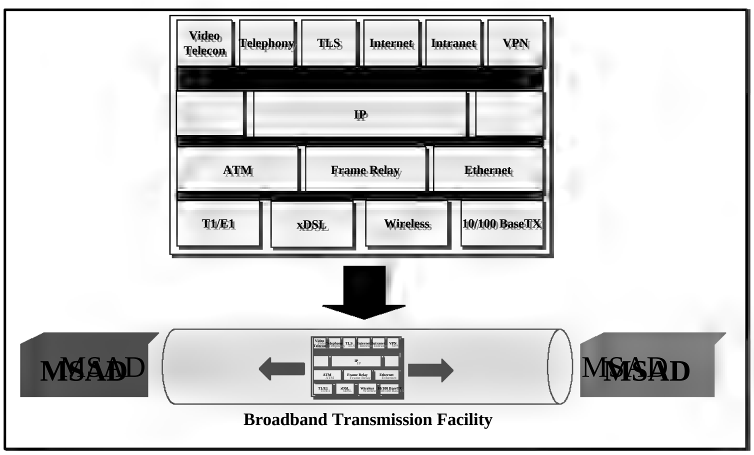


Figure 4-3. Multiple Traffic Types over a Single Transmission Facility

The integrated traffic may be an ATM or Frame Relay virtual circuit, an IP/Ethernet flow, etc., but it rides over a single transmission facility. The transmission facility could be an existing T1 or DSL connection. Alternatively, it might be one of the newer broadband wireless technologies (e.g., wireless LAN, or Multichannel Multipoint Distribution Service (MMDS)). We address these alternatives in Section 5.

4.2.1 MSAD INTERFACES

In order to accommodate many different traffic types, MSADs have a variety of subscriber interfaces – those the user would access (see Figure 4-4).

The following are typical for voice services.

- FXS ports for analog voice – and similar services (e.g., FAX machines, key systems)
- FX0 ports for PSTN access (connectivity at a central office (CO))
- DS-1 ports for digital voice (e.g., PCM, ADPCM). These are usually to support high-density voice requirements, such as those through a PBX.

Note: *Packet voice (e.g., VoIP, Voice over ATM) is supported via the LAN interface*

For data services, there are typically two interface types:

- LAN ports (e.g., RJ-45 10BaseT and 10/100BaseTx) for local area network access and IP-based services.
- Serial ports (e.g., V.35 / RS-530, RS-232, FRAD) for connections to video teleconferencing, auxiliary or legacy LAN equipment, data multiplexers, and Frame Relay access devices (FRADs). MSADs typically support Frame Relay to ATM inter-networking, and Frame Relay to ATM services.

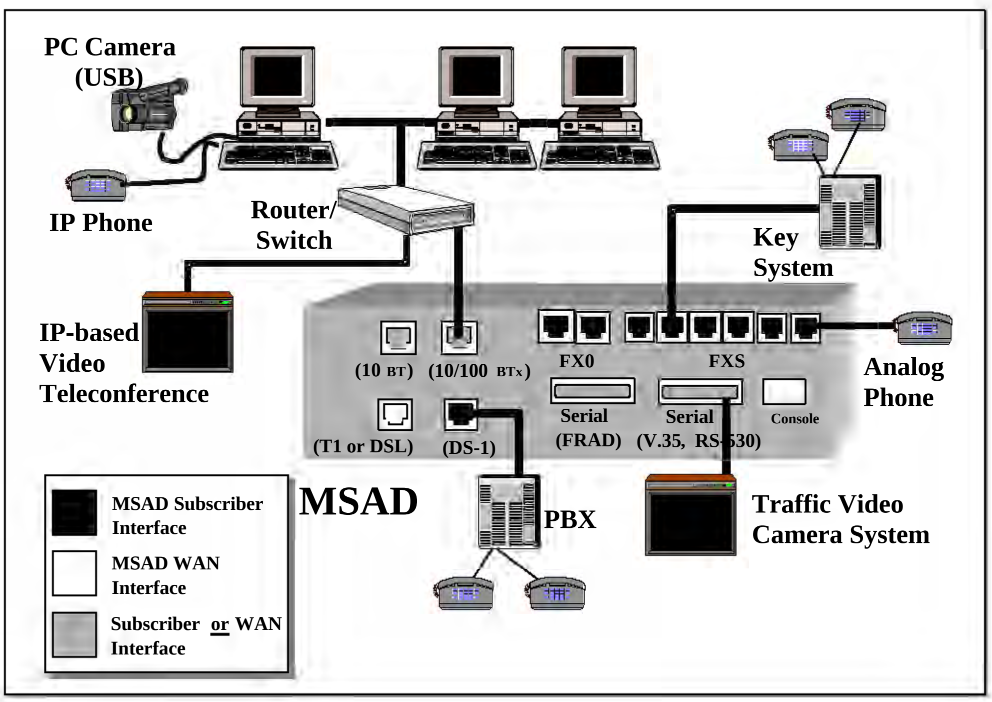


Figure 4-4. Multi-Service Access Device (MSAD) Interfaces

All traffic from subscriber interfaces is integrated for transmission over the WAN. If the WAN connection is an ATM virtual circuit, then each traffic component (or the circuit as a whole) may be assigned various "quality of service" (QoS) levels to help manage voice and data traffic prioritization. These include the ATM Adaptation Layer standards: AAL-1 for constant bit rate, time-dependent traffic, such as voice and video; AAL-2 for variable bit rate video transmissions; and AAL-5 for variable bit rate, delay-tolerant connection-oriented data traffic.

WAN interfaces on the MSAD, or those available to the transmission facility, typically include:

- Digital subscriber line (DSL) ports supporting various data rates up to approximately 2.3 Mbps
- T1/E1ports supporting data rates of 1.544/2.048 Mbps, respectively

Some MSADs have more flexible cross-over capabilities and allow either a serial port or a LAN port to be used for the wide area network connection (i.e., serve as the WAN port). Consequently, more broadband technologies can support the integrated platform.

4.2.2 DEPLOYMENT CONFIGURATIONS

The MSAD is designed as customer premise equipment. In a typical deployment, such as that often used by competitive local exchange carriers (CLECs), a more complex counterpart is located at the central office (Figure 4-5).

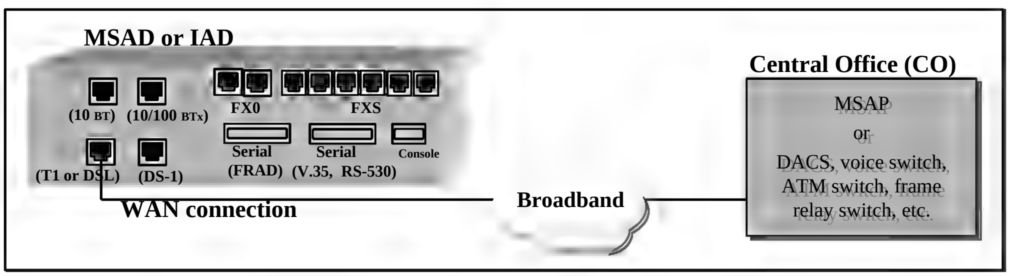


Figure 4-5. Traditional MSAD Deployment Configuration

The central office equipment is often referred to as a multi-service access platform (MSAP). The MSAP performs two essential functions.

- First, it concentrates a large number of relatively low-speed circuits (e.g., T1/E1) into a small number of high-speed circuits (e.g., DS-3, OC-3) for transmission to upstream networks – the backbone networks.

- Second, an MSAP provides inter-networking, switching, and gateway functions, converting traffic to the appropriate format for the upstream networks (e.g., connecting telephone traffic with the PSTN and switching data traffic to the correct backbone network).

The MSAPs also incorporate system features to provide for:

- Configuration management
- Fault management
- Performance management
- Accounting management
- Security management
- Dynamic bandwidth allocation

MSAPs are not required to establish an integrated service platform; these devices are simply useful to providers with large networks to manage. Integrated services can be provided on smaller networks as well. In this instance, one could use the MSADs in a back-to-back configuration (i.e., connecting one MSAD to another), as shown in Figure 4-6.

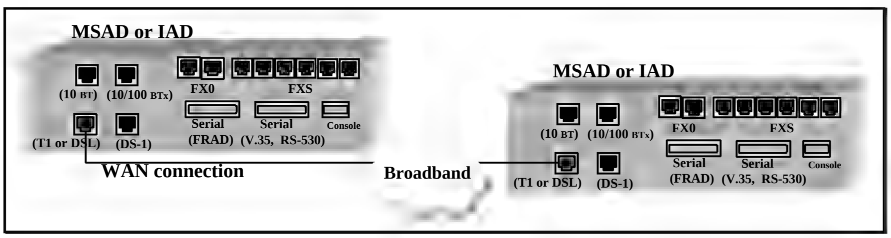


Figure 4-6. Smaller MSAD Deployment Configuration

This back-to-back configuration is more than sufficient for most of the transportation-related applications we note in this document. It will also be the configuration we use in the prototyping phase of this effort.

4.3 BROADBAND WIRELESS FOR THE INTEGRATED SERVICE PLATFORM

MSADs support efficient and cost-effective multiple service provisioning, whether by commercial provider, private corporation, or public agency. They lower equipment costs by consolidating communications into a single, scalable, integrated platform, and they lower administrative costs related to training, maintenance, and network management.

The resulting integrated service platforms are practical alternatives to traditional multi-service networks. By using broadband wireless to support the ISP, there are the added benefits of mobility and rapid deployment. We present several broadband wireless alternatives in the following section.

SECTION 5

BROADBAND WIRELESS TECHNOLOGIES

In Section 3, we addressed the potential of the broadband wireless market. Of particular interest was the fact that wireless will soon surpass wireline as the dominant method of telecommunications worldwide. While voice services were the driving factor in the past, the next decade's growth will be spurred by the demand for high-speed data services – those that require broadband communications.

Again, broadband wireless refers to those communications technologies that use larger portions of the RF spectrum – spectrum that is needed to achieve higher data rates. For the purpose of this effort, and to limit the scope of the task, broadband will refer to those technologies that can support bi-directional data rates of at least 384 kbps.

There are several older broadband technologies, both wireline and wireless. Through the remainder of this section, we review many of the newer wireless technologies[1]. Some are relatively inexpensive and use unlicensed spectrum; others require more expensive implementations that depend on licensed spectrum. The coverage, architecture, mobility, and various performance parameters will depend on the specific technology. Each has its advantages and disadvantages.

<u>Note</u>*: *It's not necessary to read this entire section. Each subsection is independent and self-explanatory with regards to the scope of this effort. Tables 5-1 and 5-2 provide reference to the types of technologies reviewed (e.g., p 5-19 addresses IEEE 802.11a).

Table 5-1. Unlicensed Spectrum Technologies Reference Guide

	Unlicensed Spectrum Technologies	Data Rates (per channel)	Max Range [1] indoor [1]	outdoor [2]	Product Availability
p. 5-3	**2.4 GHz ISM Band**				
p. 5-4	IEEE 802.11b	1 - 11 Mbps	~300 - 400 ft	2-20+ mi	2000
p. 5-9	OpenAir	0.8 - 1.6 Mbps	~300 - 400 ft	3-20+ mi	1996
p. 5-11	HomeRF	1-2 Mbps	~100 ft	-	2000
p. 5-12	Bluetooth	< 0.5 Mbps	~ 30 ft	-	2000
p. 5-13	Proprietary Technologies	~ 1 - 11 Mbps	~100 - 500 ft	2-20+ mi	1990's
p. 5-19	**5 GHz ISM and/or UNII Bands**				
p. 5-19	IEEE 802.11a	6 - 54 Mbps	~200 ft	35+ mi	2001/2002
p. 5-22	HIPERLAN I	24 Mbps	~200 ft	35+ mi	?
p. 5-25	HIPERLAN II	6 - 54 Mbps	~200 ft	35+ mi	2001/2002
p. 5-28	HIPERAccess	~20 Mbps	-	-	?
p. 5-28	Proprietary Technologies	6 - 100+ Mbps	-	35+ mi	1999
p. 5-30	**Free Space Optics**	155 - 1000 Mbps	-	0.1 - 1.25 mi	2000
p. 5-33	**Ultra Wideband (UWB) Radio**	20 - 100 Mbps	?	?	?

[1] Nominal maximum indoor ranges
[2] Using supplemental antenna systems

[1] We are not endorsing any particular product or advocating the use of any particular service. We do not intend to address all broadband wireless technologies. We are simply noting some of the newer technologies that might be used to support concepts derived in this particular effort.

Table 5-2. Licensed Spectrum Technologies Reference Guide

	Licensed Spectrum Technologies	Data Rates (per channel)	Range	Service Availability
p. 5-34	Local Multipoint Distribution Service (LMDS)	~ 155 Mbps	~ 3.5 mi	1999, limited
p. 5-39	Multichannel Multipoint Distribution Service (MMDS)	~ 37 Mbps	~ 30 mi	1997, limited
p. 5-45	Wireless Communication Service (WCS)	~ 30 Mbps	~ 30 mi	2000, limited
p. 5-47	General Wireless Communication Service (GWCS)	~ 30 Mbps	~ 30 mi	?
p. 5-48	Broadband Personal Communication Service (Broadband PCS)			
p. 5-50	Mobile Systems	0.144 - 2.048 Mbps*	~ 3 - 5 mi	2001/2002
p. 5-54	Fixed Systems	~ 2+ Mbps	~ 3 - 7 mi	2000/2001
p. 5-55	Satellite Service			
p. 5-56	Teledesic	2 - 64 Mbps	global	2003/2004
p. 5-58	SkyBridge	2 - 100 Mbps	global	2002/2003
p. 5-60	SkyDSL	0.500 Mbps	North America	2001/2002
p. 5-61	Digital Television (DTV) Alternative	19 Mbps	1 - 30 mi	-

These tables are not all inclusive (i.e., they do not represent all the technologies/services addressed in this document); nor are they completely indicative of the technologies' potential. They simply highlight general performance characteristics to help indicate which technology (or group of technologies) might be of interest.

5.1 Unlicensed Spectrum Technologies

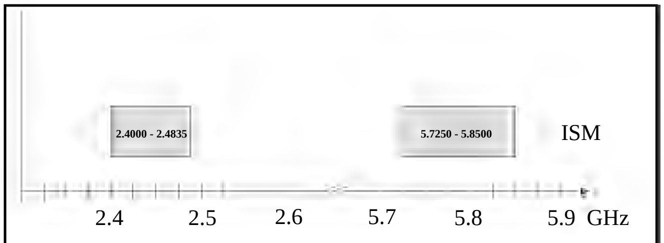
Most of the technologies described in this subsection were designed to operate under Part 15 of the FCC rules and regulations. This part sets out the conditions under which an intentional, unintentional, or incidental radiator may be operated. Intentional radiators include biomedical telemetry devices, cordless telephone systems, as well as the communication technologies we address (unintentional radiators include microwave ovens, etc.). The main advantage of Part 15 operation is that no FCC license is required. However, Part 15 does place several restrictions on the design and capabilities of these products.

There are several Part 15 frequency bands in which to operate, but we will be limiting our discussions to the 2.4GHz and 5.8GHz industrial, scientific, and medical (ISM) bands and the new 5.3GHz and 5.8 GHz the Unlicensed National Information Infrastructure (UNII) bands. Most development in broadband wireless is occurring in these areas.

In addition to Part 15 devices, we review other unlicensed alternatives. These include wireless optics and ultra-wideband (UWB) radio.

5.1.1 Part 15 ISM Bands

Section 15.247 of the FCC rules defines the operation of license-free devices in three frequency bands allocated for industrial, scientific, and medical (ISM) equipment. These bands are 902-928 MHz, 2.400-2.483 GHz, and 5.725-5.850 GHz. Again, we're covering development within the 2.4GHz and 5.8GHz bands.



2.4GHz & 5GHz ISM Bands

If using the 2.4 GHz band for point-to-multipoint services, transmitter power can not exceed 1W and the maximum antenna gain is 6dB (i.e., the maximum EIRP is 4W, or 36dBm). If using this spectrum for point-to-point links, Part 15 allows the use of directional antennas with gains above 6dB; however, the transmitter power must be reduced 1dB for every 3dB the antenna gain exceeds 6dB.

> The product of transmitter power (P_t) and transmitting antenna gain (G_t) is often referred to as the Effective Isotropic Radiated Power (**EIRP**). EIRP describes this combination of power and gain in terms of an equivalent isotropic source with power P_t x G_t Watts, radiating uniformly in all directions

The 5GHz ISM band has the same radiated power restrictions for point-to-multipoint services, but there are no limits on directional gain if using this band for point-to-point links.

One of the restrictions of Part 15 is that the license-free devices must not interfere with other authorized services in the band. They must also accept interference from these services, as well as other Part 15 devices. In order to decrease the likelihood of interference, the FCC requires the use of spread spectrum modulations for devices in the ISM bands. There are two basic forms of spread spectrum allowed: frequency hopping and direct sequence.

Frequency hopping spread spectrum (**FHSS**) systems spread their energy by rapidly changing the channel's carrier frequency (i.e., "hopping") in accordance with a pseudorandomly generated code. At any instant, the signal is being broadcast on only one frequency and the transmission remains on each frequency for only a short time before moving to the next. Part 15 requires that in the 2.4 and 5.8 GHz bands, frequency hopping systems hop over a minimum of 75 channels – each channel not exceeding 1 MHz bandwidth.

Direct sequence spread spectrum (**DSSS**) systems combine the original data stream with a pseudorandomly generated code. This has the effect of spreading the signal over a wider bandwidth and reducing interference with signals in specific bands. It also allows for a processing gain at the receiver where the spreading process is reversed. In order to establish the minimum level of interference, Part 15 requires the processing gain to be at least 10 dB.

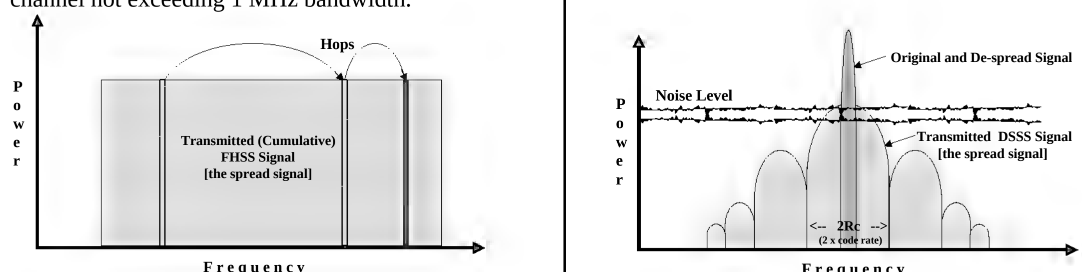


Figure 5-1. ISM Band Spread Spectrum Modulation Techniques

5.1.1.1 2.4 GHz ISM Band – Standardized WLAN Technologies

Wireless local area networks (WLANs) are already very popular in factories, warehouses, and offices where wiring computers into the corporate network is not cost effective. While these systems were specifically designed (are best suited) for short-range point-to-multipoint applications (within a few hundred feet), they can also provide for long-haul point-to-point links and wide area point-to-multipoint coverage (over several miles) with the use of supplemental amplifiers, antennas, etc. Typically, the wide-area long-haul systems are supported by proprietary wireless networking technologies. We discuss these in the following subsection.

Most new WLANs operate in the 2.4 GHz ISM band. One standard currently underpins much of the development in this market – IEEE 802.11b. The original 802.11 and the OpenAir standards form the basis for many existing 2.4 GHz WLANs, and we review these systems along with the emerging HomeRF WLAN standard and the Bluetooth personal area network (PAN) standard. However, emphasis is placed on 802.11b.

IEEE 802.11b

IEEE 802.11 is a WLAN standard that specifies the air interface between a wireless client and a hub. It also defines the interface among wireless clients. First conceived back in 1990, the standard has evolved from various drafts with approval of the final draft in June 1997.

The specification addresses both the physical and medium access control (MAC) layers. At the physical layer, IEEE 802.11 identifies three alternatives: infrared, direct sequence spread spectrum (DSSS), and frequency hopping spread spectrum (FHSS).

The original 802.11 products operate at 1 and 2 Mbps, but demand for higher data rates (and international availability of license free spectrum) spurred the development of high-rate extensions to 802.11. There are now three different 802.11 standards for WLANs – 802.11, 802.11a, and 802.11b

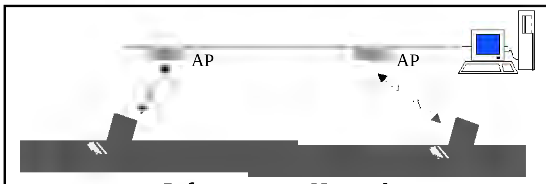
The 802.11a specification, which is still in development, calls for the use of 5 GHz unlicensed spectrum. We address this standard later in the document. 802.11b supersedes the functionality of 802.11; therefore, we focus the discussion on 802.11b.

Architecture

All 802.11 technologies were designed for point-to-multipoint communication, but they can also be used to support point-to-point links – as long as they adhere to Part 15 regulations.

Two point-to-multipont network architectures are defined: the infrastructure network, and the ad hoc network.

- An Infrastructure Network architecture uses fixed hubs (or access points (AP)) with which portable clients can communicate. The APs can communicate with each other, but wireless transmissions are half duplex and a series of APs (functioning as a wireless network infrastructure) would significantly reduce end-to-end throughput. Therefore, the APs are usually connected (bridged) to a wireline infrastructure.



