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EVALUATION OF SATELLITE COMMUNICATIONS SYSTEMS FOR MAYDAY APPLICATIONS

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FOREWORD

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16. Abstract

This report documents the results of an evaluation of satellite communication systems for mayday applications conducted as part of the Rural Applications of Advanced Traveler Information Systems (ATIS) study. It focuses on satellite communications systems that could provide full coverage in all rural areas, as well as urban areas, and could be integrated into a mayday system. Two communication systems were tested: American Mobile Satellite Corporations's (AMSC) Geosynchronous (GEO) satellite system and Orbital Communications Corporation's (ORBCOMM) low earth orbit (LEO) satellite system. Both voice and data two-way communications were considered for evaluation. Several tests were conducted to determine the time to send and receive messages between a mobile user and a response center. This report presents detailed findings of these tests and provides concepts for an in-vehicle communications device, system requirements, technical requirements, and potential development partners. The report also presents recommendations on FHWA actions for follow on testing and system deployment to meet the goals of the National Intelligent Transportation System (ITS) program, as they relate to improving safety by providing mayday assistance in rural areas.

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LIST OF ACRONYMS

AMSC	American Mobile Satellite Corporation
APCO	Associated Public-Safety Communications Officers
ATIS	Advanced Traveler Information Systems
BLOS	beyond the radio LOS
C/N	carrier-to-noise
CDPD	cellular digital packet data
COMSAT	Communications Satellite Corporation
DCE	data communications equipment
DGPS	Differential GPS
DTE	data terminals equipment
EMS	emergency medical services
FARS	Fatal Accident Reporting System
FCC	Federal Communications Commission
FHWA	Federal Highway Administration
FOTs	field operations tests
GCC	Gateway Control Centers
GEO	geosynchronous orbit
GEPs	ground entry points

GES	Gateway Earth Stations
GIS	geographic information system
GPS	global positioning system
HAZMAT	hazardous material
INMARSAT	International Maritime Satellite Organization
ITM	Irregular Terrain Model
ITS	Intelligent Transportation System
IVU	in-vehicle unit
LEO	low earth orbit
LES	land earth station
LOS	line-of-sight
MET	mobile earth terminal
MMS	Mobile Messaging Service
NCC	Network Control Center
NENA	National Emergency Number Association
ORBCOMM	Orbital Communications Corporation
PCS	Personal Communications System
PDA	personal digital assistant
PSAP	public safety answering point
RSL	received signal level
SC	subscriber communicators
TTL	transistor-transistor logic
TTW	through-the-woods
U.S. DOT	U.S. Department of Transportation

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
	AREA			
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
	VOLUME			
fl oz	fluid ounces	29.57	millimeters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
	MASS			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
	TEMPERATURE (exact)			
EF	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	EC
	ILLUMINATION			
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
	FORCE and PRESSURE or STRESS			
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
	AREA			
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
	VOLUME			
mL	milliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
	MASS			
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "metric ton")	megagrams	1.103	short tons (2000 lb)	T
	TEMPERATURE (exact)			
EC	Celsius temperature	1.8C + 32	Fahrenheit temperature	EF
	ILLUMINATION			
lx	lux	0.0929	foot-candles	fc
fl	candela/m^2	0.2919	foot-Lamberts	fl
	FORCE and PRESSURE or STRESS			
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised September 1993)

1. INTRODUCTION

This final report summarizes the research, testing, and recommendations from the Evaluation of Satellite Communications Systems for Mayday Applications project. The study was conducted under the Rural Applications of Advanced Traveler Information Systems (ATIS) study sponsored by the Federal Highway Administration (FHWA). This project focused on studying satellite communications systems that could provide full coverage in all rural areas, as well as urban areas, and could be integrated into a "mayday" system. This report presents details of satellite systems researched and tested under this project. In addition, it provides concepts for an in-vehicle communications device, system requirements, technical requirements, potential development partners, and possible FHWA actions for follow-on testing and system deployment to meet the goals of the National ITS (Intelligent Transportation System) program.

One of the important goals stated in the National ITS Program Plan(1) is improving the safety of the U.S. surface transportation network. In 1993 alone, there were 40,000 deaths and 3,000,000 injuries on our roadways. Rural accidents are a special concern, because they represent a disproportionate share of the total number of accidents. Approximately 57 percent of all fatal accidents occur in rural areas. Travel speeds are higher and travel density (the ratio of vehicle-kilometers to highway-kilometers) is lower in rural areas than in urban and suburban areas. Other factors influencing the disproportionate share of rural fatalities include the additional time required to notify emergency service providers and the length of time for these service providers to respond to the incidents. In fact, data from the Fatal Accident Reporting System (FARS) shows that it takes almost twice as long to be notified of rural incidents involving fatalities as compared to urban incidents (8.38 min versus 4.35 min). The significant human and monetary losses associated with these accidents could be reduced through an effective "mayday" system capable of responding rapidly to motor vehicle accidents and other traffic incidents. The reduction in response time achieved by such a system could significantly improve victim survival rates and decrease the severity of injuries by providing victims with more timely medical attention.

The results of the user needs assessment, conducted under the Rural Applications of ATIS project, support an ubiquitous mayday service. More than 95 percent of the respondents to a national survey felt that it would be somewhat or very useful to be able to send a help signal to a responding agency in case of an accident. Communicating with an emergency service center is clearly a need of travelers in rural areas.

Recognizing the potential human and monetary savings that a national mayday system could produce, the U.S. Department of Transportation (U.S. DOT) developed the Emergency Management user service bundle described in the National ITS Program Plan. This user service bundle, which includes the Emergency Notification, Personal Security, and Emergency Vehicle Management user services, specifically addresses the ITS goal of improving safety by providing an 8-percent reduction in traffic fatalities (approximately 3,300 lives per year) by the year 2011.[2]

1.1 RURAL ATIS BACKGROUND

Early in 1993, FHWA set out to determine applications of intelligent transportation systems that would be of value in rural environments. In particular, FHWA initiated a research project entitled Rural Applications of Advanced Traveler Information Systems (ATIS). This project proposes a blueprint for rural ATIS on the development and deployment of technologies, services, and products for future activities. The project's objectives are twofold:

- To provide recommended direction for Federal initiatives with respect to ATIS technologies in rural and small urban areas (fewer than 50,000 people) in the United States.
- To provide guidelines for ATIS implementation efforts by state and local government agencies in meeting rural traveler information needs.

To meet the project objectives, a well-defined process was established as a foundation for recommending actions. The steps in the process include user-needs assessment, technology assessment, concept development and evaluation, and focus-area recommendations. The results of these steps are documented in a series of reports and pamphlets under this project.

A series of recommendations have been developed to address FHWA's level of involvement in rural ATIS. Based on an evaluation of items recommended for future ATIS development in which FHWA should play a critical and important role, two concepts have been selected for field testing under this project: an evaluation of satellite communications for mayday applications and Surveillance and Delay Advisory Systems. This report documents the results of the first concept.

1.2 OVERVIEW OF THE ITS MAYDAY CONCEPT

The mayday system will be an emergency notification and personal security service that gives vehicle occupants the ability to notify emergency service providers of an incident and request an appropriate response. The notification could be performed by the driver through a "panic button" or initiated automatically by a crash-sensing device. In either case, the vehicle would transmit its position and the nature of the incident to the public safety answering point (PSAP), where it would be forwarded to the appropriate service provider.

The Emergency Vehicle Management user service, which includes emergency vehicle fleet management, route guidance, and signal priority, is intended to reduce the time for a service provider to respond to an incident. It is specifically intended to reduce the time required to dispatch and route emergency response vehicles once the PSAP has received notification. Emergency vehicle fleet management would probably use a geographic information system (GIS)-based situation display to inform the dispatcher of existing fleet vehicle locations and assist in the selection of the most appropriate emergency service vehicle for a given incident. Once the appropriate emergency service vehicle is identified, route guidance is used by the dispatcher and the vehicle's operator to identify the travel route that minimizes travel time to the incident. Signal priority further reduces response time by allowing enroute emergency vehicles to pre-empt traffic signals.

The in-vehicle unit (IVU) is the "heart" of the mayday system. It provides the vehicle occupants with a manual means of initiating an emergency service request as well as being a survivable device designed to ensure the generation of automatic service requests following a debilitating crash or other incident. The IVU records vehicle location using one or more navigation systems (e.g., global positioning system [GPS]), determines vehicle physical status using an in-vehicle sensor system, and initiates vehicle occupant requests for emergency services. The IVU includes a communications system used to transmit service requests and receive acknowledgments from the PSAP or the relevant emergency-service providers. This communications system must operate in rural and urban areas throughout the United States.