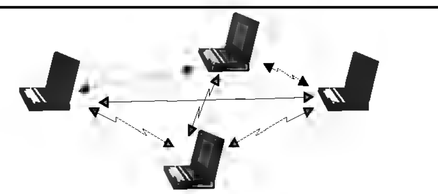
Infrastructure Network

The coverage area is defined by the APs' and their particular attributes, including the antenna systems. An 802.11b system, which is a DSSS system, uses approximately 11 MHz of bandwidth per channel. Eleven channels are available, but only three are non-overlapping, which means that only three APs can be collocated. Channels can be reused by providing coverage in a cellular fashion. Adjacent cells would use non-overlapping channels.

Most APs now have the ability to manage hand-offs between coverage areas – as long as one remains within the same subnet.

***Note**: When a wireless client accesses the network, it typically registers with a single access point. APs on the same subnet can hand-off clients; those on different subnets can not. Surprisingly, most WLAN equipment is not presently capable of addressing the problem of roaming between subnets.*

- An ad hoc network architecture is used to support mutual communication among portable clients. Users communicate directly without going through an AP. Typically, ad hoc networks are created spontaneously (e.g., employees bring their laptops together in a meeting). There is no structure to the network; there are no fixed points; and usually every node is able to communicate with every other node.



Ad Hoc Network

The coverage area is defined by the range of the associated wireless clients, including any external antennas on the client device.

802.11 devices can be built into the client hardware, such as a laptop PC or household appliance, but they are more commonly found as PC Cards (to be inserted/removed from a laptop PC). The APs have standard interfaces for wired network connectivity (e.g., 10BaseT).

The 802.11 and 802.11b standards were designed for APs and client devices to be fixed or portable, but stationary when in use. As such, they could provide for the fixed communications configurations presented in Section 2, including those that consider transportable devices. Some individuals have found 802.11 devices to work in the mobile environment – even at speeds above 30 mph. However, the technology was not designed for such use and performance is uncertain.

System Performance

Data Rate: 802.11b devices use the same allocated bandwidth as original 802.11 equipment – 83.5 MHz. However, by using complementary code keying (CCK) modulation, 802.11b systems can achieve data rates up to 11 Mbps. If the signal between an AP and a client device is too weak to support the higher data rates, the transmission will back off to a lower rate in an effort to maintain connectivity.

802.11b specifies four data rates: 1 and 2 Mbps (allowing backward compatibility with 802.11 devices), 5.5 Mbps, and 11 Mbps. Due to overhead, the actual information throughputs are approximately 0.8, 1.6, 3.4, and 5.1 Mbps, respectively. Additionally, these are half duplex data rates.

Eleven channels are available when operating at the higher rates (5.5 and 11 Mbps), but only three may be used simultaneously within the same coverage area (i.e., only 3 are non-overlapping).

Coverage: Indoor coverage has a maximum range of about 500 ft. without the use of external antennas on client devices; however, 300-400 ft. is more realistic in an office environment. External antennas on the client device (or supplemental antennas on the AP) can be used to extend the range, but emissions are limited by Part 15 restrictions. (Part 15 states that the EIRP must not exceed 4W, or 36dBm). Additionally, the range can be extended if the data rate is backed off (e.g., backing off to 2 Mbps may allow another 100ft or so).

If using 802.11b devices for outdoor coverage, the same Part 15 FCC regulations apply. For omni-directional coverage, the maximum range is approximately:

- 2 miles at 11 Mbps
- 2.5 miles at 5.5 Mbps
- 3 miles at 2 Mbps
- 5 miles at 1 Mbps

If using 802.11b for point-to-point links, Part 15 allows the use of directional antennas with gains larger than 6dB. Under good conditions, the maximum range between nodes (transmitter and receiver) is approximately:

- 5 miles at 11 Mbps
- 8 miles at 5.5 Mbps
- 10+ miles at 2 Mbps
- 20+ miles at 1 Mbps

All coverage values are estimates (indoor and outdoor). Actual coverage will depend on the particular vendor equipment, system design, environmental conditions, line-of-sight (LOS), etc.

Standards

The 802.11b standard received final approval from IEEE in September 1999. At the physical layer, the standard specifies the use of Direct Sequence Spread Spectrum (DSSS). Complimentary code keying (CCK) modulation is used to achieve the 11 and 5 Mbps rates, DQPSK for 2Mbps, and DBPSK for 1Mbps.

802.11b employs the same Medium Access Control (MAC) layer protocol as 802.11 – Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) – making it backward compatible.

> *Note: To work with 802.11 systems, 802.11b devices would have to be using DSSS. 802.11 specifies the use of DSSS, FHSS, or infrared at the physical layer.*

The Wirelesss Ethernet Compatibility Alliance (WECA) will certify the interoperability of IEEE 802.11b products. This organization will develop interoperability tests and certify equipment through an independent third party testing lab. Products that pass the WECA test will be stamped with a WECA "good housekeeping" seal of approval, called WiFi and pronounced "Y-Phi" for wireless fidelity. The stamp should help consumers identify interoperable 802.11b products.

Existing Products

802.11b products only recently became available (spring 2000). Companies such as, Cisco Systems (Aironet), Lucent Technologies, 3Com, Nokia, Symbol Technologies, Cabletron, etc., are now shipping equipment to customers all over the world. This includes other companies that wish to integrate these devices into their product lines.

Personal computer manufacturers, including Apple, IBM, Dell, and Compaq, are also all offering (will soon offer) new PCs with integrated 802.11b client devices.

- Apple Computer recently introduced a $99 option for their new iBook. Their hub is about $300.
- Compaq, only last summer (1999), introduced a 2 Mbps 802.11 option for their Armada line of notebook computers. They have since swapped this for an 802.11b option.
- Dell is testing prototype notebooks equipped with 802.11b
- IBM also looks to incorporate an 802.11b option into its notebook systems.

Each of these PC makers is a member of WECA, meaning – at least in theory – that their equipment will be WiFi compatible.

> ***Note:*** *Many of these manufacturers also plan to offer Bluetooth wireless devices in their PC products. This creates an interesting problem if one expects to use both 802.11 and Bluetooth at the same time (e.g. Bluetooth for printer connectivity; and 802.11 for WLAN connectivity). Both technologies use the*

2.4Ghz ISM band, and interference would most likely prevent both from functioning adequately. We mention Bluetooth later in this paper, but do not go into detail. Bluetooth technologies are not particularly suited for most of the applications we address in this document.

Existing Systems

Some of the specific applications presented in Section 3 of this document rely on 802.11 technologies. This includes both general and transportation-related applications.

- Microserv Computer Technologies Inc. is providing wireless virtual private networking for customers throughout Idaho Falls, ID. To establish the VPNs, they used 802.11-based WLAN technology.

  Microserv began building their wireless network a little over two years ago using Lucent Technologies' WaveLAN (now Orinico) equipment. Today, nine hubs covering the southeast corner of Idaho provide service to over 7000 subscribers.

- PNV Inc., a trucking industry service provider, is deploying a wireless extension to their national network. Services enable truck drivers, industry suppliers, and travelers to gain access to the Internet, e-mail, multimedia traveler information, etc.

  The wireless network extension is built around Cisco Systems (Aironet) 802.11b WLAN technology. With a PC laptop or other peripheral, users can connect anywhere within a ½ mile radius of a hub.

Other Issues

- Security

  802.11b specifies the option to use Wired Equivalent Privacy (WEP), an encryption protocol to help protect user confidentiality and data integrity. In order to receive WiFi certification, WECA will require that 802.11b products support the Wired Equivalent Privacy (WEP) option and be able to communicate successfully when WEP is enabled. After a relaxation in encryption legislation, some vendors have enhanced WEP's initial 40-bit encryption capabilities to 128-bit.

  While encryption has been addressed, other security issues remain. Building a device to jam the few channels used by 802.11b devices would not be that difficult (i.e., denial-of-service attacks). Some suggest that since these devices use a rapidly populating unlicensed band, denial of service might not even be an intentional attack. It may be incidental. However, this argument applies to all the technologies using the unlicensed bands.

- Costs

  Prices vary across product line, but all continue to drop as more products are released. Integrated 802.11b devices (built-in to the laptops and other portable devices) are usually options on the order of $100. Separate PC cards are slightly more – $100 to $200, but dropping. The access points can range from $500 to $1000 depending on features supported.

OpenAir

The OpenAir specification is based on a 2.4GHz frequency hopping WLAN technology introduced by Proxim, Inc. The standard was completed in 1996, and the Wireless LAN Interoperability Forum (WLIF) has certified more than 40 different products since that time.

Most OpenAir technology is integrated into the client device (e.g., a hand held scanner or mobile data terminal (MDT)). And most of these client devices are designed for interactive transaction processing (ITP) functions, which are used heavily in the manufacturing, warehousing, and retail sales domains.

Architecture

OpenAir systems use a point-to-multipoint infrastructure based network architecture. Portable clients communicate with fixed hubs (or access points (APs)) that are bridged to a wireline network infrastructure.

The specification does not explicitly define an AP, but does define key interfaces for connecting to a wired network, including: bridging to IEEE 802.3, translation between Ethernet and OpenAir packets, and roaming from one AP to another. There are three general levels of roaming (fast, normal, and slow) to allow for different application and coverage requirements.

FHSS WLANs, like OpenAir systems, can support between 12-15 collocated APs (i.e., 12-15 independent 1 MHz channels, each using a unique hopping sequence). This enables multiple independent WLANs to operate in the same physical space. The new 802.11b DSSS systems can collocate only three APs. However, while FHSS systems allow more collocated channels, DSSS systems have better receiver sensitivities, and APs using the same channel can be packed more densely.

While the OperAir specification was designed to support devices in motion, they were not intended to be moving at high speeds (e.g., above 20 mph). OperAir devices could support many of the fixed communications configurations presented in Section 2, including those that consider transportable devices. They might also be tried in a highly mobile environment, (above 20 mph), but performance would be questionable.

System Performance

Data Rate: OpenAir devices support data rates of either 1 or 2 Mbps per channel, half duplex. The actual throughputs are 0.8 Mbps and 1.6Mbps, respectively.

Coverage: Like 802.11b, a single cell has indoor coverage of about 300-400 ft. in an office environment. External antennas on the client device (or supplemental antennas on the AP) can be used to extend the range provided they comply with Part 15 restrictions. Additionally, range can be extended if operating at the lower data rate.

OpenAir devices can also be used for outdoor point-to-point and point-to-multipoint links; the same Part 15 FCC regulations apply. This equipment is typically not used in such fashion since most OpenAir devices are integrated into ITP-type devices.

Standards

The WLIF owns and maintains the OpenAir specification. The specification describes the physical and MAC layer information required to achieve interoperability, including: data communication, roaming, security, configuration, and co-existance. XXCAL Inc., a computer product testing and certification lab, has been accredited by the WLIF to certify OpenAir products.

Existing Products/Systems

WLI Forum has certified over thirty OpenAir client products in a variety of product categories including, adapters, pen computers, scan/key hand-held products, vehicle mount units, serial modems, hand-held printers and PDAs – all interoperable with a wide variety of APs. Manufacturers include: Data General, IBM, HP, Intermec, Motorola, Proxim, etc. Hundreds of thousands of these devices are installed in working networks today.

There are also PC Cards that can be inserted/removed from devices such as laptop computers. However most current users have equipment with integrated devices.

Other Issues

- Costs

  Costs of the client products with integrated OpenAir devices vary greatly. An individual OpenAir NIC (PC Card) cost on the order of $100. APs cost anywhere from $250 to $1000.

- Security

  Beyond the inherent security features of a spread spectrum system, OpenAir uses a 20-bit security ID for network access control. Unless the ID is validated by the network, access will not be permitted. The ID is encrypted during access, but any user data encryption is left to the end-systems.

- Higher Data Rates?

  The FCC recently issued a Notice of Proposed Rule Making (NPRM) that could affect the operation of 2.4GHz FHSS systems. Specifically the FCC is considering widening the occupied channel widths for FHSS radios. Channel bandwidths are now limited to 1 MHz. The proposal calls for the use of 5MHz channels. As a result of wider channel bandwidths, systems would be capable of higher data rates – 10 to 11

Mbps as opposed to 2 Mbps. These wide-band FHSS (WBFH) systems could then compete with 802.11b.

Opponents of the proposal argue this would cause major interference problems for all other devices using the 2.4GHz ISM band. The FCC expected to rule by midyear 2000.

5.1.1.2 2.4 GHz ISM Band – Other Standardized Wireless Networking Initiatives

There are other wireless network standardization efforts in the 2.4GHz ISM band. Two of the more recently popular are Bluetooth and HomeHF. While incorporating broadband wireless, these technologies were designed for smaller networks requiring less throughput and covering less area than most other technologies we discuss. They could be used to support integrated services platforms in rare situations, but other technologies are probably more suitable for the scenarios we present in Section 2. Therefore, we discuss them in general, but do not consider them to be widely applicable within the scope of this particular effort.

HomeRF

The HomeRF WLAN standard is based on the Shared Wireless Access Protocol (SWAP) – an open industry specification. SWAP was developed for wireless networking between products in the home environment, such as computers, computer peripherals, PDAs, and cordless phones. The HomeRF Working Group (HRFWG) believed that existing WLAN products were too complex for home applications and lacked good methods for supporting voice services. Therefore, they developed SWAP, which was derived from a simplified version of frequency hopping 802.11 and an extension of the Digital Enhanced Cordless Telephone (DECT) protocol. It is designed to carry both voice and data traffic and to interface with the Public Switched Telephone Network (PSTN) and the Internet.

SWAP allows two variants of point-to-multipoint architecture: ad-hoc and infrastructure-based. In an ad-hoc network, where only data communication is supported, all devices are equal and control of the network is distributed between the devices. In an infrastructure-based network, the hub (referred to as a connection point) provides the gateway to the PSTN. The connection point also supports data communications among clients.

Without supplemental antennas, devices have a maximum range of about 100 ft. A HomeRF network can accommodate a maximum of 127 devices, including voice terminals and data nodes (which are clients), and connection points. Performance will decline as the number of simultaneous uses increases.

HomeRF devices support either 1 Mbps using BFSK modulation, or 2 Mbps using QFSK modulation. Voice terminals use a Time Division Multiple Access (TDMA) variant of the DECT standard to support interactive voice and other time-critical services. Data nodes use a relaxed version the 802.11 CSMA/CA to support high-speed data. Connection points use both access methods.

SWAP specifies the use of the Blowfish encryption algorithm to protect confidentiality and provide data integrity. A 48-bit ID is used for network access control.

HRFWG members now exceed 90, and the group is expected to soon appoint an independent body for product certification. Compaq, one of the members, previously announced it will add HomeRF devices into its one of it Presario PC lines. Other manufacturers are planning similar products.

Most HomeRF products will be integrated (i.e., the wireless device will be built into the product). However, PC cards will also be available. Products should be introduced by the end of 2000.

Costs will vary since the wireless device is built into many different types of product. Costs for individual HomeRF NICs (PC Cards) and connection points should be slightly less than those for similar 802.11 devices. The reason for toning down DECT and 802.11when developing the specification was to simplify and save costs.

> ***Note:*** *The HRFWG was the group that petitioned the FCC to increase frequency hopping channel bandwidths. If granted, HomeRF performance could be enhanced significantly. Data rates would be on the order of 10 Mbps as opposed to 2 Mbps.*

Bluetooth

Bluetooth is a new Personal Area Network (PAN) specification intended to provide wireless connections for devices such as mobile computers, PDAs, mobile phones, and devices connected by short cables.

Bluetooth devices, like other Personal Area Network technologies, form piconets – small networks that operate in the vicinity of the user or device. The maximum range is approximately 30 ft., but may be extended to 300 feet in future versions of the specification. The device first establishing a network connection becomes a master, and all other devices will act as slaves for the duration of the session. Devices can be registered in more than one piconet, but only eight devices can be active within the piconet at any one time.

Bluetooth devices use a fast FHSS modulation and can support an asynchronous data channel, up to three simultaneous synchronous voice channels (64kbps), or a channel simultaneously supporting both asynchronous data and synchronous voice. The data channel can support up to 432 kbps – full duplex.

Bluetooth devices will be capable of both authentication and encryption. Encryption is currently 64-bit, so users requiring stronger measures will need to rely on additional products.

The Bluetooth Special Interest Group (SIG) is responsible for the specification. Version 1.0B was released in December 1999. Devices complying with the specification will receive certification from an independent testing lab, which has yet to be named by the SIG. All certified devices will be interoperable and will display the Bluetooth logo. The SIG is also working closely with IEEE, and it's expected that the Bluetooth specification will form the basis for the IEEE 802.15 PAN standard.

Consumer products are currently not available, but they should be introduced to the US by the end of 2000. Like HomeRF, most Bluetooth wireless devices will be built into many different product types, and costs will vary. It is unknown whether individual PC Cards will be commercially available. If so, costs should be comparable to or slightly less than those for similar 802.11 devices. Software developers kits (including PC Card) can be obtained today for about $5000.

> ***Note:*** *As was noted earlier, Bluetooth and the 802.11 WLAN technologies use the same 2.4Ghz spectrum, and interference will be a concern for products attempting to use of both devices simultaneously (e.g. a Laptop PC using Bluetooth for printer connectivity and 802.11 for WLAN connectivity). Basing the new IEEE PAN standard on the Bluetooth specification should help resolve the issue.*

5.1.1.3 2.4 GHz ISM Band – Proprietary Wireless Networking Technologies

There are many proprietary networking technologies using the 2.4GHz ISM band, but most are part of wide-area infrastructure-based systems. Service providers offering wireless "last mile" connectivity have formed the largest market for such equipment.

Some of these technologies have been around (and evolving) for years. Some are similar to and have formed the basis of the new WLAN technologies. Others offer alternative methods. All of them can support the applications we presented earlier in the document.

Architecture

Most proprietary networking is enabled by wireless bridge or wireless routing technologies. In typical infrastructure-based point-to-multipoint architectures, the router/bridge serves as the hub and is used to communicate with remote clients (users). In point-to-point architectures, the bridges/routers serve as the nodes on either end of the link.

Most wireless bridges were originally designed to support single point-to-point long-range connections, and while such simple architectures are still predominant, these technologies now support point-to-multipoint configurations as well. Most wireless routers are designed to support point-to-multipoint configurations.

> A **router** connects any number of LANs. They use forwarding tables (i.e., routing tables) to determine where to send data packets. Routers also communicate with each other to configure optimal paths between any two hosts.
>
> A **bridge** connects two LANs, which can be dissimilar (e.g., Ethernet and Token-Ring). They can also be used to connect two segments of the same LAN. Unlike routers, bridges are protocol - independent. They simply forward data packets without analyzing and re-routing. Consequently, they're faster than routers, but also less versatile.

The number of channels that can be supported depends on the particular technology and how it is employed. Some use DSSS modulation schemes and some use FHSS. Some are used for omni-directional point-to-multipoint coverage, others are used for point-to-point links.

Most 2.4 GHz proprietary networking technologies were intended for fixed communications. However, some have been found to support mobile users as well, such as those used in San Antonio's LifeLink system. Since these technologies were not designed for such environments, performance is uncertain.

System Performance

Data Rate: Most new technologies in this band have channel data rates on the order of 11 Mbps (often based on the same or similar modulation techniques used for 802.11b). These might be half duplex or full duplex rates depending on the equipment. Information throughputs are slightly less.

Occasionally, providers will tout throughputs in excess of 20 Mbps, but for systems currently using the 2.4GHz spectrum, such capacity is usually due to the use of multiple radios at the hub (i.e., a system design feature, not the capability of a single radio). These higher "system" throughputs are aggregate channel throughputs. The rates allowed individual users vary with system design.

Coverage: Most proprietary wireless networking technologies are intended for outdoor use. As with other 2.4 GHz ISM-band equipment, these technologies must comply with FCC Part 15 rules and regulations (e.g., emissions limitations, use of spread spectrum modulations, etc.), but omni-directional coverage can be on the order of 5 miles. Point-to-point links can be in excess of 20 miles – again depending on several system design and environmental factors.

Standards

The technologies addressed in this subsection comply with no particular wireless networking standards. Almost no long-range unlicensed wireless equipment is standards-based. Compliance with 802.11 is not even considered by most manufacturers, largely because that standard was designed around short-range use. In order to provide certain levels of interoperability, some equipment might comply with parts of a WLAN standard.

Existing Products

Non-standard wireless bridge and wireless routing products (and their remote client counterparts) are available from companies such as, Cisco (Aironet), BreezeCom Inc., C-Spec Corp., Cabletron Systems Inc., Hyperlink Technologies Inc., Lucent Technologies, National DataCom Corp., Symbol Technologies Inc., Wi-LAN Inc., Wireless Inc. and many more. Most of these manufacturers also build standardized WLAN equipment – products for a different market.

Existing Systems

There are several hundred types of 2.4GHz proprietary wireless networking devices installed in thousands of operational systems throughout the world. The majority of these systems are operated by commercial service providers, but some are used to support transportation-related applications we presented in Section 3.

- Cyber Internet Services, a provider in the City of Salem, OR, uses Aironet BR2000 wireless bridges and a series of omni-directional antennas to support customers throughout the Salem metropolitan area. Each hub can support up to 2 Mbps.

- LifeLink is a system used by the San Antonio Fire Department (SAFD) to provide audio/video conferencing and vital statistic data telemetry between ambulance crews and physicians in hospitals. It was designed to allow early assessment and treatment in the field, including while the ambulance is en-route.