Figure 1-1 shows an IVU concept incorporating all of the capabilities discussed above. Vehicle occupants may employ either audio or data messaging (or both) to initiate a mayday service request. The automatic functions of vehicle location, crash sensing,

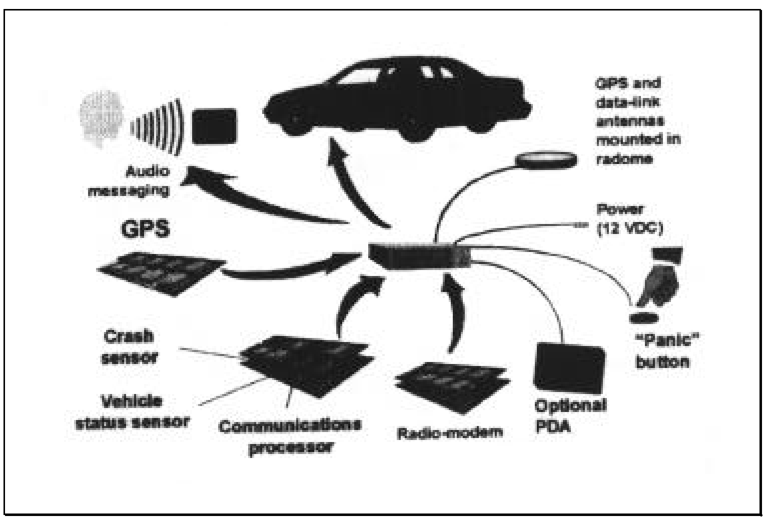

Figure 1-1: In-Vehicle Unit (IVU) Concept

vehicle status, and service request initiation are combined into a single crash-hardened unit. Navigation and communications systems antennas are mounted into one or more radomes mounted to provide maximum visibility. For example, roof and underside mounting provide optimum visibility for both satellite and terrestrial systems regardless of post-incident vehicle orientation. The personal digital assistant (PDA) may be used to provide incident-related service requests and other ITS services, such as traveler information and route planning. The communications processor would maintain a mayday service request, including frequent position updates, as a short message in its transmit queue. If the crash sensor detected an incident (e.g., rapid deceleration), it would initiate a sequence of automatic transmissions with the intent of reducing the risk that the communications system or its antennas would be damaged by the incident. Because transmissions last only tens of milliseconds, one or more of these transmissions would be transmitted before crash damage prevented subsequent transmissions.

The IVU could be designed not only for the mayday service, but also for the full range of ITS functionality desired by the consumer. Because these services and their public acceptance would be developed in an evolutionary manner, the development of an optimum IVU design (accepted by the public) must be accomplished with minimum government regulation. Although the IVU must meet certain minimum functional requirements to serve the mayday function, its physical design and the associated navigation and communications systems will not be standardized. In other words, the individual

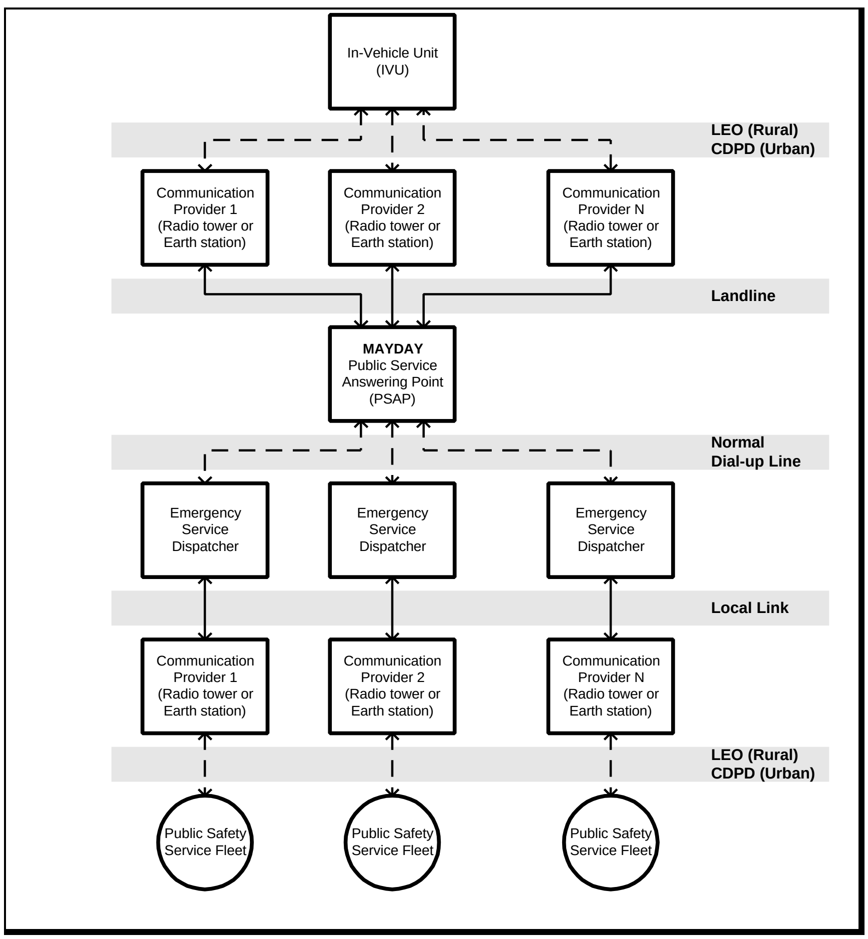

Figure 1-2: Mayday System Communications Concept

IVU manufacturers would be free to design innovative IVUs. The only required standardization would be the interface between the communications provider (e.g., cellular, satellite) and the PSAP. As illustrated in Figure 1-2, cellular digital packet data (CDPD) could be used in urban areas for which cellular coverage is available, while satellite systems would be used where cellular coverage is unavailable.

1.3 PURPOSE FOR THIS TEST OF SATELLITE COMMUNICATIONS

The in-vehicle mayday system transmits an emergency notification message signal through a communications system to an emergency response center. Operational tests of cellular-based mayday systems have been or are being carried out in Colorado, Minnesota, New York, and Washington State. Mayday systems are also being marketed by the private sector (such as ONSTAR by GM and RESCU System by Ford); however, these cellular-based systems are limited to the communications system's coverage area, which is insufficient in many rural areas. Other communications systems with better rural coverage (e.g., low earth orbit [LEO] and geosynchronous orbit [GEO] satellites, two-way pagers) have not been fully tested to determine their functionality for mayday systems.

This project was specifically tasked to evaluate satellite communications systems that may be applied to national/regional mayday systems. The work included the research into and testing of current and near-future GEO and LEO satellite communications systems. Both voice and data two-way communications were considered. The following items were of the most importance in the research effort:

- Availability of satellite communications technology.
- Transmission time for relaying a message from a remote location to a potential response center.
- Estimated initial capital cost to the user.
- Estimated recurring cost to the user.

Test plans were developed for evaluating systems and equipment tested based on defined functional and performance requirements. A preliminary study and testing of the accuracy of vehicle position by communications satellites were also conducted. The delay time for transmission, time to transmit, time to relay transmission from satellite, and transmission/data capacity were determined. Additionally, the system performance was evaluated in mountainous and level terrain, under a range of geographic locations and both high tree and foliage density.

2. TECHNICAL ISSUES

There are five significant technical issues related to mayday system implementation: positioning techniques, communications coverage, vehicle-to-PSAP and PSAP-to-vehicle communications requirements, satellite blockage, and antenna requirements. This section addresses each of these issues at an introductory level. Additional information can be found in the appendices to this document.

2.1 POSITION TECHNIQUES

A variety of techniques are available to provide the necessary vehicle-location data to support the mayday mission. The most notable off-the-shelf equipment for geolocation is GPS. Other approaches use satellite or terrestrial signals to determine the vehicle's position either at a central location or at the vehicle itself. Accuracy requirements for route guidance typically require a geolocation technique capable of locating a vehicle within 10 m. Accuracy requirements for mayday have not been determined and the requirements may depend on terrain. Table 2-1 summarizes the accuracy of potential geolocation techniques. Detailed information on the GPS system is included in Appendix A (Section 0).

Table 2-1: Geolocation Technique Accuracy

Technique	Accuracy
GPS	100 m
Loran-C	800 m
Dead Reckoning	<2% of distance traveled
LEO-based	100 m to 2 km

2.2 COMMUNICATIONS COVERAGE

The primary technical challenge in the implementation of a nationwide mayday system is the vehicle-to-PSAP and PSAP-to-vehicle communications link. This mobile communications link may be implemented as a terrestrial or space-based system. It is important to realize that regardless of whether a terrestrial or space-based system is employed, it is impossible to guarantee adequate signal coverage 100 percent of the time in 100 percent of all possible post-incident vehicle locations and vehicle orientations.

Terrestrial-based systems, such as cellular systems, provide the easiest and most cost-effective means of communication. However, cellular coverage does not meet the needs of rural areas of the continental United States and Alaska.

Satellite-based systems can provide coverage to all of the United States, including Alaska and Hawaii, as well as Canada and Mexico. LEO satellites can provide global coverage, but require many satellites to ensure that one is in view at all times. GEO satellite systems can provide continuous service if they are stationed over the same region of the globe as the user. LEO satellites operate at altitudes as low as 650 km, while GEO satellite orbit is 37,000 km.

More information about both terrestrial- and satellite-based communications systems can be found in Appendix C (Section 9).

2.3 SATELLITE BLOCKAGE

Determining vehicle location is the cornerstone of a mayday system. Even satellite positioning systems that have nationwide coverage experience a problem in some situations. Satellite blockage can be particularly troublesome in an urban canyon environment where tall buildings cause satellite signal shadow zones that prevent signal reception. Signal reception would be virtually non-existent for accidents that occur under bridges, in tunnels, or in parking garages. This problem will probably dictate that a GPS mayday system be augmented by some other technique.