  Communication between fixed roadside network nodes and the hospital end-systems is provided by TxDOT's fiber-optic network. To make the connection between the vehicle and roadside nodes (i.e., the wireless link), the Lifelike system uses an Aironet 2040EE wireless bridge – a DSSS-based product that can achieve data rates up to 4 Mbps (half duplex).

- The wireless-enabled cameras used by CALTRANS to monitor the San Francisco Bay Bridge are supported by Aironet BR500 802.11 compliant wireless bridges (built to support the long-range links and wide-area coverage, but also complying with 802.11 standards). This equipment can provide raw data rates of up to 11 Mbps. The CALTRANS system, which was designed by Dartech Technologies, LLC, achieves data rates of 5.5 Mbps (half duplex). Throughput is approximately 2.2 Mbps.

- Wireless, Inc. developed a technology that they refer to as Wireless Digital Subscriber Line (W-DSL). While not true DSL, it offers performance similar to some of the DSL technologies. W-DSL allows service providers to offer Internet access to their customers located in the Tier II and Tier III cities (i.e., rural locations lacking broadband wireline alternatives).

  W-DSL is actually enabled by Wireless Inc.'s WaveNet® IP 2458 – a point-to-multipoint wireless router that uses FHSS radios. In a typical system design, multiple radios are used at a hub, and multiple hubs are used to cover a particular geographic area. Each hub has a coverage radius of 10-15 miles. Each radio will support 1.7 Mbps (full duplex), and with multiple radios, the system is scaleable to approximately 20 Mbps per hub. Individual users can achieve burst rates of up to 512 kbps.

  Over the past year, Wireless Inc. has shipped W-DSL products to various providers, including:

  - MultiLink Wireless Solutions, Inc. – offering services within Fort Walton Beach and Pensacola, Florida.

- EZNET Total Access – soon to offer Internet access throughout West Virginia, Kentucky, and Ohio.
- Quest Wireless, Inc. – to initially offer Internet services from South of Miami up to West Palm Beach.

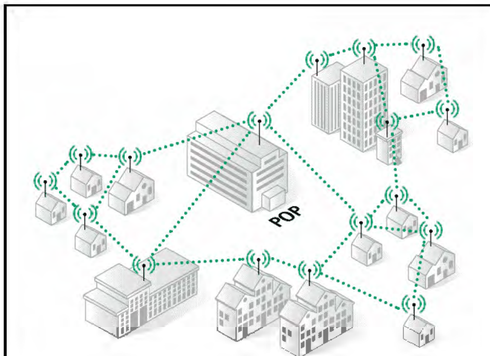
Other Issues

- Costs

  As with any technology, performance and functionality heavily influence the costs of proprietary wireless network equipment. Wireless bridge/router costs can vary considerably. Client (end-user) devices that are comparable to standard WLAN equipment are usually similar in cost.

- A Multipoint-to-Multipoint Alternative

  Nokia recently acquired a company called Rooftop Communications and their unique broadband wireless technology. Now referred to by Nokia as "Neighborhood Networks", these systems use a multipoint-to-multipoint architecture formed by a mesh of independent wireless nodes. Each node in the network becomes part of the infrastructure and will route data through the wireless network to its destination, like a mini Internet.



Multipoint-to-multipoint Architecture

  Neighborhood Network nodes combine 2.4GHz Part 15 compliant FHSS radios with IP-based routing functions. Nodes are both end-user access points and network relays that can transmit, receive, and forward data. This allows connectivity to extend beyond the reach of a typical point-to-multipoint network. As nodes are added, they simply extend the network. As nodes are moved, adaptive routing allows them to automatically learn neighbor nodes and compute the best routing paths. Changes in topology are transparent to the users and administrators.

  A multipoint-to-multipoint configuration inherently solves some of the line-of-sight (LOS) problems associated with wireless communication. Clear LOS is required between nodes, but it is not required between the source and destination. A node only needs LOS to another node in the network.

  The number of users supported by a single network depends on individual user requirements and network traffic. Between 15 and 20 nodes can be supported by a networks central node – usually placed at the provider's point-of-presence (POP). Each node can support up to 12 separate networks.

Neighborhood Networks were designed to provide fixed communication services. It's unlikely that they would be able to support devices while in motion.

Depending on the particular equipment model, nodes can support full duplex rates from 1.0 to 1.6 Mbps. Actual throughputs will depend on the network topology and usage, but user burst rates will range from 100 to 500 kbps. Rates might also be improved in future models that incorporate the newer modulation techniques (e.g., CCK, OFDM).

The range of a node's radio depends on not only the equipment model, but also the network configuration and the types of antennas used, etc. The lower-end models can cover an area with an approximate 1-mile radius (LOS). Directional antennas extend this range to over 6 miles. The higher-end model is capable of links up to 30 miles.

Neighborhood Networks are transparent to end users, applications, and network administrators, and can support any of the general applications we note in Section 3. The network equipment will be privately owned and controlled by ISPs (public or private), companies, agencies, etc. The provider or user will purchase, deploy, operate, manage, and maintain the network. Low level nodes cost approximately $2000 each.

5.1.1.4 5GHz ISM Band – Wireless Networking Technologies

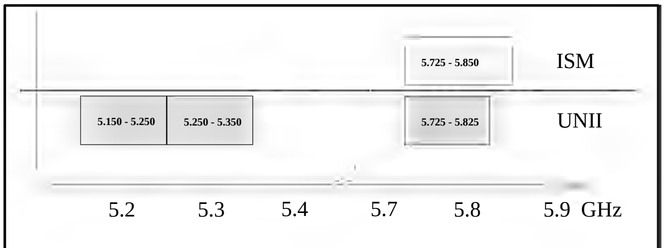
With the new 2.4GHz wireless networking technologies setting the benchmark for performance, manufactures are already beginning to move toward the next level – systems with data rates up to 100 Mbps. These faster systems require the use of higher frequencies, such as those in the 5GHz ISM band (5725 to 5850 MHz).

While these higher frequencies allow for greater data rates, they also suffer greater attenuation, and the nominal coverage area is less than that at 2.4 GHz. However, unlike systems at 2.4 GHz, systems using the 5Ghz band for fixed point-to-point operations do not have as many restrictions on the amount of directional gain provided by their antenna systems. Thus, the 5GHz band can be quite useful for building-to-building (i.e., long-haul) wireless links.

There are very few commercially available communication technologies that use the 5 GHz ISM band, and even fewer operational systems that use such equipment. While various new WLANs technologies (e.g., 802.11a) and a host of wireless routers/bridges could use this spectrum, they will most likely utilize the newly allocated UNII bands (also in the 5 GHz range). The UNII bands, unlike the ISM bands, were specifically intended for communications. They also have more usable bandwidth and present less regulatory constraint than the 5GHz ISM band. Therefore, we discuss the new 5GHz wireless networking technologies in the following subsections.

5.1.2 Part 15 UNII Bands

In January 1997, the FCC adopted an amendment to Part 15 that made available 300 MHz of unlicensed spectrum. This spectrum is referred to as the Unlicensed National Information Infrastructure (UNII) and comprises three bands within the 5GHz range, 5.15-5.25 GHz, 5.25-5.35 GHz, and 5.725-5.825 GHz.



5GHz ISM and UNII Bands

Part 15 Subpart E of the FCC rules sets out the regulations for UNII devices operating in these bands. Section 15.407 notes the general technical requirements, and unlike equipment in the ISM bands, UNII devices are not required to use spread spectrum modulation to mitigate interference.

For the 5.15-5.25 GHz band, the transmitter power can not exceed 50 mW and the maximum EIRP is 200mW. Additionally, any device that operates in this band must use a transmitting antenna that is an integral part of the device. Devices are also restricted to indoor operations. For the 5.25-5.35 GHz band , the peak transmit power is 250 mW and the maximum EIRP is 1W, but there are no such restrictions on indoor use or integrated antennas. These lower bands could be used to support point-to-point communication, but if transmitting antennas have a directional gain greater than 6 dBi, the transmit power must be reduced by the same amount that the gain exceeds 6 dBi. While permitted for point-to-point operation, these bands are best suited for point-to-multipoint use – true local area networking.

The upper band (5.725-5.825) is more appropriate for point-to-point links (e.g., between buildings). It's also more suited for wide-area outdoor coverage. Within this band, the maximum transmit power is 1000 mW. In addition, fixed point-to-point operations in this band may use antennas with directional gain up to 23 dBi without any corresponding reduction in the transmitter power. Once the 23dBi threshold is reached, a 1dB reduction in transmitter power is required for each additional 1dB of antenna gain. This allows for a maximum EIRP of 200W. In point-to-multipoint configurations, the maximum EIRP is 4W.

The following communications technologies will utilize the UNII bands. Again, they might also be type accepted for use within the 5 GHz ISM band.

Note: *Some very high powered government radar systems operate with in the5GHz range, and the FCC strongly recommends that those using UNII or 5GHZ ISM band devices for critical communications services should determine if these radar systems could affect their operation.*

5.1.2.1 5 GHz – Standardized WLAN Technologies

The new 802.11b standard has put wireless LANs on a rough parity with wireline Ethernet. However, new 5 GHz WLAN technologies will offer even better performance with raw throughputs exceeding 50 Mbps and quality-of-service (QoS) features that can adequately support isochronous services such as voice and video.

> **Isochronous** "eye-sock-ra-nuss" refers to processes where data must be delivered within certain time constraints. For example, multimedia streams require isochronous transmission to ensure that data is delivered as fast as it is displayed and to ensure that the audio is synchronized with the video. ATM-based networks are said to be isochronous.
>
> Isochronous can be contrasted with ***asynchronous***, which refers to processes in which data streams can be broken by random intervals, and ***synchronous*** processes, in which data streams can be delivered only at specific intervals. Isochronous service is not as rigid as synchronous service, but not as relaxed as asynchronous service.

Manufacturers have begun to develop 5GHz WLAN equipment. However, most of these products are either based on a specification that has not yet been standardized (e.g., 802.11a), or they claim to operate according to a standard but have not yet demonstrated the capability.

Like at 2.4GHz, most of the 5GHz standardized WLAN technologies will be best suited for short-range point-to-multipoint applications. They can also support long-haul point-to-point links and wide area point-to-multipoint coverage with the use of supplemental amplifiers, antennas, etc. But again, such wide-area long-haul systems are typically supported by proprietary wireless networking technologies. We discuss some of these in the following subsection.

The only ratified 5GHz WLAN standard is ETSI HIPERLAN1. Two other (and more predominant) standards are under development, IEEE 802.11a, and ETSI HIPERLAN2. We discusss all three.

IEEE 802.11a

Like the other IEEE 802.11 standards, 802.11a specifies the air interface between a wireless client and a hub, and among wireless clients. It addresses both the physical and MAC layers. At the physical layer, 802.11a supports only one medium, 5GHz orthogonal frequency division multiplexing (OFDM).

OFDM is a special form of multi-carrier modulation. The basic idea is to transmit broadband data by separating the data into several interleaved, parallel bit streams. A given RF channel (e.g., 20 MHz within the UNII band) is divided into a number of independent sub-channels, each carrying one of the bit streams. Together, these sub-channels are used to establish one wireless connection.

Sub-channel carriers use one of many possible modulation schemes, but typically BPSK, QPSK, 16QAM, or 64QAM. The modulation schemes in conjunction with forward error correction (at various code rates) allow a full channel to support data rates from 6 to 54 Mbps (see Table 5-3, Potential OFDM Modulation Schemes).

Table 5-3. Potential OFDM Modulation Schemes

Modulation	Code Rate	Data Rate
BPSK	1/2	6 Mbps
BPSK	3/4	9 Mbps
QPSK	1/2	12 Mbps
QPSK	3/4	18 Mbps
16QAM	1/2	24 Mbps
16QAM	9/16	27 Mbps
16QAM	3/4	36 Mbps
64QAM	2/3	48 Mbps
64QAM	3/4	54 Mbps

One of the benefits to OFDM is resistance to the adverse effects of multipath propagation (see insert). Multipath signals are integrated at the receiver, effectively creating a stronger transmission and allowing greater data rates over longer distances. Other methods can be used to handle multipath, such as coupling TDMA with a dynamic equalization scheme, but OFDM variants (of which there are many) seem to have an advantage in mobile and non-LOS scenarios.

Wi-LAN Inc. developed and patented their version of wide-band OFDM (W-OFDM), which might become the basis for the 802.11a standard. The company performed the first mobile application of W-OFDM with their demonstration to Caltrans. This application was referenced in Section 3. Wireless nodes – one along the roadside and another in the test vehicle – exchanged information at data rates of up to 30 Mbps. Tests were successful with the vehicle traveling at speeds of up to 70 mph.

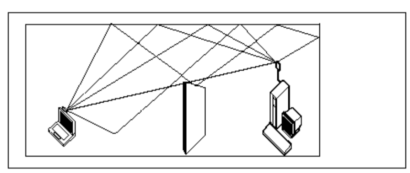
In December 1999, a group of over 100 representatives from 60 companies met to establish the OFDM Forum – an international organization to help develop and market the technology. This group has a particular focus on the WLAN market. Cisco Systems has also developed a version of the OFDM technology. They are attempting to make their version a defacto standard for fixed broadband wireless systems. We discuss this effort later in the document.

Architecture

As noted previously, all 802.11 technologies were designed for point-to-multipoint communication, but because of fewer FCC restrictions in the 5GHz bands (particularly the upper UNII band), 802.11a will also serve well for point-to-point communications.

The two point-to-multipont network architectures are the infrastructure network and the ad hoc network. Infrastructure-based networks can hand-off clients as they pass from between coverage areas. According to some manufacturers, this will include roaming between subnets.

Multipath describes a situation in which a transmitted signal follows several propagation paths from a transmitter to a receiver. This may result from the signal reflecting off objects such as buildings or office walls. Several time-delayed copies of the signal arrive at the receiver. This is referred to as delay spread and causes frequency selective fading. Multipath fading is particularly a problem in indoor, urban, and mobile environments.



802.11a will use the Point Control Function (PCF) to establish QoS levels (see insert). PCF can reserve time slots for critical traffic, but does not provide for guaranteed bit rates or control of latency like ATM. 802.11a supports Ethernet, but not ATM.

> **Quality of Service (QoS)** parameters manage the way in which data is transmitted through a network from source to destination. Examples of such parameters are bandwidth, bit error rate, delay, and jitter. These parameters help prioritize network traffic and deliver time-sensitive packets first, ensuring predictable performance for isochronous services, such as video and voice. The ATM protocol supports many QoS parameters. Ethernet does not.

The use of OFDM allows 802.11a to support not only fixed and transportable devices, but mobile devices as well. The level of mobility and the performance of the device while mobile have yet to be quantified. If 802.11a is used to support highly mobile clients (i.e., those moving at high velocities), the ability to manage rapid hand-offs between access points could also be an issue. This will be an important consideration in the system design.

Performance

Data Rates: 802.11a technologies will be able to support channel data rates from 6 to 54 Mbps. Information throughputs will be slightly less. Channel spacings are 20 MHz with the maximum number of channels depending on spectrum being used, UNII or ISM. There are approximately 13 channels across the entire UNII band (3 channels in the upper band), and 4 channels in the 5GHz ISM band.

All implementations are required to support 6, 12, and 24 Mbps. Optional extensions are for 9, 18, 36, 48, and 54 Mbps. A multi-rate mechanism of the MAC protocol ensures that all devices communicate with each other at the best data rate in the present channel.

Coverage**:** Coverage is inherently less at 5GHz than at 2.4GHz, but due to the nature of OFDM modulation, ranges are uncertain and will fluctuate with environment. Range will also vary inversely with data rate. In an ad-hoc network, coverage is defined by the range of the associated client devices (and any external antennas the devices might be using).

Using an infrastructure-based network, the maximum indoor range will most likely be less than 200 ft. External antennas on the client device (or supplemental antennas on the access point) can be used to extend the range, but emissions are limited by Part 15 restrictions in point-to-multipoint configurations. The same Part 15 FCC regulations apply for outdoor point-to-multipoint networks.

For point-to-point links, systems in the upper UNII band can use directional antenna gains of up to 23 dBi without reducing transmitter power. Gains above 23dBi are also permitted but with an equivalent reduction in transmitter power. Within the 5 GHz ISM-band, there are no restrictions on antenna gain for point-to-point links. The maximum range for such links will be in excess of 35 miles.

Note: *Actual coverage will depend on the particular vendor equipment, system design, environmental conditions, line-of-sight (LOS), etc.*

Standards

The IEEE 802.11a standard has yet to be ratified. 802.11a will not be backward compatible with 802.11b and/or 802.11. While the MAC layer is similar, the physical layer is based at 5GHz and the proposed standard specifies the use of OFDM modulation. When products become available, interoperability tests and product certification will be provided by an independent testing lab.

Existing products

Wi-LAN Inc. was first to introduce their OFDM products to the market. Their proprietary design can support throughputs in the range of 40Mbps and have been shown to provide 30Mbps data services to a vehicle moving at over 70 mph, as noted previously. This equipment is also the commercial predecessor to the company's 802.11(a) design.

Most 802.11 WLAN manufacturers are also working on their 802.11a products. Like other 802.11 equipment, 802.11a devices can be built into the client hardware, such as a laptop PC or household appliance, but they will also be available as PC cards.

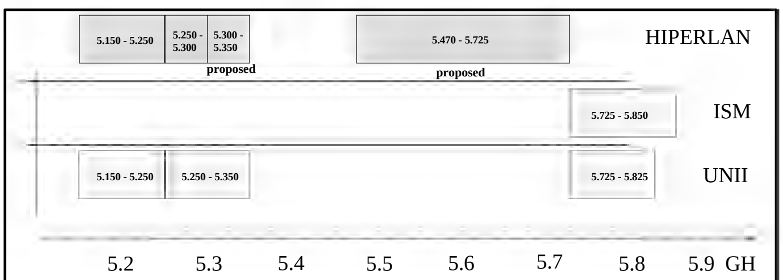
Other Issues

- Security

  802.11a will provide for encryption, but it does not incorporate any authentication mechanisms. Authentication will need to be handled by the end-systems.

HIPERLAN

In November 1991, the European Telecommunications Standards Institute (ETSI) formed a sub-technical committee to work on standards for HIgh PErformance Radio LANs (HIPERLAN).



HIPERLAN, 5GHz ISM, and UNII Bands

With support from the European Radiocommunications Committee (ERC), the HIPERLAN committee identified 150 MHz for use by HIPERLAN technologies in two bands: 5.15-5.25 GHz and 5.25-5.30 GHz). This spectrum was approved by the ERC in 1992. The maximum EIRP for systems using these bands is currently 200mW.

In the past few years an additional 305 MHz has been requested (5.300 to 5.350 and 5.470 to 5.725). These new bands will have different operational conditions set by the ERC. It's proposed that the new upper band have a maximum 1W EIRP. A final decision by the ERC is pending.

By 1996, the HIPERLAN committee had completed HIPERLAN1 – a WLAN standard defining operations similar to those characterized by the 802.11 standards. During the development of HIPERLAN1, a series of new HIPERLAN standards was identified.

- HIPERLAN2 will focus on high-speed wireless LANs with enhanced QoS provisions
- HIPERAccess will address the needs of the wireless local loop
- HIPERLink will support very high-speed wireless indoor backbones – 155 Mbps point-to-point links

> ***Note:*** *A separate HIPERLAN band at 17 GHz was identified by the ERC for HIPERLink technologies.*

These subsequent standardization efforts were united within ETSI as part of an effort called the Broadband Radio Access Network (BRAN) project.

While the HIPERLAN technologies were designed to comply with ERC regulations, these technologies can also be easily modified to operate within the UNII and 5GHZ ISM bands. HIPERAccess and HIPERLink are still in the early stages of development; therefore, we focus our discussion on the HIPERLAN1 and HIPERLAN2 technologies.

HIPERLAN1

The HIPERLAN1 standard defines a high-speed WLAN technology with limited QoS features to support isochronous services (e.g., voice and video). Like 802.11, the HIPERLAN1 standard addresses the air interface among wireless clients and between wireless clients and a hub. It also addresses just the MAC sub-layer and its underlying physical layer.

Architecture

HIPERLAN1 can be implemented in an infrastructure-based or ad hoc network configuration. In the infrastructure-based network, all traffic flows through a 'controller', which may or may not be connected to a larger network infrastructure. This controller is as a hub – similar to the 802.11 access point (AP) if connected to an infrastructure.

Network discovery and dynamic routing protocols are used to establish how information is distributed. While HIPERLAN1 has no integral protocol to "hand-off" clients as they pass between coverage areas, the infrastructure network can be configured to handle this process.

HIPERLAN1 devices will also operate in an ad-hoc mode. Unlike 802.11 implementations, ad-hoc networks are not limited to small areas where all devices are within range of each other. A multi-hop routing (MHR) algorithm is used to establish localized routing tables, and devices re-transmit packets (pass the packet along) until the destination is reached – or until the packet's lifetime expires.

HIPERLAN1's support for isochronous services is based on a Non-premptive Priority Multiple Access (NPMA) scheme. The HIPERLAN MAC incorporates a Channel Access Layer (CAC) which defines a connectionless data transfer (see insert). "Packet lifetime" and "user priority" parameters help establish a channel access priority, which is updated until the packet is transmitted

> **Connectionless**: a source device can send information to a destination device without establishing a connection between the two. The source simply puts the message onto the network with the destination address and hopes that it arrives. Examples of connectionless protocols include Ethernet, IPX, and UDP

HIPERLAN1's QoS support may or may not be invoked, depending on whether the upper layer protocols and the applications they support have been programmed to use the CAC parameters.