2.4 ANTENNA REQUIREMENTS

Antenna system design is critical for geolocation in a mayday system. Appropriate antennas could be designed into vehicle chassis for normal operation; however, these same antennas would be unusable if the vehicle is rolled over. The relatively low operating frequency of LORAN-C (100 kHz) makes its optimal antennas fairly large. Use of smaller antennas is possible, but degrades performance. The issues raised here underscore the need to address mayday system requirements within the context of the national ITS architecture. In this way, the communications and navigation devices can be designed to support a variety of ITS mission requirements simultaneously. This approach will maximize ITS acceptance and market penetration, because user devices will then be capable of providing a number of important user services. The consumer would be able to benefit from multiple services with the purchase of a single device.

3. AMERICAN MOBILE SATELLITE CORPORATION

3.1 SYSTEM DESCRIPTION AND CAPABILITIES

A national GEO satellite communications system was developed by American Mobile Satellite Corporation (AMSC) in the United States and Telesat Mobile in Canada.(3) The system uses large hub stations and geostationary spacecraft with multiple high-gain beams. AMSC's system operates in the L-band range (1544 to 1559 MHz and 1645.5 to 1660.5 MHz); is licensed as a common carrier; and provides land, aeronautical, and maritime mobile satellite services (mobile telephone service, mobile radio service, mobile data service, and mobile fax service). The system provides full-duplex voice and data services for fixed and mobile users. The user can choose a steerable antenna, a switchable antenna, or an omni-directional antenna. The lower cost omni antenna will require increased transmission time, thereby offsetting the reduced user equipment cost with increased message charges.(4)

The geostationary satellites use five regional spot beams and provide coverage across North America, Alaska, and the offshore points of Hawaii and Puerto Rico, plus 370 km off the U.S. and Canadian coasts. Although the satellites will be visible over a greater area than the planned service area, the satellite's spot beams will focus on the land mass illustrated in Figure 3-1.(5)

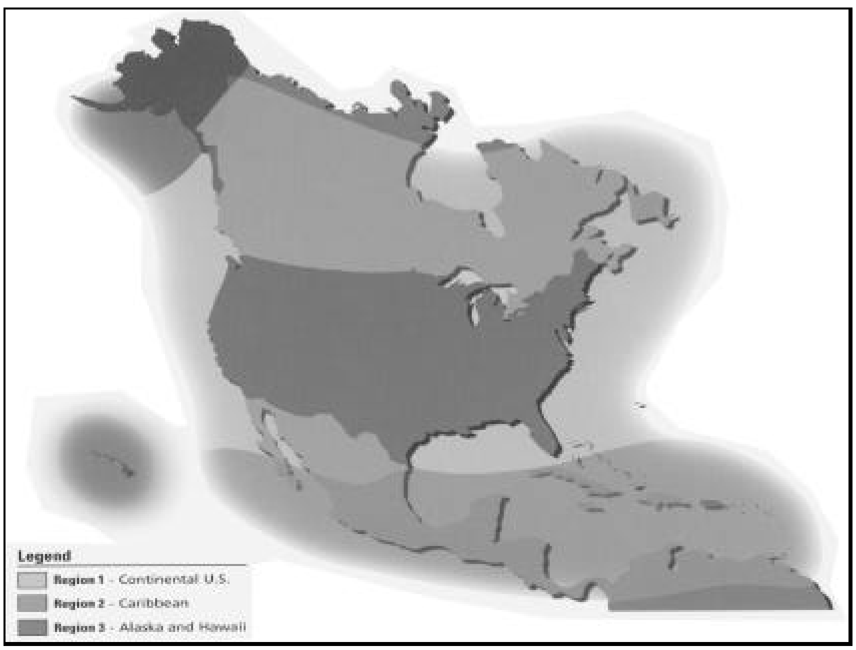

Figure 3-1: AMSC Coverage

The L-band frequencies are used by the satellite to communicate with the user. The satellite uses the Ku-band frequency range (10.75 to 10.95 GHz and 13.2 to 13.25 GHz) to transmit and receive signals from AMSC's land earth station (LES) located at AMSC's headquarters in Reston, Virginia. The LES consists of an earth station antenna, associated radio frequency equipment, and the access control and signaling equipment.

3.2 TEST SYSTEMS

Tests were conducted on AMSC's voice and data system using three different devices: one data and two voice. In all three cases, current off-the-shelf hardware and software were used. The systems tested were provided by AMSC and were installed as specified in TransCore and AMSC vehicles. The tested data service (Mobile Messaging Service) is used primarily by the trucking industry for fleet management. This service was tested to evaluate the data relay capabilities of AMSC's system and is discussed in Section 3.2.1. The mobile voice service tested is currently provided to a wide range of mobile users and is discussed in Section 3.2.2.

3.2.1 Mobile Messaging Service

The first test was with AMSC's Mobile Messaging Service (MMS), which provides two-way mobile data communications and positioning. AMSC has been offering this service to the transportation industry since 1992. The MMS uses the "Standard C" protocol within the L-band frequencies. The access control and signaling equipment performs the following functions:

- Provides interface to the public switch data networks (PSDN) via X.25.
- Performs message handling.
- Generates the master clock and frame timing.

The PSDN provides the final link to the customer's host computer via the X.25 data network through local terrestrial telephone companies (see Figure 3-2).

The MMS provides two-way point-to-multipoint messaging between trucks and dispatchers, group messaging, and periodic position reports. The system uses GPS to provide the vehicle's location and movement. The mobile earth terminal (MET) is the in-vehicle system for the MMS. The MET is made up of four major components: the antenna; the communications transceiver, called the data communications equipment (DCE); the GPS receiver; and the data terminals equipment (DTE), which serves as a data input/output device. See Figure 3-3 for system communications specifications.

A low-profile, low-power antenna handles both data communications and GPS communications. The unit has no moving parts and weighs 1.1 kg. The antenna is connected via coaxial cable to the DCE. The transceiver or DCE operates at a receiver bandwidth of 1530.0 to 1559.0 MHz and a transmitter bandwidth of 1626.5 to 1630.5 MHz.

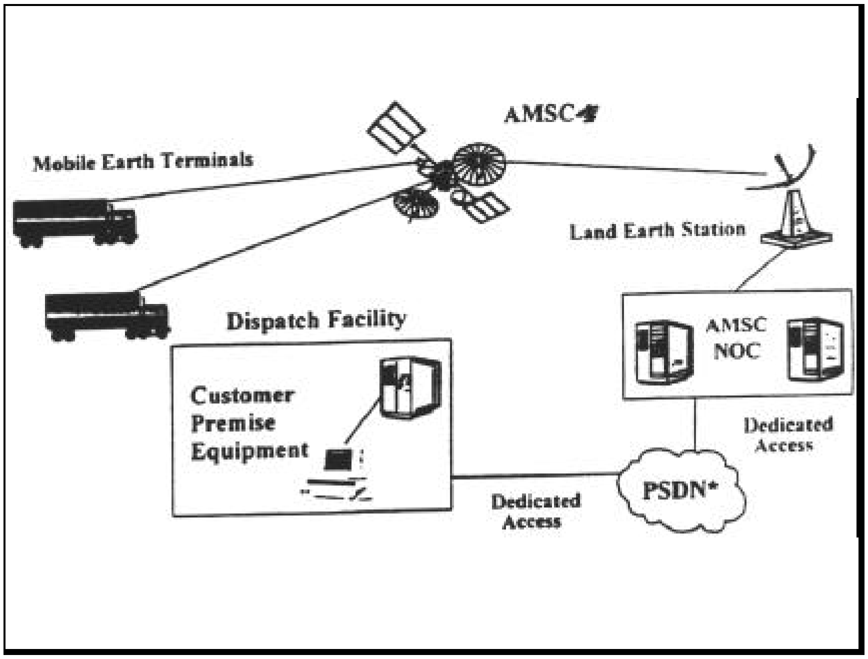

Figure 3-2: AMSC's Network Architecture

The DCE is normally connected to the DTE, but can be interfaced with a PC or sensor monitor via an RS-232 serial port. The DTE is manufactured exclusively by AMSC. This mobile communicator is interfaced with the transceiver and is a ruggedized PC device with the following configuration:[6]

- An 80386SX 25-MHz processor with DOS 6.0 in ROM.
- 1-Mb EPROM for the communications application.
- 2 Mb of RAM.
- One PCMCIA type 2 slot (PCMCIA card is optional).
- Two serial ports and one parallel port.
- Backlit CGS nonglare screen and keyboard.
- Elastomeric rubber keyboard.
- Power supply, 12 VDC with transient filters built in for raw vehicle power, 12-W power drain with backlight off/24-W power drain with backlight on.
- Reported operating temperature -20 to 50°C (storage -30 to 60°C).