Like the 802.11b, HIPERLAN1 was designed to accommodate portable devices, but they should be stationary when in use. These devices might work in a mobile environment, but the specification was not designed for such operation.

Performance

Data Rates**:** HIPERLAN1 technologies can achieve channel data rates of 23.5 Mbps and information throughputs of 18 Mbps. Channels are approximately 25MHz wide. The maximum number of channels that can be used depends on the spectrum. Approximately 5 channels can be supported in the current HIPERLAN spectrum, 10 channels across the entire UNII band (3 channels in the upper band), and 4 channels in the 5GHz ISM band.

HIPERLAN1 technologies use Gaussian Minimum Shift Keying (GMSK) modulation, which is also used by the GSM-based European cellular networks and some Personal Communications Service (PCS) networks in the United States.

Coverage**:** In an infrastructure-based network, the maximum indoor range is approximately 200 ft. External antennas on the client device (or supplemental antennas on the controller) can be used to extend the range, but emissions are limited by ERC regulations. In the US, these emissions would be limited by the appropriate Part 15 restrictions.

Standards

The HIPERLAN1 standard was ratified and published by ETSI in 1996. Conformance testing rules and a full conformance standard were published by 1998.

The HIPERLAN1 Alliance was established in May 1999 to promote the standard as well as any associated companies, products, and applications. Companies represented at the

Alliance kick-off meeting included: Apple Computer, The Harris Corporation, Hewlett-Packard, IBM, Intermec, Nokia, and Proxim.

Existing products

While the standard has been out for some time, there are currently no HIPERLAN1 compliant devices on the market. Proxim has announced, but has yet to demonstrate, their first HIPERLAN1 product.

Other Issues

- Security

  HIPERLAN1, like 802.11b, uses wire equivalent privacy (WEP) for encryption; however, the implementation is slightly different. Additionally, HIPERLAN1 has no authentication mechanism.

HIPERLAN2

HIPERLAN2, like the other WLAN standards, defines an air interface among wireless clients and between wireless clients and hubs. In addition to the physical layer, it also defines a more specific data link layer (which includes the MAC) and a higher convergence sub-layer. These features allow HIPERLAN2 to support seamless connectivity with various network infrastructures (e.g., ATM- or Ethernet-based). They also support advanced QoS features for multimedia applications.

Architecture

HIPERLAN2 network architectures will be either infrastructure-based or ad-hoc. In the infrastructure-based network, mobile terminals (MTs) (i.e., client devices) communicate with the access points over an air interface. Access points can interface with virtually any type of wired network technology and can carry Ethernet frames, ATM cells, IP packets, etc. In the ad-hoc mode, MT's will communicate directly; the specification for this mode is still under development.

In contrast to the IEEE 802.11a and HIPERLAN1, HIPERLAN2 networks are connection-oriented (see insert). Individual connections are time-division-multiplexed over the air interface. There are both point-to-point and point-to-multipoint connections, the former of which are bidirectional, the latter are unidirectional – towards the MT. There is also a broadcast channel through which information reaches all MTs.

> In contrast to connectionless transfer, **connection-oriented** devices require a channel to be established between the source and destination before any information is exchanged. Examples of connection-oriented protocols include TCP and HTTP.

The connection-oriented nature of HIPERLAN2 makes it easier to implement QoS. Each connection can be assigned a specific QoS level for bandwidth, delay, bit error rate, etc.

Additionally, HIPERLAN2 will support ATM's QoS provisions as well as the RSVP reservation protocol to be incorporated in IPv6. These features, along with the high data rates, will facilitate the use of many simultaneous voice, data, and video services.

In an infrastructure-based network, MTs may move around freely, but each communicates with only one access point at a time. An MT will use the access point with the strongest radio signal. As a user moves, the MT is will automatically detect alternative access points. If a stronger signal is detected, a hand-off will be issued, and all connections will be moved to this new access point. Since HIPERLAN2 is a connection-oriented technology, some packet loss may occur during hand off. If an MT moves out of radio coverage for a long enough time, it may loose its association to the network and release all connections.

Since HIPERLAN2 is connection-oriented, the hand-off process could severely limit its applicability in a highly mobile environment. An OFDM modulation scheme helps with mobility, but the connection-oriented design hampers it. HIPERLAN2 technologies are best suited for the fixed communications configurations, such as those presented in Section 2.

Performance

Data Rates: Like 802.11a, HIPERLAN2 technologies will be able to support channel data rates from 6 to 54 Mbps. Information throughputs will be slightly less. Again, channel spacings are 20 MHz with the maximum number channels depending on spectrum being used. Approximately 6 channels can be supported in the current HIPERLAN spectrum, 13 channels across the entire UNII band (3 channels in the upper band), and 4 channels in the 5GHz ISM band. The specification requires HIPERLAN2 devices to support 6, 9, 12, 18, 27, and 36 Mbps. A 54 Mbps data rate is optional.

The MAC protocol implements a form of dynamic time-division duplexing (TDD) to allow for most efficient utilization of channel resources and to support full duplex communications at maximum speeds. TDMA is used for media access control.

Coverage: The OFDM modulation scheme makes maximum ranges tough to estimate, but indoor range will most likely be less than 200 ft., like 802.11a. Outdoor range might reach 500ft. External antennas on the MT (or supplemental antennas on the access point) can be used to extend the range, but emissions are limited by ERC (or Part 15) restrictions. Range will also vary inversely with data rate.

As with any communication technology using the upper UNII band, point-to-point systems can have directional antennas gains of up to 23 dBi without reducing transmitter power. Within the ISM-band, there are no restrictions on antenna gain for point-to-point links. The maximum point-to-point range will be over 35 miles.

HIPERLAN2 also supports the use of multibeam antennas (on the access point) to help improve network capacities and performance. The MAC protocol and the frame structure allow up to 7 beams to be used.

Standards

The HIPERLAN2 standard is being developed under the BRAN project within ETSI. The standard was to be finalized by the end of 1999 and available to non-ETSI-members by mid 2000.

The HIPERLAN2 Global Forum (H2GF) – an open industry forum to promote HiperLAN2 – was established in September 1999. As of February 2000, there were 25 members in the H2GF, including founders Bosch, Dell, Ericsson, Nokia, Telia, and Texas Instruments.

Existing Products

HIPERLAN2-based equipment is rumored to be under development by Nokia and Ericsson among others. Some vendors indicate that products should be available by the latter half of 2001 with general availability in large volumes early 2002. However, these are liberal estimates.

Other Issues

- Security

  HIPERLAN2 has security mechanisms for both encryption and authentication. Encryption is enabled only after a connection is made.

- WATMnet: An proprietary WLAN technology similar to HIPERLAN2

  The NEC Corporation has been developing their wireless ATM network (WATMnet) technology for years, but the design was recently modified to operate in the 5GHz unlicensed bands. This proprietary WLAN technology now uses 25MHz channels and GPSK modulation schemes to achieve data rates of 25Mbps – full duplex. While data rates are less than some of those supported by HIPERLAN2, WATMnet has similar networking capabilities and QoS features.

  Like HIPERLAN2, WATMnet is connection-oriented and uses TDMA/TDD medium access and data link control protocols. Each channel can be assigned QoS levels and mobile terminals are supported by integrating location management and hand-off mechanisms into standard network protocols. This allows seamless wireless extension to IP- or ATM-based wireline infrastructures.

  In April 1999, NEC (along with Telia, Sweden's national telecommunications provider) began test trials of a WATMnet network. The trial, named SEBRA (Semi-mobile Broadband Radio Access), was set to evaluate WATMnet's ability to support both IP- and ATM-based multimedia services. The trials were expected to conclude in June 1999. Results, if available, are not yet public.

HIPERAccess

The third standard in the HIPERLAN family will be HIPERAccess. These technologies will provide high-speed access (approximately 20 Mbps) for point-to-multipoint networks and support wireless local loops for residential and small business users. As such, they will be more suited for outdoor environments and longer links. They will be used to connect HIPERLAN2 systems, which more appropriately support in-building and other small area networks. The standards process has begun, but products are several years away – at best.

HIPERLink

While part of the HIPERLAN family, HIPERLink technologies will not be designed to use the 5GHZ unlicensed spectrum. They will use additional HIPERLAN spectrum at 17GHz (Europe only). HIPERLink systems will support very high-speed wireless indoor backbones; 155 Mbps point-to-point links. This standard has not yet been started.

5.1.2.2 5GHz – Proprietary Wireless Networking Technologies

The 5GHz unlicensed spectrum is (will be) primarily used for long-range systems, particularly in the 5GHz ISM and upper UNII bands. These bands offer a generous bandwidth allocation and less regulatory constraint than the unlicensed spectrum at 2.4 GHz. While there are not many operational systems using 5GHZ technologies, proprietary wireless equipment constitutes the most rapidly evolving type of equipment in the service provider domain.

Architecture

As in the 2.4GHz ISM band, most proprietary networking is enabled by wireless bridge or wireless routing technologies. In typical infrastructure-based point-to-multipoint architectures, the router/bridge serves as the hub and is used to communicate with remote clients. In point-to-point architectures, the bridges/routers serve as the nodes on either end of the link.

Again, wireless bridges were originally designed to support single point-to-point long-range connections, but these technologies now support point-to-multipoint configurations as well. Most wireless routers are designed to support point-to-multipoint configurations.

The number of channels that can be supported depends on the particular technology and the spectrum being used; ISM, UNII, or HIPERLAN (Europe). Because these technologies are increasingly used for quick-start ISPs wanting to serve the masses, channel reuse is often needed. Sectorized antennas permit such reuse and are becoming increasingly common.

Most 5GHz proprietary networking technologies were intended for fixed communications. However, those using OFDM modulation schemes might be capable of supporting mobile users as well.

System Performance

Data Rate: 5GHz proprietary technologies have reportedly achieved channel data rates of up to 100Mbps – full duplex or half duplex depending on implementation. Information throughputs are less. Modulation schemes, multiple access techniques, and resource sharing (i.e., duplexing) vary among products. Some use more complex methods (e.g., OFDM variants and TDD); others use a more traditional approach.

Coverage: Most proprietary wireless networking technologies are intended for outdoor use, and as with other 5GHz equipment, these technologies must comply with appropriate FCC or ERC rules and regulations. Using the upper UNII band, point-to-point systems can have directional antennas gains of up to 23 dBi without reducing transmitter power, and within the ISM-band, there are no restrictions on antenna gain. The maximum point-to-point range for such systems will be in excess of 35 miles – depending on system design and environmental factors. Regulatory constraints limit the attainable coverage radius to approximately 3 miles for point-to-multipoint operations.

Standards

The technologies addressed in this subsection comply with no particular wireless networking standards. Almost no long-range unlicensed wireless equipment is standards-based.

Existing Products

Many companies building 2.4GHz equipment are also developing 5GHz products – C-Spec Corp., Hyperlink Technologies Inc., Wi-LAN Inc., Wireless Inc. etc. In addition, there are companies like Wavespan and Adaptive Broadband, both offering 100Mbps products.

Existing Systems

Most existing 5GHz systems are privately owned pilot networks, but there are a few networks operated by commercial service providers. To the best of our knowledge, no such systems are currently being used to support transportation related applications – at least with in the U.S.

One of the 5GHz commercial service providers is Fuzion Wireless Communications, a recently licensed CLEC based in Boca Raton, FL. Fuzion plans to become one of the first carriers to launch UNII broadband data services. Over the next 3 years, they intend to deploy their broadband wireless system throughout the nation. Some business user services are already available in the Boca Raton and Delray areas of South Florida.

Both the wireless and wireline portions of Fuzion's network are ATM-based and have a variety of QoS features. The fiber optic infrastructure (backbone) is supported by Qwest Communications International Inc. The wireless portions of the network are enabled by Adaptive Broadband's AB-Access technologies.

These particular AB-Access technologies can use either the middle or upper UNII band. Each channel can provide up to 25 Mbps - full duplex. Individual user rates will vary depending on the type of service. With bandwidth on-demand (or packet on-demand) options, rates can be increased in 250 kbps increments up to 25 Mbps (provided network resources are available and appropriately allocated). The most popular service to date is a 2 Mbps connection (full duplex) for approximately $1500 per month.

The AB-Access subscriber unit (i.e., client device) can have either an ATM 25 or 10BaseT Ethernet interface for connection to a LAN or individual PC. The wireless hub has a 155 Mbps ATM interface to the Qwest infrastructure. A six-sector hub covering a 3 mile radius can support approximately 256 (average) users per sector.

While such technologies are not currently used within the transportation domain, they could easily support many of the applications we noted in Section 3.

Other Issues

- Cost

  As noted previously, wireless bridge/router costs can vary considerably – a few hundred to several thousand dollars. Costs might also depend on how the equipment is sold: as part of a service, as part of a system (e.g., complete hub site equipment), as individual units, etc. Performance and functionality requirements will influence the costs as well. Client (end-user) devices that are comparable to standard WLAN equipment will probably be similar in cost.

5.1.3 Other Unlicensed Communications Technologies

There are two additional types of unlicensed broadband communications technologies worth noting: free space optics and ulta-wideband (UWB) radio. Free space optical networks are more established. UWB shows promise for broadband communications, but the technology is still under development. Additionally, the methods by which UWB systems operate is under review by the FCC.

5.1.3.1 Free Space Optics

Unlike traditional fiber optic systems, free space optics use no fiber. Communications occur through the air. The lasers used for free space optics (as well as for traditional fiber optic systems) operate at frequencies unregulated by the FCC, and therefore no license is required to operate such systems.

There are several advantages to wireless optical systems. They can transmit data at least 10 times faster than most fixed wireless systems – up to 1000 Mbps, full duplex. Additionally, optical signals are directional (as opposed to radio frequencies, which are radial) providing inherent benefits to security and scalability. It's difficult to intercept a laser transmission without being in direct line of sight. And large amounts of scalability can be achieved since beams can be placed almost on top of each other without interference.

Still, these technologies have technical challenges. Heavy rain, snow, sometimes turbulence in the air, and particularly fog can attenuate laser signals and cause outages or slow connection speeds.

Free space laser technologies have been around for years, but most were used for point-to-point systems and were not particularly designed for distributed networks. However, advancements in optical systems (e.g. Dense Wavelength Division Multiplexing (DWDM), optical switching, automatic tracking, power control, etc.) have significantly improved wireless optical networking.

> Dense wavelength division multiplexing (**DWDM**) increases the capacity of optical transmissions by assigning incoming signals to specific wavelengths (or frequencies), and then multiplexing the these wavelengths for transmission over a single link. Each signal carried can be at a different rate (e.g., OC–3, OC-12) and in a different format (e.g., SONET, ATM).

Both Terabeam Networks and AirFiber have developed new free space optical networking systems – proprietary systems. Both companies have also recently teamed with a large telecommunications provider (Lucent and Nortel, respectively) lending significant credibility to the technology. We briefly review each of these systems.

TeraBeam's Fiberless Optics

TeraBeam Networks has been working on their free space optical network design since 1997. Their Fiberless Optics product and services, which were just recently unveiled (spring 2000), are aimed at businesses, universities, and other large enterprises looking for high data rate services. The system is not yet designed (or priced) for home users.

System Architecture

The Fiberless Optics design uses a point-to-multipoint configuration. Hubs are installed on building rooftops in an overlapping cellular pattern. Each hub typically supports four 90-degree sectors. Each sector can support up to 24 links.

The remote device must be in a direct line of sight, but it does not need to be rooftop mounted. It is designed to sit on a window sill and send/receive data through the window. Terabeam claims that thick reflective coatings and dirt have not prevented the beam from penetrating windows. Since no roof rights are required, this design can save both deployment time and lease expenses.

The system is strictly designed for fixed users. It could provide for some of the fixed communications configurations presented in Section 2, but this probably excludes transportable devices.

Performance

Data Rate: A single Fiberless Optics link can provide IP-based services at speeds of up to 1 Gbps, full duplex. That's fast enough to support extensions to existing Gigabit Ethernet and Fast Ethernet (100 Mbps) LANs, and more than sufficient to support any of the applications we note in this document.

Coverage: The range of each link is limited to approximately 1.25 miles.

Existing Systems

To address the potential problems with adverse weather (e.g., fog, mist), Terabeam established a test-bed within the city of Seattle, WA. The first consumer trials began there this past spring (2000).

In their joint venture with Lucent Technologies (to be called TeraBeam Internet Systems), the company expects to launch commercial service by summer 2000 and aims to cover the top national markets over the next four years. Initially, services will be offered at approximately $6300/mo for a 1 Gbps full duplex link.

AirFiber's OptiMesh

After two years of development, AirFiber also recently unveiled its free space optical network design. Their OptiMesh product, like TeraBeam's Fiberless Optics, it is currently aimed at large business users only.

System Architecture

The AirFiber system is deployed in a multipoint-to-multipoint network configuration. Many nodes – typically roof-mounted – are used to build a meshed network of optical links. Nodes function as both an access point for local users and a relay point to other nodes. Configuration and performance management are monitored and controlled from a single node.

Each node is equipped with up to four optical transceivers and an ATM switch to support voice, data, and video services. Each also has automatic tracking and power control that is used continually optimize signal strength and take into account building motion due to solar loading, wind, and other atmospheric conditions.

This system, like the Terabeam system, is designed for fixed users only.

Performance

Data Rate: Each optical link in the network is capable of supporting data rates of up to 622 Mbps, full duplex. Any data rate up to 622Mbps can be dropped from a single node.

Coverage: The links between nodes are relatively short, between 500 and 1500 feet depending on the local environment. However, signals can be passed throughout the network, which may extend for several miles.

AirFiber believes it can solve some of the availability problems by installing nodes closer together and creating a mesh of optical links. The shorter links will help with connectivity in poor atmospheric conditions (e.g., dense fog). The mesh provides independent and redundant links throughout the network should connectivity on a particular link be disrupted.

Existing Systems

AirFiber is currently conducting trials in Dallas, TX, and has plans to continue tests in Chicago, IL, Washington, DC, Denver, CO, and Portland, OR, later this year. The OptiMesh equipment product should become commercially available by the end of the year (2000).

5.1.3.2 Ultra Wideband (UWB) Radio

Conventional radio transmitters operate at a particular frequency, but a UWB transmitter emits a pulse that consists of many frequencies. The pulse is very short – about half a billionth of a second – and is transmitted at extremely low power. Because the pulse is a mixture of so many frequencies, it passes unnoticed by conventional receivers. It’s simply perceived as a brief fluctuation in the RF noise floor. However, a UWB receiver, simultaneously listening on a wide range of frequencies, can recognize and capture the pulse.

Information is sent by transmitting a stream of pulses at select intervals between 50 and 150 nanoseconds. By varying the timing of each pulse to within a tenth of a nanosecond, slightly early and slightly late pulses can be used to encode the zeroes and ones of digital information. This form of communication occurs without interference to/from conventional RF transmissions. Data rates of 20 Mbps have been reached in laboratory testing. Some hope to build systems capable of 100 Mbps by the end of the year.

The range of current UWB technologies is limited, but UWB could be used to support local-area communication systems, such as a WLAN or a micro cellular phone system. They also demonstrate potential for localized radar systems.

Existing Federal regulations prohibit the intentional emission of signals in the ultra-wideband by anyone who has not purchased the right to operate on a specific frequency. But in 1998, the FCC issued a Notice of Inquiry that proposed allowing the use of UWB as an unlicensed device under Part 15 (ET Docket No. 98-153). And in 1999, as part of an effort to open the use of UWB, the FCC issued waivers to three companies for limited marketing of UWB-based technologies.

- Time Domain Corporation, whose founder is credited with inventing the technology, was authorized to develop an ultra-wideband system that will be used either as a covert communications system or to detect people in a building environment.
- U.S. Radar Inc. was authorized to develop a ground-penetrating radar system.
- Zircon Corp. was authorized to develop a surface-probing impulse radar system.

Each has developed and demonstrated radar products. However, communications equipment, such as that used for local area networking is not yet available – or permitted for that matter.

So far, the FCC has not approved the technology for anything more than experimental use. They are currently drafting proposed rules for UWB and intend to issue a Notice of Proposed Rulemaking by the end of the year (2000). They do not intend to release final rules until testing for interference to other systems – particularly GPS – is complete. The USDOT and NTIA will conduct UWB testing in this country. All test results should be submitted by 30 October 2000.

5.2 Licensed Spectrum Technologies

The broadband technologies described in this subsection require the use of licensed spectrum. We do not address narrowband systems such as CDPD, ARDIS, and Metricom. These technologies, while useful within the transportation domain, are outside the scope of this effort and would not adequately support an integrated service platform.

We also do not address many older leased spectrum alternatives (e.g., conventional terrestrial microwave). Part of the objective to this effort is to introduce new broadband wireless technologies. This includes those that use the new LMDS and MMDS allocations, as well as some satellite and HDTV alternatives, among others.