Transceiver Specifications	
Assembly:	Aluminum Diecast housing; hard epoxy finish
Size:	21.45 cm W x 24.49 cm L x 24.49 cm H (excluding connectors)
Weight:	2.9 kg
Power:	9.6-31.2 VDC (+30%, -20%), 12-W receiver, 70-W transmitter
Operating Temperature:	From -28°C to 55°C
Humidity:	95% RH noncondensing at 40°C
Vibration, survival:	5-20 Hz, .05g2/Hz; 20-150 Hz, -3 dB/act
Vibration, operational:	5-20 Hz, .005g2/Hz; 20-150 Hz, -3 dB/act
Connector:	Type N
Antenna, AMSC & GPS	
Size:	12.7 cm H x 18.3 cm D (base)
Weight:	1.2 kg
Operating Temperature:	From -35°C to 55°C
Wind:	350 km/h
Ice:	2.50-cm-thick survival
Mounting:	Surface mount
Antenna Cable Loss:	Up to 10 dB at 1600 MHz (up to 30 m with RG-213)
Connector:	Type N
GPS Receivers	
General:	Tracks up to 8 GPS satellites
Update Rate:	1 second (typical)
Accuracy (typical):	Position: 14.9 m RMS
Frequencies Transmit:	1626.5-1646.5 MHz
Receive:	1530.0-1545.0 MHz
Data Rate:	TX Symbol Rate: 1200 s/sec
RX Symbol Rate:	1200 s/sec
External Interfaces:	
Data and GPS 1/0:	Serial, RS-422 (NMEA 0183 Protocol)
Power:	Main power, remote on/off

Figure 3-3: MMS Mobile Terminal Technical Specifications[5]

3.2.1.1 Hardware Configuration

The test system was installed in a test vehicle by TransCore. The MMS was configured as designed. The antenna was temporarily installed on top of a mask from the back of the vehicle so that the antenna was in line with the top of the vehicle's roof. The MMS was powered by the vehicle's power and was not connected to any other equipment. A PC in TransCore's office was used to connect to AMSC's network via modem to send and receive messages and positioning data from the vehicle. The PC used a DOS application supplied by AMSC. This PC was used only to poll AMSC to ensure that messages were received by the network. The time involved and the method used to retrieve the messages would be different in a mayday application; a mayday center would have a direct, continuous connection to the network and would not poll the vehicles.

3.2.1.2 Procedures

The MMS was tested by transmitting formatted messages and GPS data from various locations in north Georgia. Two specific times were tracked: the time from message initiation to message transmission and the time from message initiation to the time a response was received. This gave the time required to generate the message with GPS data and the time for AMSC to respond with a confirmation that the message was received. Five test sites were used for all tests. Appendix B (Section 8) lists and describes the test sites.

3.2.2 Mobile Voice and Data Service

AMSC's voice services provide full-duplex, high-quality voice telephone and push-to-talk dispatch services. Mitsubishi and Westinghouse manufacture in-vehicle, fixed, and personal portable units. Three units were tested: Mitsubishi's ST141 and ST111D, and Westinghouse's D1000. All three units use high-gain antennas and provide the following features:

- Digital full-duplex voice.
- Optional data ports for PCs and GPS.
- Optional point-to-multipoint digital dispatch capability.
- Optional fax capability.
- Hands-free microphone.
- Speed dialing.

3.2.2.1 Hardware Configuration

Three different voice systems were tested simultaneously. The systems offered the same features, but were made by two different manufacturers: Mitsubishi and Westinghouse. The two Mitsubishi units used in the test differed only in the

Communications Modes		
Voice:	Full-duplex digital voice	
	Half-duplex digital voice (net radio option)	
Fax:	Group III facsimile at 4800 bps (option)	
Data:	1200 bps/2400 bps/4800 bps	
System Specifications		
Transmit Frequencies:	1626.5-1660.5 MHz	
Receive Frequencies:	1525.0-1559.0 MHz	
Polarization:	Right-Hand Circular Polarization (RHCP)	
Channel Spacing:	6 kHz	
Interface Specifications		
Voice:	MELCO Handset	
Fax:	RJ-11C, two-wire (option)	
Data:	DB-25, RS-232C,	
	AT Command Set (without escape sequence)	
Power:	12 VDC Nominal (11.5 to 15.6-V range)	
Antenna Unit (AU)	**ST141**	**ST111D**
Diameter:	31.5 cm	17.3 cm
Height:	18.5 cm	16.8 cm
Base Diameter:	18.5 cm	17.3 cm
Weight:	2.5 kg	1.4 kg

Figure 3-4: ST141/ST111D Specifications

antennas. See Figure 3-4 for the Mitsubishi units' specifications. The Westinghouse unit's specifications are given in Figure 3-5.

3.2.2.2 Procedures

The ST111D was connected to a GPS receiver and notebook computer to record the test vehicle's location throughout the test and to record the satellite's carrier-to-noise ratio. The D1000 made outgoing telephone calls automatically to test link capability as the vehicle was moving and at each test site described in Appendix B (Section 8). The ST141 was used to make manual calls to TransCore's office to check voice quality.

Communications Modes	
Voice:	Full-duplex digital voice
	Half-duplex digital voice (net radio option)
Fax:	Group III facsimile at 4800 bps (option)
Data:	1200 bps/2400 bps/4800 bps
System Specifications	
Transmit Frequencies:	1626.5-1650.5 MHz
Receive Frequencies:	1525.0-1559.0 MHz
Polarization:	Right-Hand Circular Polarization (RHCP)
Channel Spacing:	6 kHz
Interface Specifications	
Voice:	Westinghouse Handset
Fax:	DB-25
Data:	DB-25, RS-232C,
	AT Command Set (without escape sequence)
Power:	12 VDC Nominal (11.5 to 15.6-V range)
Antenna Unit	
Length:	26.4 cm
Width:	23.9 cm
Height:	19.1 cm
Weight:	1.0 kg

Figure 3-5: D1000 Specifications

3.3 SYSTEM AVAILABILITY AND FUTURE DEVELOPMENT

The AMSC system is operational and available. All associated hardware is in full production and future capability enhancements and designs are underway. The AMSC system can be backed up with Canada's Telesat Satellite if needed.

Both Mitsubishi and Westinghouse have vested interests in further development of satellite mobile communications technology. Future development will be in the design of smaller devices and antennas. Most of this development is toward mobile voice systems.

3.4 TRANSMISSION TIMES

3.4.1 Mobile Messaging Service

A total of 41 message attempts were made. There were two time spans tracked for each message: the time to queue up a message and the time from message initiation to a returned acknowledgment. The average time to generate a message and queue it up to be transmitted was 38 s. During this time, the system generated a current GPS position and formatted the message. The system then transmitted the message, including the GPS data. Once received at AMSC, an acknowledgment message was transmitted back to the vehicle from AMSC. The total time to generate the message, transmit the message, and receive the acknowledgment message averaged 2 min and 14 s.

The variances in queuing messages and transmitting messages are due to tracking the GPS satellites and maintaining a communications link with the AMSC satellite. In general, the system operated without delay and was able to send messages in the north Georgia mountains where cellular communication was not possible. Table 3-1 shows all results of attempted messaging for each site.

3.4.2 Mobile Voice Service Test Results

This 2-day test evaluated three parameters of AMSC's voice system: voice quality, carrier-to-noise ratio, and connectivity of outbound calls. Voice quality was manually tested, while noise ratios and connectivity were automated with a PC notebook. The results of the test were plotted by AMSC and are shown in Figure 3-6.

Table 3-1: Test Results for AMSC

Signal Strength	Duration of MGS Queued	Total Time to Receive Response
Site 1		
7	0:35	2:10
7	0:35	2:05
7	0:33	1:55
7	0:31	1:55
7	0:34	2:05
7	0:33	2:01
7	0:36	1:45
7	1:05	1:48
7	0:35	2:08
7	0:33	2:07
Average Times	0:37	2:01
Site 2		
6	0:38	2:05
6	0:35	2:40
7	0:33	2:06
6	0:34	2:02
4 to 6	0:34	4:02
6	0:35	2:10
5 to 6	0:38	2:08
6	0:33	2:01
4 to 5	0:37	2:15
6	0:36	2:10
Average Times	0:35	2:21
Site 3		
6	0:31	1:56
5	0:34	2:10
6	0:35	2:06
5	0:33	1:59
4 to 6	1:02	2:36
6	0:32	2:08
5	0:32	1:56
5 to 6	0:35	2:08
5	0:34	2:08
5	0:35	2:05
Average Times	0:36	2:07
Site 4		
0	0:35	0:00
Site 5		
3 to 5	0:32	3:31
4	0:40	2:02
2 to 5	0:38	2:08
4 to 5	0:36	2:09
4 to 5	1:02	1:57
3 to 5	0:35	2:16
4 to 5	1:04	4:10
4 to 5	0:37	1:59
3 to 5	0:35	2:14
4 to 5	0:33	2:12
Average Times	0:41	2:27
Total Average	**0:38**	**2:14**
Maximum	**1:05**	**4:10**
Minimum	**0:31**	**1:48**