5.2.1 Local Multipoint Distribution Service (LMDS)

Local Multipoint Distribution Service (LMDS) is a bidirectional, high-speed, wireless networking service that operates in the 28-31 GHz range. The service is intended to support many different applications, most of which were presented in Sections 3-2 and 3-3, but primary applications of the technology include:

- Telephony (local loop)
- Video teleconferencing (business, educational, medical)
- Video on-demand and interactive video (entertainment, education, e-commerce)
- High speed Internet/intranet access and dedicated digital services (e.g., fractional T1, T1, T3 and OC-3)

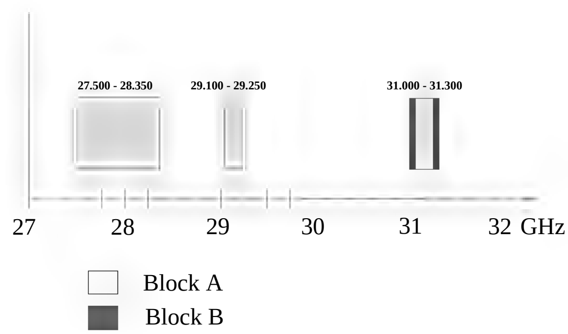
Because it can provide for multiple applications, LMDS has the potential to become a major competitor to incumbent local exchange carriers (ILECs) and cable television service providers.

> ***Note***: *ILECs are restricted from owning licenses, but the FCC is considering removing the restrictions after the initial three-year ownership period.*

Spectrum and Licensing

The FCC closed the original auctions for US LMDS spectrum in March 1998 after awarding 984 licences for over $580 million. Each of 492 Basic Trading Areas (BTAs) has 2 separately licensed blocks, A and B.

The A block has a total of 1150 MHz located in three bands: 27.500 to 28.350 GHz, 29.100 to 29.250 GHz, and 31.075 to 31.225 GHz. The B block has a total of 150 MHz located in two75 MHz bands between 31 to 31.075 GHz and 31.225 to 31.300 GHz. In May 1999, 161 defaulted licenses were awarded in a re-auction of this spectrum.



LMDS Spectrum

LMDS and non-geostationary mobile satellite service (NGSO-MSS) feeder links have co-primary status in the 29,100 MHz - 29,250 MHz band. However, because of concerns that LMDS transceiver may interfere with NGSO-MSS feeder link space station receivers, LMDS transceivers are prohibited from transmitting in this band.

More detailed information can be found in the Code of Federal Regulations. Title 47 Part101 (47CFR101) Subpart L is the section most pertaining to LMDS. One particularly appealing aspect of LMDS; the licensees are free to use the spectrum in any reasonable system design configuration and for almost any service they wish to provide.

System Architecture

There are two predominant architectures for LMDS systems (as well as most other fixed wireless broadband communication systems).

- Point-to-point: In this architecture, a "hub" concentrates one end of multiple point to point links between remote facilities. Multiple hubs are interconnected with high-speed wireline connections.

- Point-to-multipoint: This architecture allows a many-to-one relationship between hubs and remote facilities. Its consists of sectorized cells, each with of a number of sectors ranging from 15 to 90 degrees. A hub will be located in the center of each cell. A 90 degree sector will typically support between 250-1000 users, based on the intended service provisions and end-user demand.

* Many providers will also use hybrids of the point-to-point and point-to-multipoint architectures.

There are technical and economic tradeoffs to each of these architectures. Technical tradeoffs come down to: how many customers can be supported at a given data rate, and what type of services can be provided to them. Fiscal tradeoffs are based competition with other local services. Again, licensees are free to use the spectrum in any reasonable system design configuration they wish. This flexibility allows scaleable network architectures and a gradual system build-out to occur as the customer base increases.

LMDS is a fixed broadband wireless service, and as such could provide for the fixed communications configurations presented in Section 2, including those that consider transportable devices. Using LMDS for mobile applications is unlikely.

System Performance

Data Rate: The bandwidth of the LMDS spectrum is extremely large – more than twice the total bandwidth of AM/FM radio, VHF/UHF TV, and cellular telephone combined. It's enough to broadcast all the channels of direct broadcast satellite TV, all of the local VHF/UHF TV, and up to 1 Gbps of full duplex data. Realistically, the spectrum will be divided into several channels for various cells and sectors or for various point-to-point links.

Channel bandwidths vary from approximately 10 to 50 MHz and can deliver aggregate channel data rates of up to 155 Mbps (4xDS3 or OC-3). However, the maximum data rate allowed the individual user will be more like 1.544 Mbps (i.e., a T1 rate). Some service providers are looking to offer 10BaseT (10 Mbps Ethernet) – a common IP-based network interface.

Coverage: Because LMDS uses higher frequencies, there is greater attenuation, and signals can't bend around obstacles the way longer waves do. LMDS, as well as the other millimeter wave services, require line of sight between transmitter and receiver. This limits the potential coverage area of a single cell site and the distance between point-to-point tranceivers. The range for coverage depends on many local environmental characteristics – particularly rainfall and terrain. In climates where heavy rainfall is common, shorter link distances are required to achieve desired performance and availability. Field trials suggest an average coverage range 5 km.

The reliability of most radio links fairly high, somewhere between 99.995% and 99.999% depending on the provider and proper network design. Additionally, many providers intend to deploy ATM-based networks. ATM has the quality of service (QoS) metrics required to support simultaneous voice, video, and data traffic.

Standards

There are currently few standards affecting LMDS. Vendors are manufacturing equipment with different modulation techniques (e.g., nQAM, M-ary PKS, etc.), different duplexing (e.g., time division duplexing (TDD),and frequency (FDD)), and different multiple access schemes (time division multiple access (TDMA), frequency division multiple access (FDMA)). Recall that licensees are free to use any reasonable system design configuration they wish.

The LMDS industry does recognize the Data over Cable System Interface Specification (DOCSIS) – a defacto standard for compatible cable modem products in North America – as well as standards developed by the Digital Audio Visual Council (DAVIC). However, both DOCSIS and DAVIC are voluntary standards. The industry also considers the proposed standards under development by IEEE 802.16, but this effort is very new.

IEEE 802.16 , established in March 1999, addresses broadband wireless access standards. These will include specifications for the physical and media access control layers of fixed point-to-multipoint broadband wireless systems. The standards will apply to systems operating in the vicinity of 30 GHz but will be broadly applicable to systems operating between 10 and 66 GHz.

Further information is available through the LMDS Research Consortium. A group of providers and manufactures involved in research and development (including standards), LMDS test-bed services, information dissemination, etc. (see http://www.cwt.vt.edu/lmds/consortium.htm)

Existing Systems

LMDS providers, such as NextLink, are rolling out systems in several US cities. Some commercial services are available in Dallas and Los Angeles, but most are currently resold voice and T1 services from the ILECs. More systems and services will be deployed throughout the major metropolitan areas in 2000.

The Strategis Groups's report, " US Wireless Broadband: LMDS, MMDS and Unlicensed Spectrum,", indicates that, in 1997, "less than five vendors had the ability to produce an operating LMDS system, and few had been tested extensively. Today, any number of vendors can provide a working system capable of providing voice, data, and or video services".

Other Issues

- LMDS-like Service Providers

  In addition to LMDS, there are other mmwave (24 to 40 GHz) technologies and service providers, LMDS-like providers. Their system architecture's, coverages, user data rates, and services (voice, video, and data) are similar. Some of these providers have operational (and commercially available) systems in the United States, but the roll out is not much ahead of LMDS deployments.

These providers include: Winstar Communications, Inc. and Advanced Radio Telecom Corp., operating systems at 38 GHz; and Teligent, Inc., operating systems at 24 GHz), etc. There are many others. WinStar and Teligent offer services in major metropolitan areas throughout the country, as well as some of the larger business suburbs. Advanced Radio currently offers services to businesses in Portland OR, Seattle, and Phoenix. All will continue deployments throughout the year. Again, most services are currently resold voice and data services, but some offer offering Web hosting, e-mail, and news services as well.

Note: Teligent and Remec Inc. have jointly developed an "active antenna repeater" that can significantly extend the reach of fixed broadband wireless systems. Designed to be placed in both view of the hub and the CPE, these repeaters will receive, amplify, and re-transmit signals as required.

Teligent's systems can currently reach 60 to 65 percent of the buildings within approximately 3 miles of their hubs. The rest are blocked. The repeater brings about 90 percent of the buildings within range.

The device was tested in Teligent's Broadband Research lab and developed on a trial basis in Washington, DC. Though Teligent maintains the exclusive right to use the devices for the rest of the year, Remec can sell them to other providers next year (2001).

Many of the broadband wireless providers are arranging deals or merging with broadband wireline network/service providers (e.g., Qwest Communications, Inc.). The wireless providers support local access (i.e., "last mile") connectivity, and the wireline providers will provide the network backbone

- Costs

  Past estimates for LMDS customer premise equipment (CPE) were approximately $500 to $1000 non-recurring. As deployments progress, one can expect these prices to drop. Monthly recurring costs would depend on bandwidth requirements. LMDS-like providers offer similar costs.

- A Multipoint-to-Multipoint Solution

  Most LMDS providers will deploy point-to-point and/or point-to-multipoint systems. However, the licensees are free to use the spectrum in any reasonable system design configuration they wish. One alternative is a meshed network design, such as that recently developed by Radiant Networks, Inc.

Radiant developed a LMDS system that can overcome LOS problems by routing around obstacles using an Internet–style mesh configuration. Intelligent nodes mounted on rooftops, poles, etc. act as small ATM switches and communicate with one another in a multipoint-to-multipoint fashion. There are no base stations. Customer access nodes and system relay nodes comprise the entire network infrastructure.

Each node is capable of both receiving and transmitting information for itself and other nodes. In addition, each node is capable of supporting multiple links with other nodes. If one path fails, service is not interrupted. The approach is similar to that used by Nokia in their 2.4GHz Neighborhood Networks system.

Radiant claims the design is capable of connecting residential customers at bit rates of 25Mbps (full duplex) for a total cost of less than $1,000 per customer. A demonstration network has ben built and is operational.

The general concept of a wireless meshed network is not unique, but the idea for broadband systems is interesting and might be worth consideration for specific applications and users. Recall however that LMDS spectrum is licensed, and such a design might not be provided or permitted by the licensee. If it were, some innovative spectrum planning would probably be required.

5.2.2 Multichannel Multipoint Distribution Service (MMDS)

Multichannel Multipoint Distribution Service (MMDS), like LMDS, will provide wide-area, high-speed, bi-directional wireless networking. MMDS systems will support all of the applications presented in Sections 3-2 and 3-3; the most likely to be used in commercial deployments include:

- High speed Internet/intranet access and dedicated digital services
- Video teleconferencing
- Video on-demand and interactive video
- Telephony

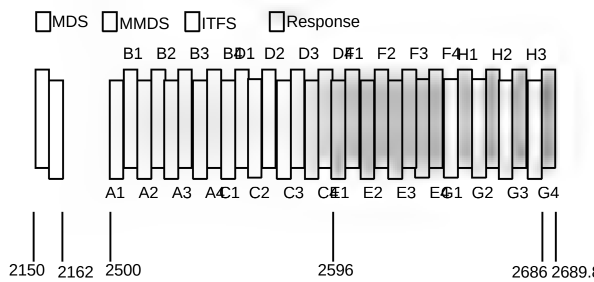
Spectrum and Licensing

The Multipoint Distribution Service (MDS) was established by the Federal Communications Commission (FCC) in 1972. MDS, often referred to as "wireless cable", was used in the United States to deliver analog video programming.

In 1983 the Commission reassigned eight channels from the Instructional Television Fixed Service (ITFS) to MDS. Originally, this spectrum was also to be used for video distribution, but the FCC’s Mass Media Bureau announced its Digital Declaratory Ruling that approved the use of high speed data applications, including Internet access. Operators were therefore authorized to transmit “digital” signals to multiple subscriber locations.

In March 1996, the FCC re-auctioned the MDS spectrum for a net revenue of over $216 million. A single license for 33 channels (6 MHz each, distributed between 2150-2680 MHz) was awarded for each of 493 BTAs. Twenty of the 33 channels are earmarked for ITFS educational use, 11 channels are for MMDS, and two remain for general MDS applications – primarily video distribution, although they can also be used in MMDS systems.

MMDS Spectrum



Frequency Range (Bandwidth)	Number of Channels	Type of Service	Channel Groups
2,150 - 2,162	2	MDS	1, 2
2,500 - 2,596	16	ITFS	A, B, C, D
2,596 - 2,644	8	MMDS	E, F
2,644 - 2,686	4	ITFS	G
2,644 - 2,686	3	MMDS	H
2,686 - 2,689.875	31	MMDS	Response

Currently, the 6 MHz channels are to be used for downstream transmissions only (i.e., to the subscriber). The license does include a group of thirty-one 125 kHz response channels (2686.000 - 2689.875 MHz) for MMDS upstream transmissions (from the subscriber), but the FCC only recently permitted the transmission of digital information on these channels.

As a result of several petitions, the FCC is expected to approve high-speed bi-directional transmissions on the 6 MHz channels. This will allow providers to support applications such as those noted above. FCC rules should receive final acceptance this summer (2000).

More detailed information can be found in the Code of Federal Regulations. Title 47 Part21 (47CFR21) Subpart K is the section most pertaining to MMDS.

System Architecture

As with LMDS, there are two predominant architectures for MMDS systems: point-to-point and point-to-multipoint. The traditional MMDS point-to-multipoint architecture consists of large unsectored cells. However, many providers are now considering a sectored approach. This is primarily due to two events:

- A shift in the MDS/MMDS paradigm. MDS/MMDS was originally used to provide video distribution for a few subscribers in a few locations; it's now intended to support several high-speed data applications (e.g., Internet/intranet) for many subscribers in many locations.
- The improving cost/benefit ratios associated with deploying sectored antenna systems. Sectored antennas systems increase spectral efficiency (i.e., reuse available spectrum), and the cost of such antenna systems is declining.

Cells will likely have sectors ranging from 15 to 90 degrees. A hub is located in the center of each cell.

* Many providers will also use hybrids of these architectures.

There are currently two approved methods for providing bi-directional data. One uses the 6 MHz channels for high-speed downstream transmissions, and a common phone line for upstream transmissions. A second approach uses the 125 kHz channels for the upstream transmissions. Either way, the upstream link is severely restricted and barely adequate for todays Internet demands.

Once the FCC has approved bi-directional transmissions on the 6 MHz channels, a third technique will use these channels (in part or in whole) for both upstream and downstream transmissions. This will be the primary method for most systems deployed over the next several years.

MMDS is a fixed broadband wireless service, and as such could provide for the fixed communications configurations presented in Section 2. Using MMDS for mobile applications is unlikely; however, it is a good prospect for transportable applications (see OFDM below).

System Performance

<u>Data Rate</u>: Bandwidth of the MMDS spectrum is not as large as that of LMDS, but each 6 MHz channel can be used to support data rates up to 37 Mbps (using 256 QAM). A pair of 6 MHz channels will be used for full duplex communication. The maximum data rate per user (or subscriber) will depend on the application and the available bandwidth, but these rates will range from 64 kbps to as much as 10 Mbps (e.g., 10BaseT Ethernet).

<u>Coverage</u>: Like LMDS, most MMDS systems require line of sight between transmitter and receiver, and the potential coverage area is limited. However, the lower MMDS frequencies (2 GHz) do not attenuate as quickly and are not significantly affected by weather conditions. Services can be provided at up to 30 miles from the hub – a coverage area of approximately 2,800 square miles. This is one of the largest coverage areas of any point-to-multipoint communications system available today.

Because of it large coverage potential, MMDS is well suited for rural and suburban markets, particularly those with little or no communications infrastructure. However, most new deployments are targeted at major metropolitan areas, the location of current demand.

As with LMDS systems, the projected service reliability is fairly high, usually above 99% depending on the provider and proper network design. Many providers will also deploy ATM-based networks. ATM has the QoS metrics required to support simultaneous voice, video, and data traffic.

Standards

Most MMDS systems use equipment that complies with DOCSIS, the defacto standard for compatible cable modem products in North America. This includes the use of 64 or 256 QAM for downstream transmissions and QPSK or 16 QAM for upstream transmissions. The standard also recommends upstream and downstream Reed-Solomon forward error correction (FEC), DES encryption, and 10BaseT subscriber interfaces. The multiple access methods most commonly used are TDMA and CDMA.

Equipment manufacturers also consider the standards developed by the Digital Audio Visual Council (DAVIC) and the proposed standards under development by IEEE 802.16. However, the 802.16 effort is very new, and both DOCSIS and DAVIC are voluntary standards.

With the expected approval of 6 MHz channels for bi-directional transmission, many providers will use other modulation techniques (e.g. 64 QAM) on the downstream link to achieve greater full-duplex data rates. Vendors are also closely monitoring the development of OFDM (see below).

Existing Systems

MMDS spectrum owners include CAI Wireless, Heartland Wireless, etc., but much of their spectrum is being bought by companies such as Sprint and MCI-WorldCom in efforts to integrate the "last mile" with their broadband infrastructures. Sprint and MCI-WorldCom are consolidating the MMDS operators. These two companies alone now own enough spectrum to reach more than 60% of the households in the top US markets. With a potential MCI/Sprint merger, this group would become the dominant player in the MMDS domain.

There are few MMDS systems in the US that currently provide anything other than voice and fractional T1 services. Sprint already has 300 to 500 residential customers in the San Francisco Bay area (and other locations), but the current service was not targeted at consumers. Typical installation charges were about $800, and monthly service fees were approximately $150. The company (merged or not) plans to re-launch the service with lower prices in the summer (2000). The new service, dubbed Sprint Broadband Direct, offers 1.5 Mbps downstream and 256 kbps on the return link and will cost around $40 per month for residential users, plus $400 for installation. The non-recurrring CPE cost is approximately $100 if you sign a two-year service contract. Phoenix, AZ, residents will be the first in the nation to get Broadband Direct, followed by those in Tucson, AZ, San Francisco and San Jose, CA, and Colorado Springs, CO.

In March 2000, MCI-WorldCom began to deploy its new system in three Southeastern US cities; Jackson, MS, Baton Rouge, LA, and Memphis, TN. The initial service offerings will provide high-speed Internet access to business and residential users. More deployments will occur later this year in Boston, MA, and Dallas, TX. By late 2001, the company intends to offer service in more than 100 cities.

Additional systems and services will be deployed throughout next few years, particularly after the FCC approves the use of 6MHz channels for bi-directional transmissions.

- An MMDS CLEC

  Spike Technologies Inc., based in Nashua, NH, holds an experimental license allowing them to use the 6 MHz channels for bi-directional transmissions. In 1997, their wholly owned subsidiary, Third Rail Wireless Services, was formed to develop broadband applications for MMDS. Third Rail was recently certified as a CLEC and supports a full range of broadband applications throughout the Nashua area, including: Internet/intranet access, video teleconferencing and IP broadcasting, traditional and IP-based telephony, WAN connectivity, and VPN capabilities.

  The unique aspect of this system is a patent pending antenna technology that can simultaneously support up to 22 independent sectors for up to 360 degrees of coverage. A single frequency pair (i.e., two channels) is used in each sector, but only two frequency pairs are needed to provide full duplex communications for the entire system. Each pair is reused 11 times – once in every other sector. Using polarization diversity (i.e., alternating vertical and horizontally polarized antennas), some providers might be able to achieve max spectral efficiency with only 1 pair of frequencies for the entire system.

  Third Rail's system in Nashua currently uses 16 QAM for both upstream and downstream transmissions. In each sector, 6 MHz is used for downstream and a 3 MHz for upstream, which equates to approximately 20 Mbps downstream and 10 Mbps upstream. Each sector is a separate network.

  The flexibility to deploy each sector independently allows the service provider to cover only those areas where subscribers are located. As demand grows, the system can adjust.

  Spike has deployed similar systems in Venezuela, Poland, and Ghana. They are planning a commercial deployment within the US this spring (2000).

- Another MMDS Provider

  Wavepath is an MMDS licensee and service provider in the San Francisco Bay area. In 1999, the company launched their "iSpeed" Internet access and corporate VPN services for small businesses and home offices throughout the area.

  Like the Spike system, Wavepath use a large amount of sectorization to help with spectral efficiency. Additionally, they have been granted a unique authorization by the FCC. The temporary license permits upstream sectorization and polarization diversity that results in over 1000% frequency reuse.

  iSpeed services are offered at symmetric rates of 128, 384, 512, and 1500 kbps. In addition, iSpeed can support asymmetric services with a 1.5Mbps downstream link and a 33.6 kbps upstream link over a standard telephone line (i.e., no upstream spectrum is used).

Other Issues

- Costs

  Estimates for MMDS customer premise equipment (CPE) are similar to those for LMDS CPE – approximately $500 to $1000 non-recurring. As deployments progress, one can expect prices to drop. As noted previously, Sprint Broadband Direct will cost around $40 to $50 per month. Actual recurring costs will depend on the provider, bandwidth requirements, etc.

- V-OFDM – Another solution to the LOS problem

  Most MMDS systems have a range of approximately 30 miles (line-of-sight) from transmitter to receiver. This past November, Cisco Systems, Inc. announced development of a new technology that will reduce this limitation. The company claims that their version of vector-based orthogonal frequency division multiplexing (V-OFDM) will overcome range, coverage, and antenna size problems.

  Using multiple antennas, the V-OFDM technology combines multipath signals that bounce off various obstructions (e.g., buildings). The process actually makes the transmission stronger. Additionally, the signals are less susceptible to the attenuating effects of foliage.

  The technology might help eliminate a significant obstacle to broadband wireless – the need for fixed line of sight between transmitter and receiver. It also provides a promising alternative to wireless transmission techniques that use Quadrature Amplitude Modulation (QAM), particularly for non-fixed (or nomadic) terminals.

  A group of twelve communications vendors (including Cisco, Motorola Inc., Texas Instruments Inc., etc.) are attempting to make the technology a defacto standard for broadband fixed wireless. The standard will address not only the V-OFDM physical layer, but the MAC layer as well. The solution has already been presented to the IEEE 802.16 standards body.