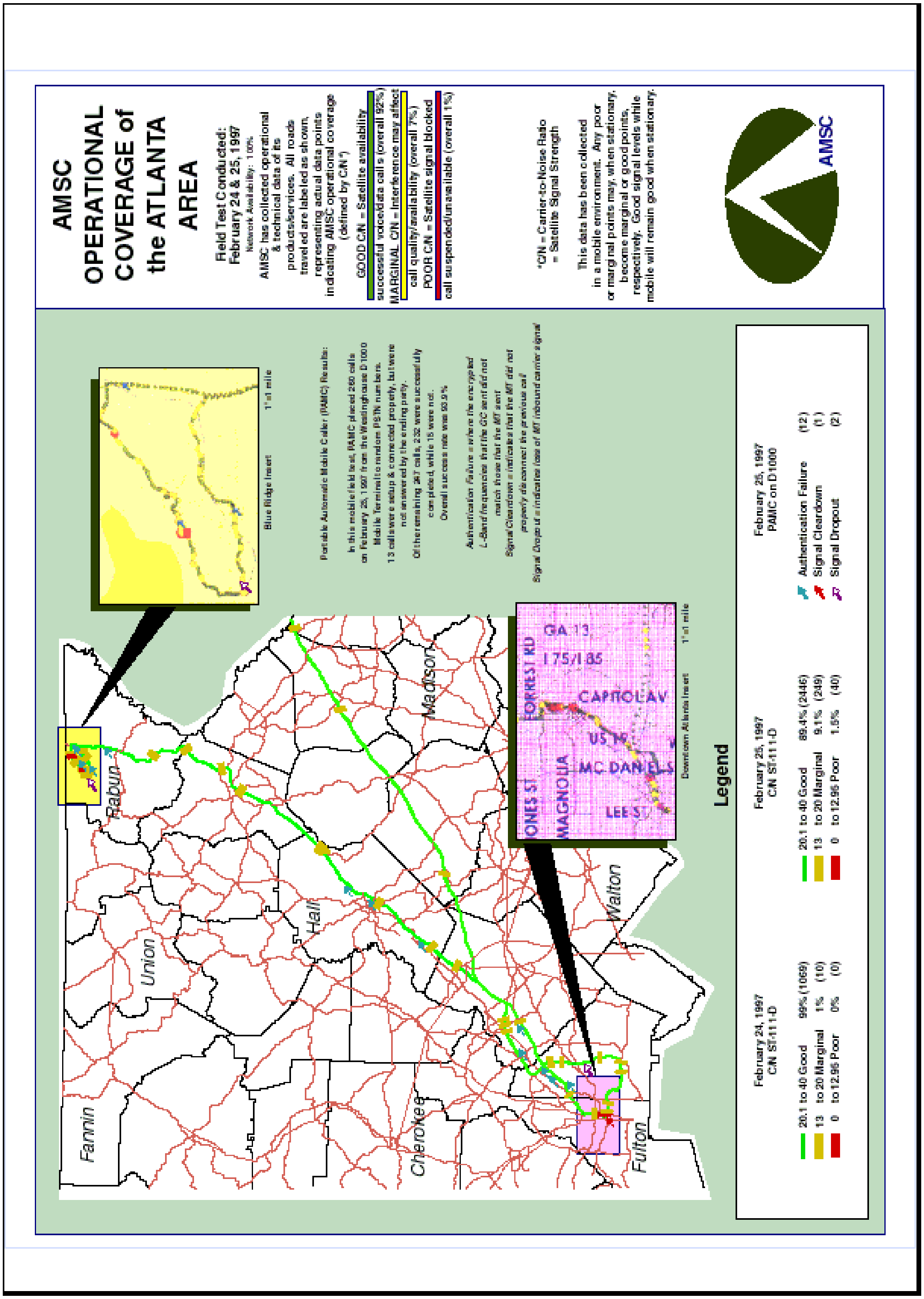

Figure 3-6: AMSC Operational Coverage of the Atlanta Area

The voice quality of the ST141 handset was very high. The sound quality and time to make a call was comparable to a cellular telephone. The only notable difference was the time delay of voice transmissions due to the time to travel up and down to a GEO satellite. In spite of the lag, the voice service would meet the needs of a mayday system. The system was intelligent enough to maintain the call's connection for short times when the vehicle was under bridges or behind obstacles.

The ST111D monitored the carrier-to-noise (C/N) ratio to evaluate the satellite signal strength. The C/N ratio was ranked into three categories: good, marginal, and poor. A good C/N ratio means the satellite was available with a strong signal strength for successful voice/data calls. A marginal C/N ratio means interference may affect the call's quality. A poor C/N ratio means the satellite signal was blocked and the call would be suspended or unavailable. On February 24, 1997, the C/N ratio was evaluated from South Carolina along I-85 to Atlanta. On February 25, 1997, the C/N ratio was evaluated in downtown Atlanta, along I-85, I-985, GA 441, and rural roads in north Georgia. Over the 2 days, 3,814 data points were collected. The results were that 92 percent of the time the C/N ratio was good, 7 percent of the time it was marginal, and 1 percent of the time it was poor.

On February 25, 1997, the D1000 was used to make outbound calls to test full connectivity. The D1000 made 260 calls, of which 13 calls were not answered. Out of the remaining 247 calls, 15 were unable to establish a link. The success rate was 93.9 percent.

3.5 ESTIMATED COST

The MMS service is $46.20/month and includes 720 messages. The suggested retail price for the MET is $3,495, including the antenna.

The cost for AMSC's voice services varies with airtime plans and equipment options. The basic service charges are $25/month and $1.50/minute. Mitsubishi's ST141 is $3,799 and the ST111D is $3,499. The Westinghouse D1000 is $4,199. Stand-alone cellular transceiver, facsimile, standard telephone, and hands-free microphones are optional.

4. ORBCOMM

4.1 SYSTEM DESCRIPTION AND CAPABILITIES[7]

The Orbitals Communications Corporation (ORBCOMM) satellite-based communication and position location system is a partnership owned by Orbital Sciences Corporation and Teleglobe Inc. of Canada. ORBCOMM's constellation of 28 satellites provides near real-time transmission of data and messages from anywhere on Earth, to anywhere on the Earth. ORBCOMM USA markets and provides ORBCOMM services inside the United States while ORBCOMM International provides services in other countries.

Until 1995 only GEO satellites, orbiting at 36,000 km above the Earth, were available to provide the satellite link for commercial data distribution. Though achieving 100 percent coverage in geographic regions, GEOs have been mostly used for distribution of television programming and thin route voice services in a one-to-many distribution pattern. Two-way data messaging or remote monitoring was not practical because the GEO system required expensive end-user equipment, large power sources to reach the satellites and high per-minute transmission charges that would not be feasible for many ongoing commercial business operations.

However, the introduction of LEO satellites—small communications transceivers in continuous motion at heights of 800 to1900 km above the Earth—made the prospect of affordable mobile and remote global network links possible. LEOs can provide 100 percent geographic coverage, but unlike GEOs, LEO systems require less power for messages to reach their Earth-based collection/uplink stations and the orbiting satellites.

The ORBCOMM constellation comprising 28 satellites is the world's second largest constellation of communications satellites and the first to provide commercial service from low-Earth orbit. The satellites were launched eight at a time by a Pegasus rocket dropped from an L-1011 jet flying at 40,000 km feet above the Atlantic Ocean off the Virginia coast.

The ORBCOMM System uses LEO satellites instead of terrestrial fixed site relay repeaters to provide worldwide geographic coverage. The system is capable of sending and receiving two-way alphanumeric packets, similar to two-way paging or e-mail. Figure 4.1 shows ORBCOMM system architecture. The three main components of the ORBCOMM System are: the space segment – the constellation of satellites; the ground segment – gateways which include the Gateway Control Centers (GCCs) and Gateway Earth Stations (GESs), and the Network Control Center (NCC) located in the United States; and subscriber communicators (SCs) – hand-held devices for personal messaging, as well as fixed and mobile units for remote monitoring and tracking applications.

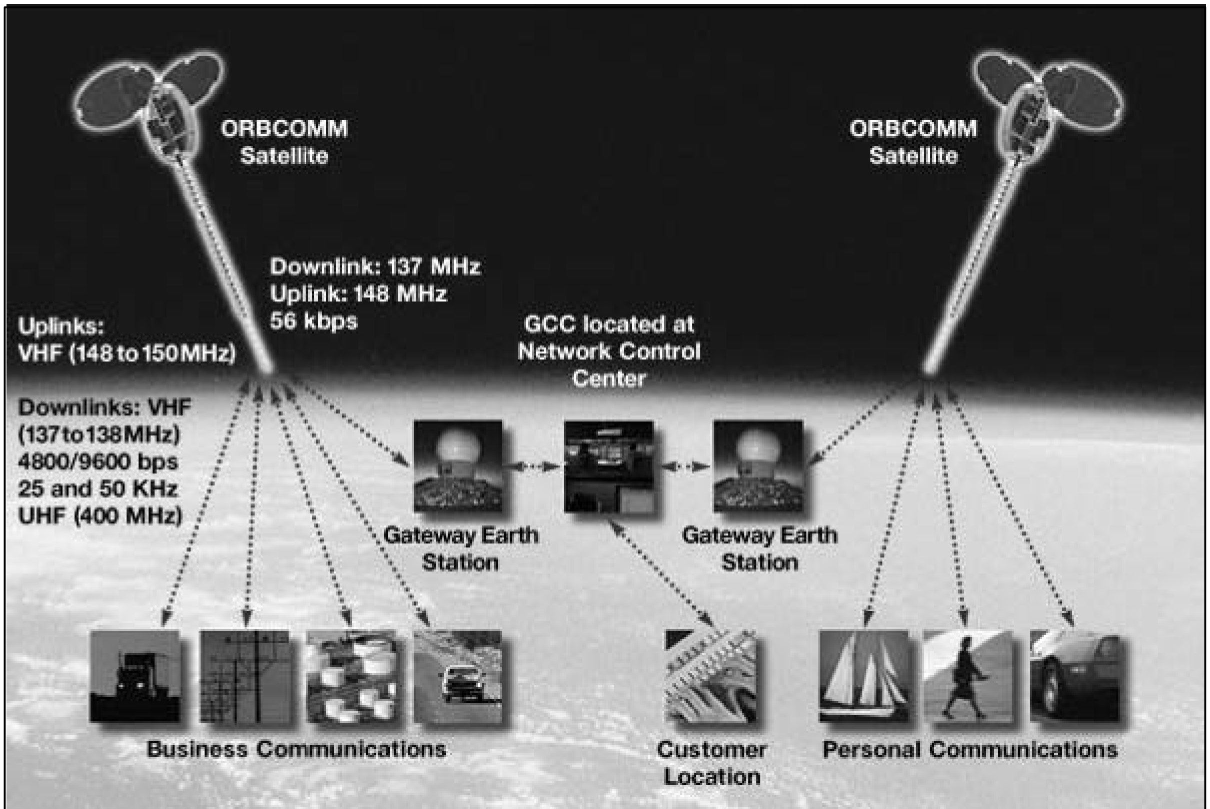

Figure 4-1: ORBCOMM System Architecture

4.1.1 Space Segment

The main function of ORBCOMM's satellites is to complete the link between the SCs and the switching capability at the U.S. NCC or a licensee's GCC. The satellites are "orbiting packet routers" ideally suited to "grab" small data packets from sensors in vehicles, containers, vessels or remote fixed sites and relay them through a tracking Earth station and then to a GCC.