  Initial standards efforts focus on MMDS operations, but the technology will also work in 5.7 GHz (unlicensed), 1.8 GHz (PCS), and the LMDS ranges. Cisco’s V-OFDM chip set does not currently exist, but it should be available by the end of the year (2000).

  Note: *Earlier in this document, we addressed the OFDM variant developed by Wi-LAN Inc. While Cisco claims its vector-based system eliminates the need for LOS, Wi-LAN claims its system provides better support for mobile applications. Both will be of value.*

5.2.3 Wireless Communication Service (WCS)

Wireless Communication Service (WCS) is the result of re-allocation of the spectrum from 2305-2320 and 2345-2360 MHz as directed by the Appropriations act of 1997. This service may be used for fixed or mobile communication, radiolocation, or digital audio broadcast satellite.

Systems using the WCS spectrum can support a variety of digital services, including high-speed bi-directional Internet access, video teleconferencing, and wide-area network (WAN) connectivity (i.e., most of the applications presented in Section 3 of this document).

Spectrum and Licensing

The WCS spectrum is divided into 4 blocks designated and assigned as:

- Block A: 2305-2310 MHz paired with 2350-2355 MHz
- Block B: 2310-2315 MHz paired with 2355-2360 MHz
- Block C: 2315-2320 MHz
- Block D: 2345-2350 MHz

In April 1997, 126 of 128 licenses were granted; the FCC retained two. Two 10MHz licenses (blocks A & B) were approved in each of 52 major economic areas (MEA), and two 5 MHz licenses (blocks C & D) were approved in each of 12 regional economic area groupings (REAG).

More detailed information can be found in the Code of Federal Regulations. Title 47 Part27 (47CFR27) states the conditions under which this spectrum is made available and licensed for the provision of WCS.

System Architecture

The paired blocks of spectrum allow full duplex communication and could be used in point-to-point or point-to-multipoint network configurations. The unpaired blocks can be used for broadcast of data and are expected to support digital audio radio applications. Bandwidth of the WCS spectrum is much less than that of MMDS, so frequency reuse and sectored antenna technologies will be needed to support larger capacity point-to-multipoint implementations.

WCS allows for both fixed and mobile services. Fixed stations can transmit with a maximum EIRP of 200 W, but mobile stations are limited to 20 W EIRP. At least for the scope of our particular effort, WCS would be most suitable for the fixed communications configurations presented in Section 2, including those that consider transportable devices.

System Performance

<u>Data Rate</u>: Each 5 MHz channel can be used to support data rates up to 30 Mbps (using 256 QAM). A pair of channels would be used for full duplex communication. The maximum data rate per user will depend on the number of users, the system design, etc.

<u>Coverage</u>: WCS systems require line of sight between transmitter and receiver. For fixed services, power limitations are similar to MMDS, and coverage can extend to approximately 30 miles from the hub. For mobile services, the EIRP is limited and coverage is only a few miles.

Standards

Standards for WCS will not be defined until more specific services are identified, modulation schemes are selected, etc. Assurance that selections do not violate the allocation is generally the responsibility of NTIA.

Existing Systems

MCI WorldCom is conducting a WCS trial for high-speed Internet access in Clifton MS. Bell South is conducting a similar field trial in rural Louisiana. Both intend to demonstrate feasibility and establish cost base-lines for service provisioning. Bell Atlantic is another licensee.

Other Issues

- Costs

  Costs for WCS customer premise equipment will initially be in the range of $1200-$2000. As deployments progress, prices will drop. Monthly recurring costs will depend on bandwidth requirements. MCI and Bell South have not yet established costs for Internet service.

- Using WCS and MMDS

  MMDS and WCS have similar power limitations and RF channel characteristics. MMDS licensees waiting for the completion of the FCC’s two-way rule-making could use MMDS spectrum for the downstream transmission and the WCS spectrum for the upstream link.

5.2.4 General Wireless Communication Service (GWCS)

The General Wireless Communication Service (GWCS) band is a reallocation of spectrum earlier designated for fixed, mobile, and stationary satellite space-to-earth wireless links. Trends toward Ku and Ka bands for satellite downlinks has diminished the role of the earlier allocation and freed the band for additional commercial use. It is now intended for fixed or mobile communication (with the exception of broadcast radiolocation, and satellite).

Systems using the new GWCS spectrum will be able to support most of the applications noted in Section 3. It appears as though GWCS will also be used for ground-to-air services (e.g., in-flight entertainment).

Spectrum and Licensing

The GWCS spectrum is divided into five 5MHz blocks, designated and assigned as:

- Block A: 4660-4665 MHz
- Block B: 4665-4670 MHz
- Block C: 4670-4675 MHz
- Block D: 4675-4680 MHz
- Block E: 4680-4685 MHz

It is anticipated that 5 licenses will be issued in each of 175 economic areas (EAs) and 3 EA-like areas (e.g., Guam). The GWCS auction, previously scheduled to begin in May 1998, and again in early 1999, will be postponed until further notice by the Wireless Telecommunications Bureau (WTB).

More detailed information can be found in the Code of Federal Regulations. Title 47 Part26 (47CFR26) states the conditions under which GWCS spectrum is made available and licensed.

System Architecture

Both point-to-point and point-to-multipoint configurations can be used. Paired blocks of spectrum will support full duplex communications.

System Performance

<u>Data Rate</u>: With comparable spectrum allocations, achievable data rates will be similar to those of WCS systems (i.e., approximately 30 Mbps using 256 QAM). User rates will be determined by the number of users, the system design, etc.

Coverage: Coverage will depend on power limitations, which have yet to be finalized. One could expect coverage similar to that provided by WCS systems.

Existing Systems

Several companies have proposed delivery of in-flight voice, data, and video to commercial airlines. However, there are incumbent licensees of this spectrum, and build-out will be delayed until after auction.

Other Issues

- Costs

  Costs for GWCS customer premise equipment should be similar to that of WCS – $1200-$2000.

5.2.5 Broadband Personal Communication Service (Broadband PCS)

Broadband Personal Communication Services (broadband PCS) are roughly defined by the FCC as "… mobile and ancillary fixed communication services that can be integrated with a variety of competing networks." Broadband PCS systems operate within both the 1900 MHz PCS bands and the 800 MHz bands, the later of which is used for conventional cellular systems that have converted to digital. In this subsection, we focus on use of the PCS spectrum.

While this spectrum will soon be used for broadband communications (i.e., at least 384 kbps), it is currently used for narrowband voice and data services. However, this is not narrowband PCS (see insert).

Currently, PCS systems would not support applications such as video teleconferencing, etc. However, the next generation (and even some interim solutions) will be able to support most of the applications we presented in Section 3.

Narrowband PCS uses a smaller portion of the spectrum than Broadband PCS. Three separate 1MHz bands have been allocated to Narrowband PCS: 901-902, 930-931, and 940-941 MHz.

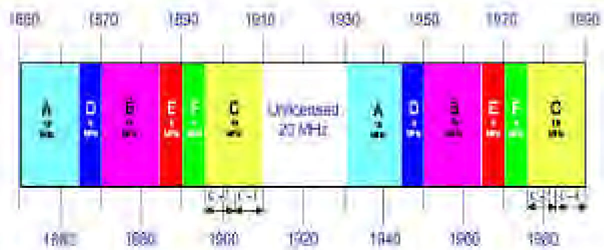
Narrowband PCS licenses will most likely be used to provide such services as voice message paging, two-way paging, and other text-based services.

Spectrum and Licensing

The broadband PCS spectrum is in the 2 GHz band – from 1850 to 1990 MHz. The spectrum totals 140 MHz; 20 MHz in that block is reserved for unlicensed applications. The 120 MHz of licensed spectrum is divided into six blocks (A through F) to serve either the MTAs or BTAs.

Ninety-nine A and B block licenses (30 MHz each) were auctioned off and granted by June 1995 raising over $7.7 billion. Three A and B block licenses were carried over based on Pioneer's Preference Awards.

Broadband PCS Spectrum



•	BLOCK A	30 MHz	1850 – 1865 , 1930 – 1945	MTA
•	BLOCK B	30 MHz	1870 – 1885 , 1950 – 1965	MTA
•	BLOCK C	30 MHz	1895 – 1910 , 1975 – 1990	MTA
•	BLOCK D	10 MHz	1865 – 1870 , 1945 – 1950	BTA
•	BLOCK E	10 MHz	1885 – 1890 , 1965 – 1970	BTA
•	BLOCK F	10 MHz	1890 – 1895 , 1970 – 1975	BTA

The C and F blocks have been named "Entrepreneur's Blocks." The auction for licenses in these bands was limited to smaller businesses that fall under certain financial caps.

The original C block auction was completed by May 1996. In 1997, the FCC provided C block licensees with a menu of options designed to assist those experiencing financial difficulties. As of June 1999, 159 licenses out of 302 had been granted. However, many of the licensees participating in the FCC’s installment payment plan were delinquent on their obligations, and their licenses have been canceled. These licenses are now available, and the FCC has announced the re-auction to begin in July 2000.

The D, E, and F blocks contain 10 MHz each, and as of April 1999, 1466 licenses out of the 1472 auctioned have been granted; some have been terminated or dismissed. These blocks raised an additional $2.5 billion for the US Treasury.

More detailed information can be found in the Code of Federal Regulations, Title 47 Part24 (47CFR24).

Note: *In addition to the existing 1900 MHz blocks, the FCC will soon auction additional spectrum in the 700MHz band. This spectrum may be used for broadband PCS systems.*

A total of 12 licenses will be awarded. One 20 MHz license (consisting of paired 10 MHz blocks, 752-762 and 782-792 MHz) and one 10 MHz license (consisting of paired 5 MHz blocks, 747-752 and 777-782 MHz) will be offered in each of six regions. These regions are to be known as the 700 MHz band economic area groupings (700 MHz Band EAGs). Licensees may subdivide channels as desired.

Approximately 100 television stations presently use the spectrum, and they have permission to do so until the year 2007. The FCC has asked the incumbents to vacate by then. To avoid any interference during the transition period, new licensees operating in this spectrum must comply with the appropriate co-channel and adjacent channel protection provisions.

The auction, originally scheduled for June 7, 2000, has been postponed until sometime in September. Licensees must provide "substantial service" to their service area(s) no later than January 1, 2015.

System Architecture

PCS systems will support full duplex communications and will primarily employ point-to-multipoint architectures, although point-to-point configurations are permitted. While most activity will involve mobile systems, there are a few fixed PCS systems under development. Licensees may provide fixed services on a co-primary basis with mobile operations, but broadcasting is prohibited.

PCS systems could support most all of the communications configurations presented in Section 2. Base stations (hubs) are limited to 1640 W EIRP while the antenna height is less than 300 meters. As heights rise above 300 m, permissible power levels drop. Mobile/portable devices are limited to 2W EIRP.

- **Mobile Systems**

  Most broadband PCS is (and will continue to be) used for a variety of mobile services. The systems supporting these services will conform to the second, third, or interim generation PCS standards.

  - **Second Generation (2G) PCS**

    There are three 2G standards used within the US: Global System for Mobile Communications (GSM), IS-136, and cdmaOne. Each uses the available spectrum in different fashions.

    - **GSM** (or PCS1900) is a TDMA-based standard developed in Europe. It allows up to eight voice circuits in a 200 kHz channel. Circuit switched data is also possible at either 9.6 or 14.4 kbps.
    - **IS-136** is also a TDMA-based standard. IS-136 uses 30 kHz channels; each supporting up to three voice circuits. The specification also allows for 9.6 kbps circuit switched data.
    - **cdmaOne** is Qualcomm's IS-95-based CDMA standard. CDMA, in general, allows many users to simultaneously access a 1.25MHz channel. There is no specific number of concurrent users, but the channel will degrade as it approaches capacity. Circuit-switched data at rates of up to 14.4 kbps are also specified.

    Many PCS providers are now using these 2G standards. Sprint PCS uses cdmaOne, AT&T Wireless has systems based on IS-136, and Bell South has systems based on GSM. While these are an improvement from analog cellular, they are not nearly sufficient to support and integrated service platform. However, their successors, the 3G technologies (and possibly some interim 2.5G technologies) to be introduced in the coming years will be able to do so.

– **Enhanced Second Generation (2.5G) PCS**

Before 3G systems are deployed, expect enhancements to the current 2G systems. These enhancements, often referred to as 2.5G technologies, offer some 3G features, such as higher system capacity and higher data rates. They are considered stepping-stones to 3G networks.

For enhancement to CDMA-based systems, there are two 2.5G technologies: IS-95B and high data rate (HDR).

- **IS-95B:** IS-95B is a modification to the IS-95A standard that allows the aggregation of CDMA channels for packet data transmissions. The maximum achievable data rate is approximately 115 kbps. However, in the early stages of implementation, rates will likely be limited to less than 57 kbps on the forward channel (from hub) and 14 kbps on the return channel.

- **HDR:** The HDR technology (developed by Qualcomm) is optimized for packet data services with a decentralized architecture based on IP protocols/platforms. HDR uses a full 1.25 MHz CDMA channel to support a maximum data rate of 1.8 Mbps per sector. Aggregate forward channel data rates range from 600 kbps to 1.8 Mbps with individual users burst rates from 38 kbps to the full 1.8 Mbps. On the reverse channel, the aggregate data rate is between 200 and 600 kbps with user burst rates ranging from 9.6 to 307 kbps.

  HDR can be deployed as a stand-alone system or integrated into a CDMA network. It is compatible with cdmaOne, IS-95A, IS-95B, and future 3G cdma2000 networks and can share cell sites, towers, and antennas with such systems.

  Korea Telecom Freetel (KT Freetel) is expected to begin technical trials by the summer of 2000. Marketing trials and commercial rollout are expected to occur during 2001.

For enhancement to GSM systems, there are also two 2.5G technologies: High Speed Circuit Switched Data (HSCSD) and General Packet Radio Service (GPRS).

- **HSCSD:** Current GSM (and other TDMA-based) technologies use a single voice channel for data – per user. HSCSD uses multiple channels (i.e., multiple time slots) to extend data rates from 28.8 kbps to as much as 76.8 kbps. HSCSD enhancements might be implemented by some providers as early as 2000.

- **GPRS:** GPRS is a packet data service that will support both IP and X.25 protocols. The technology uses a combination of dedicated and dynamic allocated time slots for packet data transmissions. With eight TDMA time slots, fixed users can achieve a data rate of 171 kbps. For mobile users (actually in motion) the data rate drops to 115 kbps. It's unlikely that all eight time slots would go to one user; therefore, the actual user rates will be less. Providers will adjust the allocation of time slots based on demand.

  This past spring (2000), Motorola and the Beijing Mobile Communication Corporation (BMCC), completed the first successful tests of GPRS in China. Similar test systems have been deployed in Germany, Austria, France, Hungary and Turkey. Commercially available GPRS systems are expected to launch in Europe and Asia late this year with systems to follow in North America.

IS-136 TDMA-based systems could be enhanced by IS-136B (or IS-136+).

- **IS-136B:** Similar to GSM enhancements, IS-136B will support high-speed data services by aggregating time slots. Circuit switched data will be offered at 28.8 kbps, and a packet switched service (similar to GPRS) will support data rates between 14.4 and 43.2 kbps.

Unless operating under optimal conditions, most of the current 2.5G technologies will not adequately support and integrated service platform. However, they are worth consideration.

– **Third Generation (3G) PCS**

At present, manufacturers and providers are supporting a number of incompatible 2G and 2.5G technologies with conflicting interface standards and spectrum-sharing techniques. Third generation (3G) technologies are being standardized by the International Telecommunications Union (ITU) as part of the International Mobile Telecommunications 2000 (IMT-2000) effort. The idea, whether attainable or not, is to come up with a single standard.

Originally there were ten proposals before the ITU, but now there are three candidates: **IMT-Multi-Carrier (MC)**, **IMT-Single-Carrier (SC)**, and **IMT-Time-Coded (TC)**. IMT-MC is based on Qualcomm's cdma2000– an IS-95 CDMA derivative. IMT- SC, formerly referred to as IS-136HS or UWC-136, evolved from the IS-136 TDMA standard. IMT- TC is the GSM-based alternative. Both IMT-SC and IMT-TC are based on the Enhanced Data Rates for GSM Evolution (EDGE) specification, which will help both GSM and TDMA networks evolve to 3G.

Although the ITU has yet to determine details of the 3G standard, providers are already planning to implement 3G systems. There is a growing consensus that the standard will be based largely on IMT-MC. The US supports either the IMT-MC or IMT-SC standard.

Third generation systems will provide users with data rates of up to 2.048 Mbps. The minimum data rate of 144 kbps will support users in vehicles moving over large areas at high speeds. A data rate of 384 kbps will provide for users that are stationary or moving at pedestrian speeds, and a data rate of 2.048 Mbps will support fixed office users. The latter is more than enough to support an integrated service platform.

This past winter Ericsson and Canada's Telesystem International Wireless (TIW) ran tests of an EDGE-based system. In March 2000, Sprint PCS Labs began testing Qualcomm's cdma2000technology. Verizon Wireless, recently formed by the combination of Bell Atlantic Mobile and Vodafone AirTouch, plans to adopt the cdma2000technology and begin testing in June.

Although progress is being made, 3G systems will not be commercially available for some time. Deployment in certain countries might begin in 2002.

Large-scale deployment of 3G systems will hinge on the success of the interim 2.5G technologies. If good enough, 3G deployments may be delayed. Additionally, efforts to develop yet another generation of PCS technologies – fourth generation (4G) technologies – are now underway.

> ***Note:*** *Many experts in the wireless industry are predicting that fourth-generation (4G) wireless technologies could make 3G services obsolete before they're ever deployed. Companies, research laboratories, and the academic community - particularly in Europe - have begun to review the possibilities for 4G systems. New modulation techniques and intelligent antenna developments are just two of the motivating factors.*
>
> *In general, 4G PCS will be a mobile alternative to Digital Subscriber Lines (DSL) and cable modems, technologies that support megabits per second data rates. However, even with the potential of 4G, it will take a while before 3G loses its luster.*
>
> *Also, PCS licensees must consider FCC build-out requirements. They must have at least 1/3 of their market covered within the first 5 years after the auction. It's also doubtful that they would forgo the revenues that can be derived by following the 3G migration path to 4G.*

- **Fixed Systems**

  While mobile systems currently (and will continue to) dominate the PCS market, there are a few licensees interested in providing fixed services. The noted PCS standards could be used to support such services, but specific fixed system designs are better suited. AT&T and NextWave each have a new fixed PCS system.

  – **AT&T's Project Angel**

    For over five years AT&T Wireless has worked on their fixed wireless service – dubbed "Project Angel". The service will provide high-speed Internet access and a local phone service that could compete with an RBOC or ILEC. When first conceived, the effort was considered too costly with little return on investment. However, the large demand for Internet access changed the outlook, and the project was resurrected.

    Project Angel could use any or all of 3 PCS bands. AT&T holds D-, E-, and F-block licenses, 10 MHz each. While specific system information is not yet available, it's expected the company will string equipment from its existing cellular towers – those used for their existing mobile PCS systems.

    In a typical configuration, a transceiver (remote device) would attach to the side of the user's house/building. The user's phone would work like a cordless phone when in range of the transceiver and a cellular phone beyond the transceiver's range (using AT&T Wireless cellular phone service). High-speed data services (available only at the home/building site) would be delivered at rates of up to 500 kbps.

    After conducting tests this past fall (1999), AT&T Wireless is now offering the service in its first commercial market, Fort Worth, Texas. It's also targeting at least two additional, yet-to-be announced, markets in the third quarter of 2000. If the customers are satisfied with the service, the company will work for nationwide deployment beginning in 2001.

  – **NextWave's iBridge**

    Rather than use their spectrum to operate mobile services as originally planned, NextWave Personal Communications is focusing on fixed wireless service. The plan is to offer broadband wireless in areas that are under-served by wireline DSL and cable data services.

    This past winter they tested their fixed PCS network that can reportedly support data rates up to1 Mbps. The company intends to offer voice and data service on a wholesale basis to other providers. The service, under the label "iBridge", will provide two voice lines as well as high-speed data.

NextWave was the leading bidder in the PCS C-block auction held three years ago, but it has been unable to use the spectrum after failing to meet payment obligations on its $4.7 billion bids. The company reorganized under Chapter 11 federal bankruptcy protection while it tried to persuade a federal court to reduce its obligations. However, the courts recently sided with the FCC ruling that the Commission may re-auction the licenses. NextWave would like to reacquire the licenses, but they are now worth significantly more than was originally bid.

Other Issues

- i-BURST – A PCS System Enhancement

  ArrayComm recently introduced a PCS system enhancement they call “i-Burst”. iBurst requires use of a full 10MHz spectrum, but in optimal conditions, it can reportedly support user burst rates up to 40 Mbps. Rates in congested networks are likely to be slower, but a 1Mbps connection should be attainable even under congested conditions. This would be fast enough for high-speed networking, streaming multimedia, etc.

  Traditional PCS systems will waste most of their capacity and signal quality by transmitting energy in all directions – either with omni-directional or large sectored antennas. These same systems, enhanced by iBurst, would transmit directly to each user while attempting to avoid interfering with other users.

  The technology is based on adaptive smart antennas that improve capacity and coverage by continuously optimizing RF channels. iBurst can also reduces spectrum needs. Spectrum re-use is achieved by creating multiple spatial channels on top of traditional voice and data channels.

  While system capacity and throughput are increased, the iBurst system enhancement decreases mobility. The technology does not work well if the user is travelling at speeds of more than 10 mph. The directional transmissions require an accurate fix on the user's location, and the antenna arrays can not yet accommodate such rapid changes.

  iBurst can supplement systems based on any one of the PCS standards, including the 3G alternatives. A market trial in the US is planned for the second half of 2001. Depending on provider acceptance, commercial deployment could begin in by 2002.

5.2.6 Satellite Services

Most of today’s broadband communications infrastructure is limited to the developed urban areas of the world. Satellite systems provide the means to extend these services to underdeveloped urban areas as well as the suburban and rural markets.

Narrowband services have been provided by geostationary Earth orbit (GEO) satellite systems for years, and they are increasingly used to support transportation-related applications. The American Mobile Satellite Corp. (AMSC) offers voice, data, and location service throughout North America. Their eLinkSM wireless e-mail service is now being used to support real-time advanced traveler information systems in several major US cities.

GEO satellite systems are also being used to provide limited broadband services. Both Direct PC (Hughes Network Systems) and CyberStar (Loral Space and Communications) use a broadband multi-cast to provide information to the users, but the response link (from the users) is via terrestrial phone lines. This slower response link severely restricts applications.

Several companies are developing non-geostationary earth orbit satellite systems, primarily low-Earth-orbit (LEO) systems. There are three distinct types of LEO satellite systems:

- **Little LEOs:** These systems (e.g., Orbcomm by Orbital Sciences Inc.) offer small messaging, paging, and position location services.

- **Big LEOs:** These systems provide narrowband telephony, low rate data transmission, paging, facsimile, position location, etc. They typically work in conjunction with existing terrestrial cellular networks. The most notable Big LEO system is Iridium – a system developed by Motorola Inc. Iridium began operation in November 1998, but has since been shut down due to financial instability. Globalstar, also a Big LEO system, is run by a consortium of international communications companies. ICO Global, a medium Earth orbit (MEO) satellite system, offers similar services.

- **Broadband LEOs:** As the name implies, these systems provide broadband services. Broadband LEO systems include Teledesic, SkyBridge, Spaceway, and Celestri (which is actually a hybrid LEO/GEO).

For the purpose of introducing broadband satellite systems, we briefly review the Teledesic and SkyBridge systems. We also review a new broadband GEO system by ALOHA Networks called SkyDSL.

5.2.6.1 Teledesic

Teledesic, backed by companies such as McCaw, Microsoft, Motorola, and Boeing, is building a global broadband network they refer to as "Internet-in-the-Sky"™. Using a constellation of low Earth orbit (LEO) satellites, Teledesic will provide high-speed digital services capable of supporting all the applications we have referenced throughout this document (e.g., Internet/intranet access, interactive multimedia). Services will be available to both providers and select end users.

Spectrum and Licensing

In March 1997, the FCC licensed Teledesic to deploy and operate their satellite-based network. It will operate in a portion of the Ka-band – 29 GHz for the uplink and 19 GHz for the downlink. Recently the International Telecommunication Union (ITU) finalized its designation of this spectrum for use by non-geostationary fixed satellite services, such as those Teledesic will provide.

System Architecture

The Teledesic network architecture is point-to-multipoint with various base station hubs and remote subscriber units. The hubs will provide connectivity to other wireline and wireless network backbones, such as the Internet.

The space segment was to consist of 288 satellites (24 satellites in one of 12 low orbit planes); each having dynamically allocated carrier frequencies. Together, they would be able to support millions of simultaneous users. The system will still support these users, but the architecture will be modified.

> *Note: In May 2000, the Teledesic partnership was expected to announce a revised strategy and possible new investors for their network of satellites. At the time of this document, no specific details had been released. However, it appears as though they will rely on the infrastructure of ICO Global, a MEO satellite system that will offer narrowband services. ICO Global Communications filed for Chapter 11 in August 1999, but was expected to emerge from bankruptcy in May 2000. After which, its system would serve as the first leg of the Teledesic deployment.*
>
> *The concept is to make the Teledesic less complex and less costly in order to get the system operational. The constellation will be built on ICO's. It will have less than the initially proposed 288 satellites and will be in mid Earth orbit rather than low Earth orbit.*
>
> *Reasons for the change include soured relations with partners, unworkable economics for the system's original design, and a financial community wary after Iridium's failure.*

Subscriber equipment will be roof-mountable and connect to a computer or network inside the facility. Currently, Teledesic plans to support only fixed users – this includes transportable users.

Reliability should remain fairly high since the satellites form a distributed network. With a distributed network, reliability can be built into the network rather than an individual unit.

System Performance

<u>Coverage</u>: Teledesic will provide global coverage. Within any 630 square kilometer area, the network will support more than 500 Mbps to and from all subscriber units.

Data Rate: Most users will have full duplex connectivity at up to 64 Mbps on the downlink and up to 2 Mbps on the uplink. Higher-speed terminals will offer 64 Mbps or greater on both links. The network will also support bandwidth on-demand, allowing a user to request and release capacity as needed.

Standards

It's expected that many manufacturers will offer standards-based subscriber equipment (e.g., 10BaseT Ethernet). Equipment specifications (and any standards to which they might adhere) are not available at this time.

Existing Systems

Teledesic's network will be deployed over the next few years. Modifications to the architecture are not expected change the basic business plan or the deployment schedule. Commercial services should be available in 2004.

Other Issues

- Costs

  Subscriber unit costs are speculative since the network will not be operational for at least four years. Service providers will set monthly fees, but most expect rates to be comparable to those of most terrestrial broadband services.

5.2.6.2 SkyBridge

The SkyBridge network will use LEO satellites to enable broadband communications for business and residential users around the world. SkyBridge LP is controlled by general partner Alcatel but holds significant interests from Boeing, Loral Space & Communications, etc.

This network is designed to support applications such as high-speed Internet/intranet access, interactive multimedia, and video teleconferencing. Narrowband applications (e.g., voice telephony) will also be available should the local operator choose to offer them.

SkyBridge LP will lease satellite bandwidth to regional/local operators, who will in turn provide capacity to regional/local service providers. The service providers are SkyBridge retailers responsible for implementation, value added services, and customer support.

Spectrum and Licensing

SkyBridge will use Ku-band frequencies. Bandwidths of at least 1.05 GHz will be used for both the uplink (12.75 to 14.5 GHz) and the downlink (10.70 to 12.75 GHz). System design features have been incorporated to protect the geostationary satellites that also use this spectrum.

System Architecture

Like Teledesic, the SkyBridge network has a point-to-multipoint architecture with various base station hubs and remote subscriber units. The hubs, owned and operated by the local operators, will interface with the existing terrestrial network through high-speed switches (e.g. ATM switches). Approximately 200 hubs will be used for global coverage.

The space segment, which is owned and operated by SkyBridge LP, comprises a constellation of 80 LEO satellites. There are 2 identical sub-constellations of 40 satellites – each with 20 planes, each plane containing 4 satellites. All 80 satellites will be in circular orbit at an altitude of approximately 1470 km. The satellites are fairly simple with no on-board switching or satellite cross-links; however, each uses up to 18 spot beams to cover fixed regions of the Earth.

LEO systems allow the use of smaller, low-powered subscriber equipment (terminals and antennas). Residential unit will be small enough for houses, but business units are larger and will generally be installed on building rooftops. Both units will be owned or leased by subscribers. As currently designed, SkyBridge will support fixed units only.

System Performance

Coverage: SkyBridge is designed to provide global coverage. The complete system will be able to support over 20 million users, with a cumulative system throughput of over 200 Gbps.

Data Rate: Individual residential units will support up to 20 Mbps on the downlink and up to 2 Mbps on the uplink. The maximum data rate supported by the larger terminals (i.e., the business units) is 100 Mbps down, 10 Mbps up.

Standards

SkyBridge retailers will offer standards-based subscriber equipment for residential and business users. Residential units will connect to a computer or similar CPE, and business units will connect to LANs, PBXs, etc. Equipment specifications (and any applicable standards) are not yet available.

Existing Systems

Development and manufacturing of the space segment is to be completed by the end of 2000, and the first satellites should be available for use in 2002. The complete system is expected to be operational by 2004.

Other Issues

- Costs

  As with Teledesic, subscriber unit costs are tentative at this time. However, the residential equipment is expected to range from $500 to $1000. The local service providers will determine monthly fees.

5.2.6.3 SkyDSL

SkyDSL is a product of ALOHA Networks. As one might assume, SkyDSL does not use the copper wiring found in traditional DSL deployments. It uses existing GEO satellites to deliver high-speed full-duplex connectivity directly between a terrestrial backbone network and remote subscribers. The system was designed to support Internet access for various service providers while allowing them to bypass the local RBOC or LEC infrastructure.

Spectrum and Licensing

ALOHA Networks' first commercially available system will use a Ku-band broadcast/fixed point/non-military satellite. Ku-band satellites use a 14 GHz for the downlink (to the subscriber) and 11 GHz for the uplink (from the subscriber).

System Architecture

SkyDSL employes a point-to-multipoint architecture. Each provider will purchase hub (or base station) equipment. With a single hub, one could support direct access to the Internet for roughly 3,000 customers.

Subscribers will have remote units that include a small roof-mounted antenna and a small indoor modem/router. ALOHA Networks will be responsible for all elements of the connection between the remote units and hubs, including satellite capacity and network management.

Currently, SkyDSL products have the ability to support service to fixed terminals. However, under a contract from DARPA, ALOHA Networks is researching the possibility for mobile terminals.

System Performance

<u>Data Rate</u>: ALOHA Networks' principal innovation is a new multiple-access protocol called Spread Aloha Multiple Access (SAMA). SAMA is an outgrowth of the conventional ALOHA protocol, which was developed to enable multiple independent transmitters to communicate reliably to a central hub or base station. It is based on all terminals sharing the same spectrum and repeating their packet transmissions in those cases where collisions occur.

SAMA combines the conventional ALOHA protocol with a direct sequence spread spectrum technology to establish a significant increase in network capacity. Conventional ALOHA networks are limited to approximately 10 kbps, SAMA networks can operate at up to 3 Mbps. For broadband data networks, SAMA is an efficient alternative to FDMA, TDMA, and CDMA techniques.

Individual subscribers/users will be provided full duplex communications at downstream rates of at least 500 kbps. Upstream rates will be at least 64 kbps, but could reach several hundred kbps.

Coverage: SkyDSL will provide coverage to most of North America and much of the South Pacific. Use of different satellites will allow more/different coverage.

Standards

Hub and subscriber equipment is expected to have standards-based interfaces. The equipment specifications (and any standards to which they might adhere) have not yet been released.

Existing Systems

There are currently no SkyDSL systems in operation, but ALOHA Networks expects commercial production by end of 2000. Deployments will follow.

Other Issues

- Costs

  Costs of the base station equipment will be on the order of $100,000. Each subscriber unit will be cost about $2,500. Monthly service fees might range from $500 to $2,000.

5.2.7 Digital Television (DTV) Alternative

Digital television (DTV) forms the basis for High Definition TV (HDTV), a new service that will become the standard method of TV broadcasting in the US. After years of study, the FCC concluded that the use of digital image compression and digital transmission would provide more effective utilization of the spectrum licensed by the broadcast TV industry.

> Digital television (**DTV**) broadcasts employ digital transmission techniques. In general, **HDTV** is a DTV with specific (high definition) formatting. Consider DTV a first step in the implementation of HDTV

DTV is unique to our study. It is the only technology we review that is intended for broadcast only communication. However, this technology offers public safety and transportation agencies an effective (and possibly inexpensive) means of disseminating broadband multimedia. It is therefore worth note in this document.

Spectrum and Licensing

The current US broadcast TV spectrum is divided into 6 MHz channels: VHF channels from 54-72 MHz (Ch 2-4), 76-88 MHz (Ch 5-6), and 174-216 MHz (Ch 7-13); and UHF channels from 470-512 MHz (Ch 14-20), 512- 608 MHz (Ch 21-36), and 614-806 (Ch 38-69). The current use of these channels is defined by the National Television Standards Committee (NTSC) standard and reflects analog audio and video transmissions.

The new HDTV systems will use these 6MHz channels according to specifications defined by the American Television Standards Committee (ATSC). This involves scaleable encoding of digitized video multiplexed with digitized audio. The prevailing practice is to use MPEG-2 for audio and video, but there is an imminent transition to MPEG-4, which will enable improved reception and higher definition video.

The FCC has begun reclaiming UHF channels 60-69 and set aside 24 MHz (764-806 MHz, Ch 66-69) for public safety and law enforcement. APCO Project 25 (see insert) proposes most of this spectrum eventually be divided into 6.25 kHz channels and used for narrowband voice and data services. Some of it will be divided into 50kHz channels, up to three of which may be aggregated to support a single 384 kbps link. However, there are better alternatives for broadband communication.

> APCO Project 25 is a joint effort of Federal, state, and local government, with support from the U.S. Telecommunications Industry Association (TIA). State government is represented by the National Association of State Telecommunications Directors (NASTD) and local government by the Association of Public Safety Communications Officials (APCO).
>
> A primary objective of the APCO Project 25 effort is to provide digital narrowband services with the best performance possible. They also look to achieve maximum radio spectrum efficiency. While permissible, broadband communications are ruled out in practice.

To utilize DTV spectrum for broadband, there are two realistic approaches: use the DTV channels assigned to existing licensees, or use the 608-614 MHz block – what would be channel 37.

- **DTV Channels**

  It is possible to coordinate with broadcasters for shared use of their <u>systems</u>. Most do not currently use the full 6 MHz for TV, and they are looking to utilize the unused spectrum for other forms of communication, particularly datacasting (i.e. broadcasting data). We address the technical aspects of this approach below.

  Alternatively, one could operate a low power DTV system. This would require a low power TV (LPTV) license, and operations would be restricted to those areas not used by existing licensees (i.e., they must operate on a non-interfering basis). Additionally, the range of such systems is limited, but the full 6 MHz is available.

  Each of these options requires coordination with a licensee, the latter also requires FCC approvals. Additionally, these alternatives could expire if/when the licensee moves to a full HTDV implementation and/or expands coverage. We explain in the following subsections.

- **Channel 37**

  Channel 37 (608-614 MHz) might be a refuge if the previous alternatives are (or become) unfeasible. Channel 37 is a shared government/non-government band that is not licensed for existing TV broadcast stations, new DTV allotments, or any other licensed service.

The Federal Wireless Policy Committee (FWPC) will make recommendations for governmental use. Members of the FWPC include all the major Federal agencies, including: the US Department of Transportation (USDOT), US Department of Justice (USDOJ), Department of Defence (USDOD), and the Federal Emergency Management Agency (FEMA). For themselves, or on behalf of parties they might represent (e.g., a state DOT), a request could be made to the NTIA for use of this spectrum. Such a request would likely define a particular purpose (e.g., public safety) and limit operation within a particular region or under a specific circumstance.

Since 608-614 MHz is government/non-government shared spectrum, NTIA approval would require consensus from the FCC. This coordination helps prevent any potential conflict with viable non-governmental interests.

Note: *The 608-614 MHz spectrum had been allocated to radio astronomy on a primary basis, but the FCC recently proposed to reallocate the band to medical telemetry equipment on a co-primary basis with radio astronomy. Under the proposal, operation in this band must not cause interference to radio astronomy operations, and users will be required to coordinate their operation with radio astronomy facilities (see ET Docket 99-255). Others may operate on a secondary non-interfering basis, but and must comply with appropriate Part 15 regulations.*

DTV devices have a minimum receiver sensitivity of about –27dBm, and if restricted to Part 15 operations, the maximum range would be much less than a mile – even with the use of a high gain directional transmitting antenna. Therefore, one of the previously noted alternatives must be used.

System Architecture

HDTV systems employ a broadcast architecture where a hub transmits data (no return) to multiple remote clients. Typically, these hubs will be part of commercial broadcast TV systems that provide omni-directional coverage, as would be expected. Each hub would be connected to an appropriate communications infrastructure. Directional antennas could be used as long as they comply with appropriate rules and regulations.

Performance

<u>Data Rate</u>: Video and audio data are multiplexed into a single MPEG-2/4 compressed data stream. After forward error correcting measures, the data is transmitted using Vestigial Sideband (VSB) modulation scheme providing a 19.4 Mbps data stream.

Note: *Both VSB and OFDM modulation schemes were reviewed by an industry consortium. Some of their results indicate that VSB is somewhat more robust than OFDM for stationary receivers. However, other tests indicate higher resistance to multipath when OFDM was used. VSB was initially selected for* *use within the US, but providers with operational DTV systems have been disappointed with coverage. However, the FCC has reaffirmed, with additional testing, that VSB is the standard for modulation. European systems employ OFDM variants.*

This 19 Mbps data stream can support the delivery of one HDTV channel, nominally 1900 x 1100 pixels per frame (16:9 format) presented at 30 frames per second. This is significantly higher in quality than the present day NTSC imagery.

Alternatively, the 19 Mbps may be used to transmit multiplexed data streams. These data streams can support the equivalent of 4 NTSC video channels (NTSC replicas), or they can support a combination of NTSC replicas and non-TV high-speed data (i.e., datacasting). In other words, it's possible to transmit NTSC equivalent video (e.g., live traffic video) and supplemental information such as medical data, weather maps, or multimedia ATIS – all over a single DTV channel.

The remote client device will decode and process the data stream, whether HDTV, NTSC replica, or other data. In addition to a typical DTV set-top box, this remote device can be a PC card or other portable unit.

DTV systems should be able to support mobile applications. However, the modulation scheme employed will have a significant impact on performance. OFDM appears to be a better candidate for supporting mobile applications. For example, Nokia recently demonstrated their Mediascreen DTV/HDTV unit in Europe. They claim this multimedia product – an OFDM-enabled device – will work while moving at speeds of up to 180 mph.

Coverage: The range for commercial DTV hub (with a maximum power level of 1000 kW) is between 30 and 50 miles. Secondary repeater/retransmitter equipment is also being developed to extend the nominal range and fill poor coverage areas.

With the smallest of the LPTV authorizations (100 W transmitter), the omni-directional range using isotropic antennas is approximately 1 mile. With the largest of the LPTV authorizations (1000 W transmitter), the range could reach 3 miles. Directional antennas (receiving and/or transmitting) could extend these ranges. For example, a 26 dBi parabolic antenna on either end could increase the ranges by a factor of 3.

Standards

There are many applicable ATSC standards and recommended practices, including:

- ATSC Document A/52 - Digital Audio Compression (AC-3) Standard
- ATSC Document A/53 - ATSC - Digital Television Standard
- ATSC Document A/54 - Guide to the Use of the ATSC Digital Television Standard
- ATSC Document A/64 - Transmission Measurement and Compliance for Digital TV

Visit ATSC's Web site for more information (http://www.atsc.org/Standards/stan_rps.html)

Existing Systems/Products

As of May 2000, there were 99 authorized DTV stations broadcasting in the US. There are also a number of other DTV stations on the air periodically under experimental or special temporary authorities (STAs). These stations may be broadcasting HDTV, NTSC replicas, and/or data. As part of the Balanced Budget Act, Congress has directed that the conversion of 1376 stations (to DTV) be completed by Dec 31, 2006.

DTV receivers (whether set-top boxes, hand held devices, or PC peripheral) will become more widely available (and less expensive) in the next couple of years as commercial broadcasters make the transition.

Some of the PC receiver cards that exist today are:

- WIN-TV-D Digital Receiver card from Hauppauge Computer
- Dstream ATSC card from Conexant/Ravisent
- Satellite Express 2035 card from Intel /Broadlogic

The Harris Corporation is the leading manufacturer of DTV transmitter equipment.

Other Issues

- Costs

  The cost of a low-power hub (encoder and 100W transmitter) will be on the order of $5000. Commercial broadcasters use 1000 kW transmitters to achieve the 30 to 50 mile coverage, but the cost of these units runs in the hundreds of thousands of dollars. PC receiver cards cost about $300. The cost of devices with integrated DTV receivers will vary.

- Transportation Related Applications

  Since DTV is slightly outside the scope of our technical review, we note some interesting transportation-related applications – those specifically supported by broadcast communications.

  1. Multimedia ATIS: Information fed from providers such as SmartRoute Systems could be broadcast to both fixed and mobile users. This could include live video and/or imagery with supplemental text messaging. Depending on system design, the information could also be source selectable – the user could choose information from a location of interest.

  2. Public Safety Information: Many public safety crews (law enforcement, EMS, and fire) would like the ability to retrieve site-specific incident information. DTV systems fed by traffic/incident/emergency management facilities could broadcast images or video clips with supplemental text addressing the location, time, and

nature of the incident. Again, with proper design, the user could choose a location (or incident) of interest.

The DTV system supporting these applications does not necessarily have to be a commercial system with large omni-directional coverage. It could also be based on a low powered system, or a group of lower-powered hubs that form a multicast system perhaps using directional antennas along a freeway corridor.

3. Transportable Multimedia ATIS or Emergency Information: A transportable DTV broadcast facility could be used to support special events activities, such as the Olympics. It might also be used for disseminating emergency information, say in the wake of a hurricane. The transportable unit can be brought in where fixed facilities do not exist or have been destroyed. The capacity and potential support services are far greater than those capable of any conventional TV station or FM audio broadcast facility.

- Additional Information on DTV

The FCC has conducted its first periodic review of the conversion to digital television. Their findings are documented in NPRM MM 00-39, as of March 8, 2000. Additional information can be found in MM Docket No. 87-268 or at http://www.fcc.gov/dtv/.