The ORBCOMM satellites have the following characteristics:

- Mass: approx. 90 pounds
- Solar Array Power BOL: 160 watts
- Transmitters:
  - VHF (subscriber links) 1
  - VHF (feeder links) 1
  - UHF 1
- Receivers:
  - VHF (subscriber links) 7 - 1 DCAAS Receiver and 6 Subscriber Receivers
  - VHF (feeder links) 2
- Propulsion: N2
- Guidance: Autonomous/GPS

4.1.2 Ground Segment

The ground segment, which has most of the "intelligence" of the ORBCOMM System, is composed of GCCs, GESs, and ORBCOMM's NCC which is located in Dulles, VA. The NCC also serves as North America's GCC. Additionally, within the U.S., there are four GESs located in Arizona, Georgia, New York State, and Washington State.

4.1.2.1 Gateway Control Center (GCC)

Generally located in a territory that is licensed to use the ORBCOMM System, the GCC provides switching capabilities to link mobile SCs with terrestrial-based customer systems via standard communications modes including X.400, X.25, leased line, dial-up modem, public or private data networks, and e-mail networks including the Internet. Interfaces to the GCC enable reliable, efficient, and cost-effective integration of the ORBCOMM System into existing or new customer MIS systems.

4.1.2.2 Gateway Earth Station (GES)

ORBCOMM's GESs link the ground segment with the space segment and will be in multiple locations worldwide. The GESs provide the following functions:

- Acquire and track satellites based on orbital information from the GCC.
- Transmit and receive transmissions from the satellites.
- Transmit and receive transmissions from the GCC or NCC.
- Monitor status of local GES hardware/software.
- Monitor the system level performance of the satellite “connected” to the GCC or NCC.

The GES is redundant and has two steerable high-gain VHF antennas that track the satellites as they cross the sky. The GES transmits to a satellite at a frequency centered at 149.61 MHz at 56.7 kbps with a nominal power of 200 watts. The GES receives 3-watt transmissions from the satellite at 137 to 138 MHz range. These up and downlink channels have a 50 KHz bandwidth.

4.1.2.3 Network Control Center (NCC)

The NCC is responsible for managing the ORBCOMM network elements and the U.S. gateways through telemetry monitoring, system commanding and mission system analysis. It provides network management of ORBCOMM's satellite constellation and is staffed 7 d/week, 24 h/d by ORBCOMM-certified controllers.

4.1.2.4 Subscriber Communicator (SC)

There are two types of SCs. One enables fixed, remote data communications while the other enables mobile, two-way data and messaging communications.

ORBCOMM's SC for fixed data applications uses low-cost VHF electronics. The simple antenna design and small package provide installation flexibility. The low-power electronics allow for extended operations using batteries, a solar panel, or available power.

The SC for mobile two-way messaging is a hand-held, stand-alone, pocket-sized unit. Typically, the units have an alphanumeric keyboard and small display screen.

4.1.3 The Message Process Flow

A message sent from an SC unit in the U.S.—either stationary or mobile—is received at the satellite and relayed down to one of four U.S. GESs that connect the ORBCOMM ground system with the satellites. The GES then relays the message via satellite link or dedicated terrestrial line to the NCC. The NCC routes the message to the final addressee via e-mail, dedicated telephone line, or facsimile. Messages originated outside the U.S. are routed through GCCs in the same manner.

Messages and data sent to an SC can be initiated from any computer using common e-mail systems including the Internet, cc:Mail, and Microsoft Mail. The NCC or GCC then transmits the information using ORBCOMM's global telecommunications network.

The ORBCOMM system also has the capability to reverse the message flow discussed above and forward information or command and control messages from the system operator to the terminal. The ORBCOMM system uses a message acknowledgment protocol for messages going to or coming from the remote terminal. The acknowledged-message protocol enables the SC transmitter to transmit the minimum number of times necessary to transfer the complete message. This feature ensures that the battery power on remote terminals is not consumed by continuously transmitting messages that have already been received.

4.2 SYSTEM TESTED

Two ORBCOMM subscriber communicators (SCs) manufactured by Panasonic (model number KX-G7001) were used for the test. The heavy-duty, water-resistant unit supports RS-232C, two bi-level transistor-transistor logic (TTL) inputs, and two output ports. The unit's operating temperature range is specified to be -40 to 75°C. The power consumptions are specified as follows:[8]

Sleep Mode:	Waiting with internal timer or external activation <1 mA.
Receive Mode:	Receiving downlink signal in power-save mode 120 mA average. Receiving downlink signal in continuous mode 240 mA.
Transmit Mode:	3 A.

The unit had a frequency range and speed of 148 to 150 MHz at 2400 bps for the uplink and 137 to 138 MHz at 4800 bps for the downlink. The unit contained an internal GPS receiver with eight channels. The SC has two antennas, one for SC communications to the satellite and one for GPS data. The ORBCOMM system uses a ½-wave whip antenna suitable for the auto industry and a micro-strip patch antenna for the GPS.

The ORBCOMM system was not tested for its positioning capabilities. The ORBCOMM position location function uses Doppler measurements of the signal transmitted from the ORBCOMM satellite. The satellites determine their positions through highly accurate on-board GPS receivers and transmit the location information to the ground terminals over a dedicated channel. By taking a series of Doppler measurements from a moving satellite and using the satellite location information, a ground terminal can calculate vehicle position to better than 1000-m accuracy. This position determination can be accomplished by the ground terminal without adding a special receiver or antennas.

4.2.1 Hardware Configuration

Two ORBCOMM SC units were installed in a test vehicle by TransCore. Both were connected via an RS-232 port to notebook PCs running a DOS messaging application supplied by Orbital Science Corporation. The PCs' main functions were to send text messages to the SC and to keep time for the user. No universal time was tagged to messages by either the satellite or ground segments until the message was passed to an outside network such as internet e-mail.

Both SC antennas were mounted on top of a TransCore vehicle. The GPS antennas were not used for the test. GPS positioning is a separate function from the messaging system with the current SC units and is not included with normal messaging.

4.2.2 Procedures

ORBCOMM's system was tested by multiple data message transmissions over a 3-d period, February 5, 6, and 7, 1997. Because on the date of the tests ORBCOMM had only 2 of the 26 planned satellites in orbit, the test time and duration were limited to the times when the satellites were in view of the test vehicle.

Between the 2 satellites, there were 8 to 10 passes per day in groups of 4 to 5 passes every 12 h at the planned test longitude and latitude. See Appendix C (Section 9) for pass times and line-of-sight parameters (i.e., azimuth and elevation). Tests were conducted on all passes between 8:00 a.m. and 6:00 p.m. that were above the horizon for more than 4 min. The tests were conducted in metropolitan Atlanta and in the north Georgia mountains along both rural and urban roadways and under varying terrain and foliage. Appendix B (Section 8) lists and describes the test sites. The two SC units used message lengths of 72 characters.

The first day of testing was used to establish a baseline of system performance parameters under optimal operating conditions to measure variances in transmission times and signal strength under less than optimal conditions. Once a stable baseline was established, the test vehicle traveled to predetermined locations (see Appendix B - Section 8) to conduct tests.

4.3 SYSTEM AVAILABILITY DURING TESTS

Although the system description in Section 4.1 is based on information current as of March 1999, the system testing was done in February 1997. During the tests conducted for this report, ORBCOMM had 28 satellites in place. All satellites were and are LEO satellites and thus none were geostationary, as this would require a much higher orbit. Two of the satellites were in polar orbits. As discussed earlier, the system currently has 28 satellites with 8 more planned for launching in August 1999.

4.4 TRANSMISSION TIME

Over the 3 d of testing, 46 message transmissions were attempted, 43 of which were used to compute the time to transmit messages. The other three messages were successfully transmitted, but the time to transmit did not reflect the true time to send a message because the messages were entered or stored for transmission when the satellite was not in view. There were 12 satellite passes during which message transmissions were attempted. Messages were unable to be transmitted by the SC units on 4 of the 12 passes due to an inadequate line of sight between the vehicle and the satellite. This was largely due to the fact that only 2 of the 28 satellites were in orbit.