SECTION 6

CONCLUSIONS

This section provides brief conclusions from our research of broadband wireless and integrated service technologies. We also introduce the next phase of this effort.

6.1 BROADBAND WIRELESS AND THE INTEGRATED SERVICE PLATFORM

- **Broadband Wireless**

  With significant advances in capacity and reliability, broadband wireless technologies now offer strong alternatives to wireline solutions. They also support the "anywhere" aspect of multimedia service provisioning. And as opposed to conventional broadband wireless, most are (or will soon be) more widely available, offer greater flexibility (i.e., better coverage for more users), offer better performance (e.g., larger data rates, enhanced quality-of-service), and are less expensive.

  Additionally, most wireless systems are usually deployed in less time and with less cost than wireline alternatives – whether by public or private service provider. Some are also capable of rapid deployment (within days or even hours) in emergency situations.

  In this initial phase, we have reviewed over fifty new broadband wireless technologies. However, by the time this document is published, many changes will have occurred, and new technologies will have emerged. Expect improvements in frequency reuse, in-building penetration, interference mitigation, mobility, quality-of-service, and data rates. Providers and manufacturers will have gone through acquisitions, alliances, deployments, and price restructuring – most likely for the better. The industry is extremely dynamic and must be followed continuously.

- **Applying Broadband Wireless to the Integrated Service Platform**

  The ability to integrate services is no longer restricted to the major carriers. In relatively inexpensive fashion, the MSAD can bundle voice, data, and video services for transmission over a single link. In this case, it's a wireless link. MSADs efficiently integrate services, and broadband wireless provides high-speed and flexible connectivity. Together, they can provide more services, between more locations, with less cost. And these trends will continue as the technologies evolve.

- **Within the Intelligent Transportation Systems Domain**

  For ITS, the broadband wireless and integrated service technologies present several ways to rapidly exchange information between fixed, transportable, and mobile units, supporting any number of applications. Broadband wireless has already begun to appear in the transportation and public safety domains, particularly traveler information, traffic management, emergency/incident management, and law-enforcement. As ITS develops, the numbers and types of transportation-related applications will grow. The ability to support these applications with the developing broadband wireless and integrated service technologies could provide significant technical and financial benefits.

6.2 PHASE II

The second phase of our study will focus on a concept prototype. Appendix A provides preliminary details on the prototyping effort, including: the general prototype design, the potential test-bed location(s), and the demonstration and evaluation process.

Again, the objective of this effort is to demonstrate the feasibility of applying broadband wireless to the integrated service platform, not to evaluate the many possible system permutations. When procuring or deploying an operational system there will be issues involving coverage, mobility, performance, functionality, equipment/service availability, and cost – among others. We will introduce some of these issues in phase II, but ultimately the approach will depend on where and for whom the system is deployed.

Phase II began with the completion of this report, and the prototype should be operational by the end of the calendar year (2000). When our limited assessment is complete, we will document in further detail the prototype design and functionality, the test location and facilities, and the assessment methodology and results. We will also address other issues, concerns, questions, and problems that arise during phase II activities.

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APPENDIX A

CONCEPT PROTOTYPING

This appendix introduces a prototype that will be built to demonstrate the concept of applying broadband wireless to the integrated service platform. Prototyping will be done in phase II of this effort.

The prototype will be used to exchange the general types of information passed between ITS subsystems.

- For Center-Center communications, this would involve traffic video feeds, analog and digital voice services, LAN extension (for exchange of documents, imagery, etc.). It might also include newer applications such as IP-based video teleconferencing and real-time multimedia collaboration. In practice, one of these Centers might be a temporary facility established for an emergency situations or special events.

- For Center-Traveler communications, this exchange would involve multimedia ATIS (e.g., real-time voice, data, and video for traffic reporting, yellow pages information, and/or emergency assistance)

- For Center-Roadside or Center-Vehicle (transportable) communications, it would involve similar services for emergency roadside assistance, remote medical triage, etc.

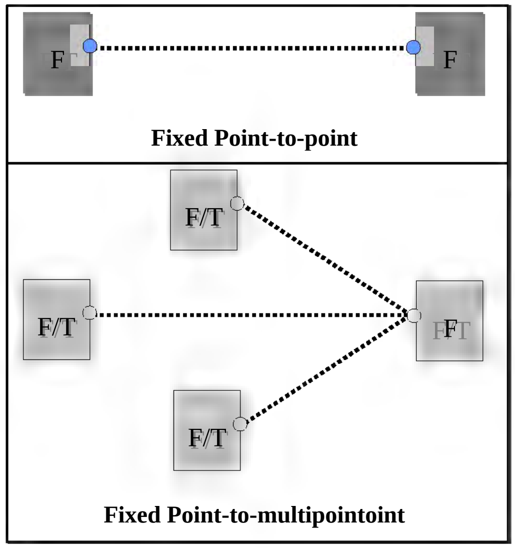
With different system designs, similar applications can be supported directly between vehicle, roadside, and/or traveler subsystems (i.e., without a center facility). We merely present a design to demonstrate the concept.

A.1 GENERAL PROTOTYPE DESIGN

The numbers and types of broadband wireless technologies present many ways to connect fixed, transportable, and mobile units. Several prototypes have been considered, but particular aspects make some designs more or less feasible for prompt development and evaluation – most importantly cost and equipment availability.

Some of the wireless technologies we reviewed are not yet (or are barely) to market. Additionally, some of the technologies require the use of licensed spectrum (and perhaps leased services). Since these options would be limited by local service availability and would likely require more time, logistics, and money to implement, the prototype will be established using an unlicensed-band alternative.

For the purpose of demonstrating the concept, we will build a fixed point-to-point prototype. However, we will incorporate enough design flexibility to establish a point-to-multipoint network as well. The former can replicate Center-Center type operations, and the later Center-Center, Center-Traveler, Center-Roadside, or Center-Vehicle functions. Priority will be given to the configuration that can be most efficiently deployed (see section 6.3, Prototype Location).



Regardless of the system design, the concept remains the same, “use broadband wireless to support an integrated service platform”. The design(s) we select will be sufficient for proof of concept.

A.2 PROTOTYPE COMPONENTS & INTERFACES

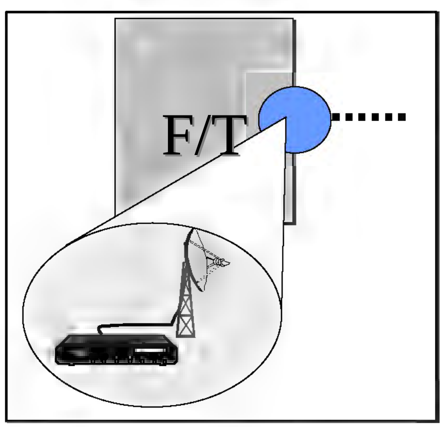
In general, there are two components to the prototype: the broadband wireless equipment and the Multi-Service Access Device (MSAD). There will also be peripheral end-system equipment to provide voice, data, and video content.

- **Broadband Wireless Equipment**

  A wireless bridge that operates in either the 2.4 GHz ISM band or the 5 GHz UNII band will form the basis of the broadband wireless component. The rationale for choosing from these types of devices is as follows.

  - They require no licensing or service leasing
  - They currently offer some of the best performance for unlicensed equipment
  - Most types of this equipment are widely available
  - The equipment is designed for outdoor point-to-point and point-to-multipoint links – configurations that provide an appropriate test-bed for many transportation-related applications.

  This component will include any amplifiers, antenna systems, etc. For the point-to-point configuration, we will use high-gain directional antennas. The point-to-multipoint system will most likely have an omni-directional antenna at the hub, and either an omni-directional or wide-beamwidth directional gain antenna on the remote unit (fixed or transportable).

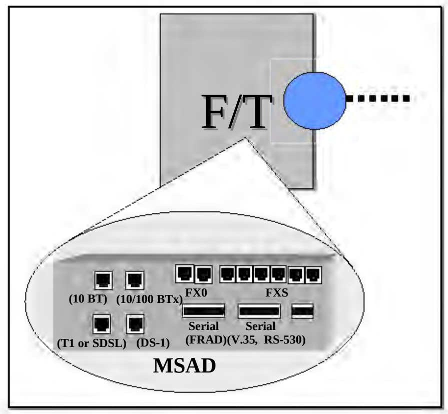


Equipment will be placed at each fixed or transportable node and will interface one of the MSAD WAN ports. Details of this component (i.e., manufacturers, equipment specifications, costs, etc.) will be determined/documented as part of the phase II effort.

Note: *The prototype will be designed such that it could be retrofit/modified with other types of broadband wireless equipment. The MSAD and end-system peripheral components will remain the same.*

- **Multi-Service Access Device**

The integrated service platform will be enabled by MSADs (or IADs). One will be placed at each end of the wireless link.



MSAD subscriber interfaces that will be used for voice, data, and video services include:

- FXS ports for analog voice
- 10BaseT and/or 10/100BaseTx LAN ports for all networked data service, including packet voice and packet video.
- V.35/RS-530 serial ports for integrated data and digital video

FXO ports (for PSTN connectivity at a CO), T1/E1 ports (for PBX connectivity), and any FRAD serial ports (for Frame Relay devices) will probably not be used in our initial efforts.

All traffic from the subscriber interfaces will be integrated as an ATM or Frame Relay virtual circuit or an IP flow for transmission over the WAN. The WAN port(s) used for the prototype will depend on the selected broadband wireless equipment, but most likely it will be a 10BaseT or 10/100BaseTx interface – possibly the T1/E1 interface.

Again, the manufacturer, equipment specifications, and cost of the MSAD will be determined/documented as part of phase II.

- **Peripheral Devices**

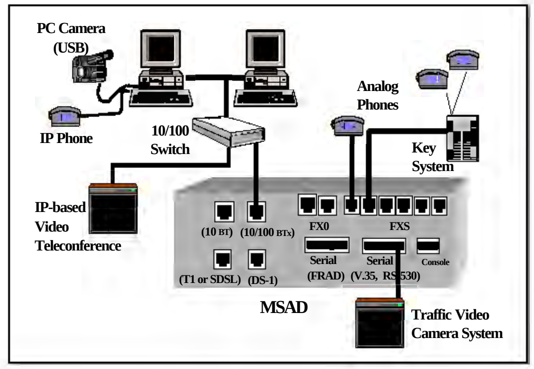
  Peripherals sourcing the voice, data, and video content will include:

  – Desktop and/or laptop computers connected via 10/100 switch to a LAN port
    - with IP enabled phones (VoIP)
    - with collaborative multimedia software (e.g., Microsoft NetMeeting)
    - with PC camera(s)

  – Key system and/or analog phone(s) connected to FXS ports

  – IP-based video teleconferencing equipment connected via 10/100 switch to a LAN port *

  – Traffic video camera system connected to a serial data port * †



  * *Will depend on equipment availability*

  † *One end of the link will support a traffic video camera, the other end will support the control and monitoring equipment*

We are not committed exclusively to the types of equipment or general design presented in this section, but they appear to support the most efficient deployment at this time. The prototype will simply represent one (or two) of many possible designs. Further review will be conducted during phase II.

A.3 PROTOTYPE LOCATIONS

Prior to completing any design, suitable locations will be selected for testing. Sites will be selected in part for the willingness of an agency, organization, or company to host these activities. However, there will be technical requirements.

For example, with the point-to-point prototype, we will require the use of two facilities (buildings) with rooftop access and/or antenna towers to establish clear LOS – preferably within 5 miles of each other so that maximum performance can be achieved. We will also need adequate space to house the equipment, power to operate the equipment, etc.

The selected locations will likely be within close proximity of Mitretek Systems research facilities and staff (i.e., the Washington DC area). This will promote better conditions for deployment and testing. One of the sites might be the Mitretek building in McLean, VA.

Any point-to-multipoint prototyping activities might also be conducted from the Mitretek facility. The hub would be located on the Mitretek building and the remote sites would comprise either fixed facilities (i.e., another participants building(s)) or transportable units. Transportables may or may not be integrated with test vehicles.

Details of the location(s) and the selection process will be presented in phase II documentation.

A.4 PROTOTYPE DEMONSTRATION & EVALUATION

The purpose in building a prototype is to demonstrate the concept. We do not intend to assess the relative performance of particular technologies or vendor specific equipment. Nor do we intend to review or compare the many possible systems design permutations – those established by various MSAD configurations, transmitter/receiver settings, antenna selections, etc. However, we will conduct low-level qualitative and quantitative assessments to illustrate and document some level of performance.

The methodology used to assess the prototype will be developed during phase II, but in general we will assess support for the following:

- **Voice**
  - Analog: toll quality voice will be sourced by analog phones via the MSAD FXS ports.
  - IP-based: VoIP will be used between IP-enabled phones
- **Video**
  - IP-based: video will be sourced from PC cameras via a LAN. Integrated IP-based voice and video well also be sourced by video teleconferencing equipment.
  - Digital: digital video and control data will be integrated and passed between traffic video system equipment via V.35/RS-530 serial port. Video will be provided from one end-point, camera control from the other.
- **Data**
  - The exchange of documents, images, etc. will be tested over the LAN using various file transfer methods (e.g., FTP)
  - Traffic video system control (command telemetry) will be tested over the serial ports.
  - Real-time multi-user document editing and “white board” sessions will be tested with multimedia collaborative tools.

Each application for each type of service will be tested individually. They will also be tested simultaneously in various groupings. For example, the traffic video system will be operational while conducting activities on the analog phones and exchanging documents via LAN connections.

Qualitative assessments will involve analyses of live and recorded voice and video. Quantitative assessments will involve measurement of various system performance parameters (throughput, error rate, availability, etc.) and review of application log files (e.g., file transfer statistics).

Performance will vary based on the particular technologies (wireless equipment, MSAD, and peripheral), the system design, the test-bed environment, the equipment configuration, the information content, etc. We will present the findings from our evaluation within the context of one or two system design scenarios. Again, the objective is to demonstrate concept feasibility and not exhaustively evaluate every possible system permutation.

GLOSSARY

2G PCS	Second Generation PCS
2.5G PCS	Enhanced Second Generation PCS
3G PCS	Third Generation PCS
AAL	ATM Adaptation Layer
ADPCM	Adaptive Differential Pulse Code Modulation
ALERT	Advanced Law Enforcement & Response Technology
AM	Amplitude Modulation
AMPS	Advance Mobile Phone Service
ANSI	American National Standards Institute
AP	Access Point
APCO	Association of Public Safety Communications Officials
ATIS	Advanced Traveler Information System
ATM	Asynchronous Transfer Mode
ATSC	American Television Standards Committee
BER	Bit Error Rate
BFSK	Binary Frequency Shift Keying
BPSK	Binary Phase Shift Keying
BRAN	Broadband Radio Access Network
BRI ISDN	Basic Rate Interface ISDN
BTA	Basic Trading Area
Caltrans	California State Department of Transportation
CCK	Complementary Code Keying
CDMA	Code Division Multiple Access
CDPD	Cellular Digital Packet Data
CLEC	Competitive Local Exchange Carrier
CO	Central Office
C-OFDM	Code-based OFDM
CPE	Customer Premises Equipment
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
CSU/DSU	Channel Service Unit / Digital Service Unit
DACS	Digital Access Cross-connect System
DARPA	Defense Advanced Research Projects Agency
DAVIC	Digital Audio Visual Council
dB	Decibel
dBm	Decibel power level referred to 1 mW
DBPSK	Differential Binary Phase Shift Keying
DCE	Data Communication Equipment
DECT	Digital Enhanced Cordless Telephone

DOCSIS	Data Over Cable System Interface Specification
DOT	Department Of Transportation
DQPSK	Differential Quadrature Phase Shift Keying
DS-1	Digital Signal Level 1. Transmission standard interface for digital data used by T1 transmission lines. DS1 operates at 1.544 Mbps.
DS-3	Digital Signal Level 3. Transmission standard interface for digital data used by T3 transmission lines. DS3 operates at 44.736 Mbps and consists of 28 DS1 channels plus overhead.
DSL	Digital Subscriber Line
DSLAM	DSL access multiplexers
DSSS	Direct Sequence Spread Spectrum
DTE	Data Terminal Equipment
DTV	Digital Television
DWDM	Dense Wavelength Division Multiplexing
E1	European Standard for high-speed digital transmission operating at 2.048 Mbps
E3	European Standard for high-speed digital transmission operating at 34 Mbps
EA	Economic Area
EDGE	Enhanced Data Rates for GSM Evolution
EIRP	Effective Isotropic Radiated Power
EMS	Emergency Medical Services
ERC	European Radiocommunications Committee
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
FDD	Frequency Division Duplexing
FDMA	Frequency Division Multiple Access
FEMA	Federal Emergency Management Agency
FHSS	Frequency Hopping Spread Spectrum
FHWA	Federal Highway Administration
FM	Frequency Modulation
FRAD	Frame Relay Access Device
FTP	File Transfer Protocol
FWPC	Federal Wireless Policy Committee
GEO	Geostationary Earth Orbit
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
GWCS	General Wireless Communication Service
H2GF	HIPERLAN2 Global Forum
HDR	High Data Rate

HDTV	High Definition Television
HIPERLAN	HIgh PErformance Radio LANs
HRFWG	HomeRF Working Group
HSCSD	High Speed Circuit Switched Data
IAD	Integrated Access Device
IEEE	Institute of Electrical and Electronics Engineers
ILEC	Incumbent Local Exchange Carrier
IMT	International Mobile Telecommunications
IMT-MC	International Mobile Telecommunications - Multi-Carrier
IMT-SC	International Mobile Telecommunications - Single-Carrier
IMT-TC	International Mobile Telecommunications - Time-Coded
IP	Internet Protocol
ISDN	Integrated Services Digital Network
ISM	Industrial, Scientific, and Medical
ISP	Internet Service Provider
ITFS	Instructional Television Fixed Service
ITP	Interactive Transaction Processing
ITS	Intelligent Transportation Systems
ITU	International Telecommunications Union
JPEG	Joint Photographic Experts Group
kbps	Kilobits per second
kHz	Kilohertz
LAN	Local Area Network
LEC	Local Exchange Carrier
LEO	Low Earth Orbit
LMDS	Local Multipoint Distribution Service
LOS	Line Of Sight
MAC	Medium Access Control
Mbps	Megabits per second
MDF	Main Distribution Frame
MDS	Multipoint Distribution Service
MDT	Mobile Data Terminal
MEA	Major Economic Area
MEO	Medium Earth Orbit
MHz	Megahertz
MMDS	Multichannel Multipoint Distribution Service
MPEG	Motion Picture Experts Group
MRC	Monthly Recurring Cost
MSAD	Multi-Service Access Device
MT	Mobile Terminal

mW	milliwatt
NASTD	National Association of State Telecommunications Directors
NATSO	National Association of Truckstops and Travel Plazas
NCIC	National Crime Information Center
NIC	Network Interface Card
NPMA	Non-premptive Priority Multiple Access
NPRM	Notice of Proposed Rule Making
NRC	Non Recurring Cost
NTIA	National Telecommunications and Information Administration
NTSC	National Television Standards Committee
OC-12	Optical Carrier level 12 (622 Mbps)
OC-3	Optical Carrier level 3 (155 Mbps)
OFDM	Orthogonal Frequency Division Multiplexing
OFSK	Orthogonal Frequency Shift Keying
PAN	Personal Area Network
PBX	Private Branch eXchange
PC	Personal Computer
PCM	Pulse Code Modulation
PCS	Personal Communication Service
PDA	Personal Data Assistant
PFC	Point Control Function
POTS	Plain Old Telephone Service
PSTN	Public Switched Telephone Network
QAM	Quadrature Amplitude Multiplexing
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RBOC	Regional Bell Operating Company
RF	Radio frequency
SAFD	San Antonio Fire Department
SAMA	Spread Aloha Multiple Access
SEBRA	Semi-mobile Broadband Radio Access
SIG	Special Interest Group
STA	Special Temporary Authority
SWAP	Shared Wireless Access Protocol
SwRI	Southwest Research Institute
T1	An AT&T digital T-carrier facility used to transmit a DS-1 formatted digital signal at 1.544 Mbps
T3	An AT&T digital T-carrier facility used to transmit a DS3-formatted digital signal at approximately 45 Mbps.
TDD	Time Division Duplexing

TDMA	Time Division Multiple Access
TIA	Telecommunications Industry Association
TLS	Transparent LAN Services
TTI	Texas Transportation Institute
TxDOT	Texas Department of Transportation
UHF	Ultra High Frequency
UNII	Unlicensed National Information Infrastructure
USDOD	United States Department of Defense
USDOJ	United States Department of Justice
USDOT	United States Department of Transportation
UWB	Ultra-wideband
V.35	ITU-T standard for a high-speed, 34-pin, DCE/DTE interface.
VDOT	Virginia Department of Transportation
VHF	Very High Frequency
V-OFDM	Vector-based OFDM
VoIP	Voice over IP (Voice over Internet Protocol)
VPN	Virtual Private Network
VSB	Vestigial Sideband
W	Watt
WAN	Wide Area Network
WATMnet	Wireless ATM Network
WAVE	Wireless Advanced Vehicle Equipment (WAVE)
WBFH	Wide-band FHSS
WCS	Wireless Communication Service
W-DSL	Wireless DSL
WECA	Wirelesss Ethernet Compatibility Alliance
WEP	Wired Equivalent Privacy
WLAN	Wireless LAN
WLIF	Wireless LAN Interoperability Forum
WTB	Wireless Telecommunications Bureau