There were four passes scheduled for testing on the first day. The first pass tested was at TransCore's Atlanta office parking lot. The location is surrounded with moderate-height evergreen trees. The other three passes tested were at a nearby parking lot clear of all trees and most buildings. On the first two passes, the times to send a message and receive a confirmation notice back from the NOC were 53 s and 43 s, respectively. On the next two passes, the satellite was lower in local elevation. This resulted in only one message being sent on the third pass and none on the last pass. The reason seemed to be that the satellite was too low to clear the surrounding skyline. Because the test vehicle was in the clear and on a slight hill, the test team believed that many of the identified passes above the horizon would not be suitable for message transmission.

The second day of testing included locations in the north Georgia mountains. Four passes were used to test the system's reliability in mountainous terrain. Two passes failed to transmit messages due to the mountains blocking transmission. The other two passes varied in average time to send and verify messages. One was 31 s and one was 1 min and 54 s. The third day gave similar results in urban surroundings. Two of the four passes tested on the third day failed to send a message due to the low pass elevation relative to the local terrain and buildings. Table 4-1 gives the transmission times to send and receive confirmation messages. The time shown in the last column is the time for the round trip.

Based on the 3 d of testing, the overall average time to send a message and receive confirmation that the message was received was 48 s. Successful message transmission was very dependent on the elevation of the satellite's pass. The majority of the low-flying ORBCOMM satellite passes are at a low elevation (5 to 40 degrees). As a result, there was limited opportunity to transmit mayday messages in real time. The fact that the satellites are in low earth orbits means that each satellite pass is at a different angle to the vehicle; therefore, if the full constellation of 26 satellites was in orbit, as soon as one satellite went out of view another would be coming up over the horizon. In addition, if one satellite were blocked by terrain to one side, another satellite would most likely come into view from a clear direction. Therefore, a full constellation of satellites will provide adequate coverage for mayday applications.

When the satellites were in view, the system worked well. With the average round-trip time of only 48 s, the system would provide a rapid communications link between a vehicle and a central system. With 26 satellites in orbit, the redundancy of multiple links and varying lines of sight to satellites would provide a reliable network for many applications. However, additional data and analysis are required to confirm this for a specific time-critical application.

Table 4-1: ORBCOMM Test Results

Orbit	Sat.	Time Sent	Time of SR	Time Delta
DAY ONE				
Site A				
9742	2	15:04:06	15:04:55	0:00:49
9742	2	15:05:52	15:08:12	0:02:20
9742	2	14:53:45	14:53:50	0:00:05
9742	2	14:53:48	***14:58:21***	
9742	2	14:58:24	14:58:40	0:00:16
		Average time to transmit message		0:00:53
Site B				
9742	1	15:49:38	15:50:01	0:00:21
9742	1	15:50:09	15:50:33	0:00:20
9742	1	15:50:42	15:50:59	0:00:17
9742	1	15:51:01	***15:58:43***	
9742	1	15:59:17	15:59:38	0:00:21
9742	1	15:59:45	16:00:05	0:00:20
9742	1	15:49:38	15:50:11	0:00:33
9742	1	15:50:16	15:50:31	0:00:15
9742	1	15:50:35	15:50:43	0:00:08
9742	1	15:50:47	15:50:57	0:00:10
9742	1	15:51:00	15:51:08	0:00:08
9742	1	15:51:40	15:53:29	0:01:49
9742	1	15:53:53	***15:54:11***	
9742	1	15:54:22	15:59:06	0:04:44
9742	1	15:59:36	15:59:53	0:00:17
9742	1	16:00:06	16:00:16	0:00:10
		Average time to transmit message		0:00:43
Site B				
9743	2	16:40:57	16:42:45	0:01:48
Site B				
9743	1	Satellite was too low (7 deg. Max.)		
DAY TWO				
Site 1				
9756	2	14:16:40	14:17:09	0:00:29
9756	2	14:17:22	14:17:43	0:00:21
9756	2	14:18:13	14:18:38	0:00:25
9756	2	14:19:54	14:20:41	0:00:47
9756	2	14:21:17	14:21:42	0:00:25
9756	2	14:21:52	14:22:29	0:00:37
		Average time to transmit message		0:00:31
Site 2				
9756	1	15:08:57	15:11:25	0:02:28
9756	1	15:10:19	15:11:04	0:00:45
9756	1	15:11:29	15:13:59	0:02:30
		Average time to transmit message		0:01:54
Site 3				
9757	2	Satellite did not rise above the terrain		
Site 4				
9757	1	Satellite did not rise above the terrain		

NOTE: **Bold** times indicate when a message was entered when a satellite was known not to be in view.

Table 4-1: ORBCOMM Test Results (Continued)

Orbit	Sat.	Time Sent	Time of SR	Time Delta
DAY THREE				
Site 5				
9770	2	Satellite did not rise above the terrain		
Site 6				
9770	1	13:59:47	14:03:16	0:03:29
Site 7				
9771	2	14:15:49	14:17:02	0:01:13
9771	2	14:17:36	14:18:37	0:01:01
9771	2	14:18:44	14:19:03	0:00:19
9771	2	14:19:06	14:19:28	0:00:22
			Average time to transmit message	0:00:44
Site 8				
9772	1	14:49:12	14:49:44	0:00:32
9772	1	14:49:54	14:50:14	0:00:20
9772	1	14:50:21	14:50:40	0:00:19
9772	1	14:50:49	14:51:07	0:00:18
9772	1	16:03:26	16:03:45	0:00:19
9772	1	16:04:44	16:05:10	0:00:26
9772	1	16:05:31	16:05:52	0:00:21
9772	1	16:07:05	16:07:26	0:00:21
9772	1	16:08:13	16:08:35	0:00:22
9772	1	16:08:43	16:09:02	0:00:19
			Average time to transmit message	0:00:22
			Total average overall passes	**0:00:48**
			Maximum	**0:03:29**
			Minimum	**0:00:05**

4.5 COMMUNICATIONS COVERAGE

Since 1997, ORBCOMM coverage is more than 95 percent over most of the U.S. The ORBCOMM satellite system provides near-continuous coverage[9] to essentially all areas of the earth bounded by the 70-degree latitude grids. Polar area coverage is provided every ½ h for 14 min.

Figure 4-2 depicts the earth coverage of the entire constellation at one point in time. (Note that as the satellites move over the tracks shown, virtually every spot on the face of the globe will be in sight of a satellite at some time.)

The orbits of the satellites have been designed so that within the boundaries of ±70 degrees latitude, every location will be in sight of an ORBCOMM satellite for a large percentage of the time. Figure 4-3 shows the percentage of time that a satellite is in view, by latitude, assuming a 5-degree elevation angle. ORBCOMM has optimized the orbits to provide as close to 100-percent coverage as possible in the latitudes encompassing the continental United States. Another way to look at this is that during each 1-h period, there will be a satellite in view of an SC terminal for at least 40 min (i.e., 66 percent of the time) and for as much as 58 min (97 percent of the time) in any latitude from the equator to 70 degrees. The coverage at the polar regions above 70 degrees latitude will be slightly less than 50 percent in each 1-h period as mentioned above. A SC terminal located virtually anywhere in the world will be able to compute its position and transmit that position information to an ORBCOMM satellite at least once every 15 min. Message transfer from the satellite to the NCC occurs by

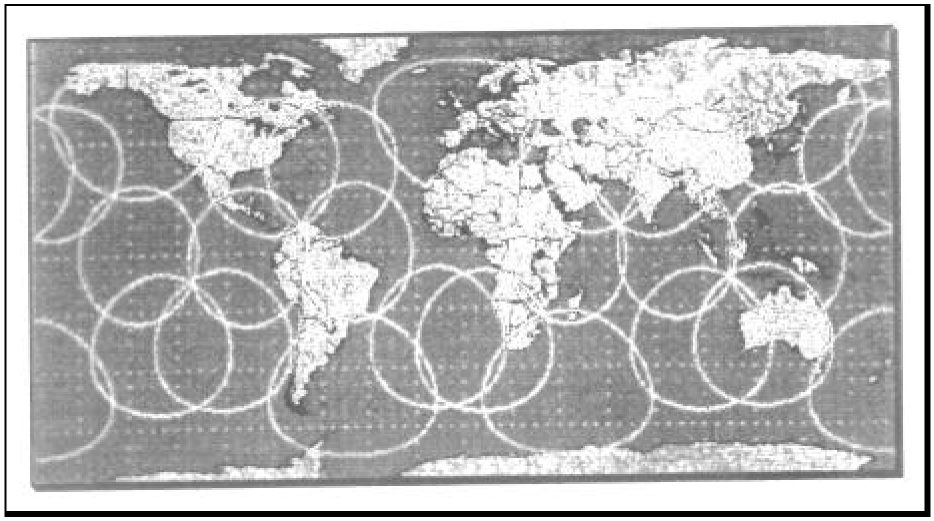

Figure 4-2: ORBCOMM Satellite Coverage

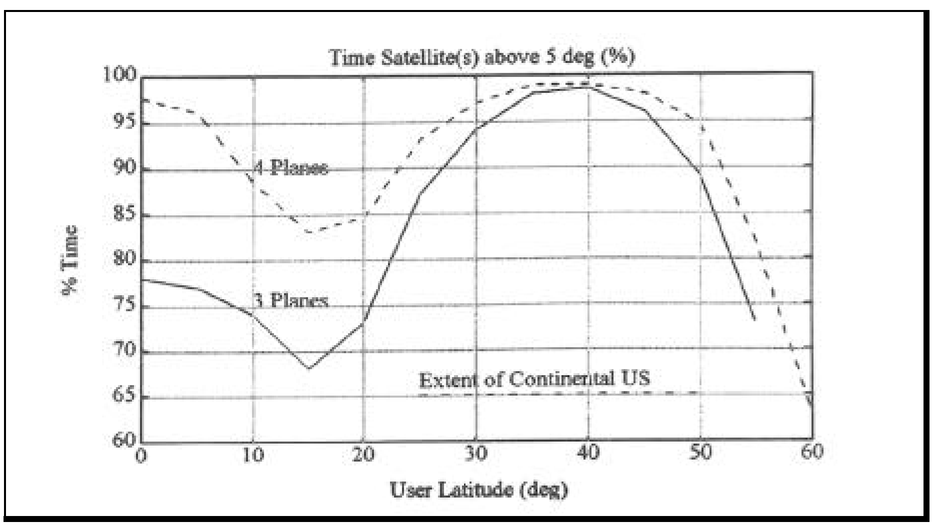

Figure 4-3: ORBCOMM Satellite Percentage of Coverage by Latitude

direct connection to the NCC or by a store and forward operation built into the satellite. These transmission means are discussed further in the sections below.

Also plotted on the graph in Figure 4-3 is the coverage provided by the ORBCOMM constellation. The fourth plane is being considered primarily to increase coverage over the continental U.S. (where most message traffic is expected) to above 95 percent. However, this fourth plane will also materially increase the system coverage over the rest of the world and will increase the amount of time in each satellite pass that a satellite remains in view. This fourth plane will also provide increased coverage in the event of satellite failure.

To understand system operation, it is important to make the distinction between satellite coverage and direct connectivity to the NCC. As previously discussed, connectivity between the subscriber terminal and the NCC is provided through a regional GES. Upon receipt of a subscriber message, the satellite relays the message to a regional GES on a 57.6-kbps dedicated downlink. The regional GES then relays the subscriber message received from the satellite to the NCC over a dedicated ground line. For the system to provide immediate message transfer to the NCC, the satellite in view of the subscriber terminal must, at the same time, be in view of a regional GES. Currently, the regional GESs are located in Arizona, Georgia, New York, and Washington State. Additional regional and international GESs are being considered to supplement the current U.S. and international markets.

The earth coverage of a single satellite (as a function of the elevation angle between the horizon and the satellite's position in the sky) will be a circular area with a diameter as shown in Table 4-3.

Table 4-3: ORBCOMM COVERAGE

Elevation Angle	Coverage Area Diameter	Coverage Time
5 degrees	5566 km	14 minutes
10 degrees	4675 km	12 minutes
15 degrees	3785 km	10 minutes

Assuming a 5-degree minimum elevation angle, a user terminal will have direct connectivity to the NCC when it is located within a circle 5500 km in diameter, centered on a satellite, and when that circle also includes a regional GES.

4.6 ESTIMATED COST

The retail price of the SC with both data and GPS antennas is around $900. The system tested would require additional electronics to connect to the SC and supply the SC with the message and other required mayday information to be transmitted. The communications cost for the air time depends on the application. Current ORBCOMM services range from $15 to $30/month with a 25-cent to 50-cent charge per message. ORBCOMM is currently evaluating the mayday market and tariffs to develop a corresponding price structure.

5. OTHER SYSTEMS NOT TESTED

5.1 IRIDIUM

The system built by Iridium, LLC was not tested for this report since it was not operational during the tests during early 1997. The remainder of this section comes from the earlier base research and information from the Iridium web site in April 1999.

Iridium has developed a satellite-based wireless personal communications network and is funded and operated by an international consortium of telecommunication and industrial companies led by Motorola. The Iridium system is based on a constellation of 72 satellites (66 plus 6 on-orbit back-up satellites) in low earth orbit at an altitude of 760 km. This Iridium system, which has been widely publicized by Motorola as a worldwide "sky-cellular," provides telephone-type transmission (voice, data, fax, paging) to any destination at any time.

The first launch by Boeing at the Space Launch Complex 2 at Vandenberg Air Force Base in Lompoc, California, USA took place on May 5, 1997. It was the initial step toward building the world's largest privately funded satellite constellation. To launch the 72 satellites required (66 plus 6 on-orbit back-up satellites) for the world's first global mobile personal communications network, in addition to Boeing, Motorola's Satellite Communications Group chose China Great Wall, and Khrunichev as launch vehicle providers. These multiple providers ensures continuing access to orbit, thus reducing the risk of delays to the launch program.

Boeing uses Delta II launch vehicles to loft the majority of the satellites comprising Iridium's telecommunications network. The first five Iridium satellites were successfully launched in May 1997. Shortly thereafter Boeing sent up five satellites in each of eight subsequent launches.

China Great Wall Industry Corporation constructed the Long March 2C/SD rocket to deploy two Iridium satellites per launch into orbit. The Long March is a three-stage rocket, developed by China Academy of Launch Vehicle Technology in accordance with the Motorola launch mission requirements for the Iridium system. Khrunichev State Research and Production Center, a state-owned aerospace engineering and manufacturing company in the Russian Federation, provided Iridium satellite launch services using Proton K rockets to launch 21 of the 66 operating satellites comprising the Iridium constellation. This four-stage rocket (a three-stage Proton combined with its Block DM2 Energia-built fourth stage) was used to launch satellites from the Baikonur Cosmodrome in the Republic of Kazakhstan.

The system operates in the L-Band (1616 to 1626.5 MHz) range using quaternary-phase shift keying with frequency division/time division multiple access. It provides full-duplex voice telephone communications services at 2.4 kbps and 2400 baud data service. Subscribers use pocket-size, hand-held (300 mW, omni-patch antenna) telephones. The Iridium telephone works in two modes. As a mobile wireless phone, it seeks out available service from existing land-based networks. In this way it operates the same as wireless systems now in existence: Iridium World Satellite Mode and Intersatellite Links. When wireless service is not available, the Iridium user can switch the phone to satellite operation. The network consists of 66 Iridium satellites, ensuring that one will always be available to receive the transmission. The call is then relayed from satellite to satellite, until it reaches its destination: either through a local Iridium gateway and the public switched telephone network, or directly to a receiving Iridium phone.

Relaying Calls to Ground-Based Networks Iridium satellites also keep track of the users' telephone location anywhere on the globe. A signal bearing the telephone's unique identification number is relayed back to the user's home gateway operator. This provides the data necessary to process customer accounts as well as to interconnect with conventional phone systems. User services cost estimates range from $3 to $10/min.

5.2 INMARSAT

The International Maritime Satellite Organization (INMARSAT) was established in 1979 to provide commercial mobile satellite communications[10] to the world, primarily for shore-to-ship and ship-to-shore markets. INMARSAT is a partnership of 64 countries providing mobile satellite communications. The members fund the organization, oversee its management, and provide the services through their own earth stations. The Directorate in London operates the space segment for the members, coordinates the networks, and develops new services.

Communications Satellite Corporation (COMSAT) is the U.S. member of INMARSAT. COMSAT provides mobile terminal communications to the satellites at L-band. The mobile terminal uplink is 1.6 GHz and the downlink is 1.5 GHz. The central earth stations operate at C-band with the uplink at 4 GHz and the downlink at 6 GHz. The COMSAT earth stations are interfaced to the public network to provide voice, data, facsimile, and telex services. COMSAT earth stations are at Southbury,Connecticut; Santa Paula, California; and Ata, Turkey. The Ata station is trunked to Southbury where all routing takes place. The COMSAT Standard A service provides toll-quality telephone connectivity to the public switched telecommunications network. The service also supports 50-baud telex, which is interconnected to the international telex network to send and receive messages. Services are billed by the minute at a rate of $10/min to commercial customers and about $7/min for government customers. Telex charges are between $3.50 and $4/min.[11] The Standard A terminals use a dish antenna of 0.85 to 1.2 m in diameter and cost from $35,000 to $55,000.

A more promising service from COMSAT is INMARSAT Standard C service, which was brought on line in 1991. The Standard C service is a data-only service with a data rate of 600 bps using a store and forward protocol; the service is designed for short messages or data reports. Terminals can be interfaced with sensors or monitors with an RS-232 format. The service is expected to cost about $0.01/ character[12] transmitted (about 35 cents for a typical message). Standard C terminals are small, weighing approximately 6.8 kg. Antennas are small, cone-shaped, and omni-directional. Terminals are currently being offered by several manufacturers and cost from $6,000 to $12,000, depending on the configuration. INMARSAT coverage is virtually continuous over the ocean areas, because the satellites are geostationary and placed over the oceans.

This system was not tested as part of this project, because COMSAT is licensed to provide the service only over water, not over the continental U.S.

5.3 OMNITRACS

The OmniTracs system was developed and is operated by Qualcomm, Inc. in San Diego, California. The system provides service via domestic Ku-band transponders to the continental U.S. and coastal waters. The moderately sized terminal (1 W, steerable high-gain antenna) provides a rate of 100 bps back to central hub terminals and can receive up to 15 kbps from the hub. Customer communications centers are connected to the hub earth station via terrestrial lines. Qualcomm has optional software that can connect customer computers (e.g., the PSAP) to the hub computers; customers' dispatchers can send and receive messages to and from the mobile terminals using the computer system already in place at their facility. The cost of the software varies according to computer type (e.g., the desktop computer system costs $4000). Message services typically cost $35/month, plus $0.05/message plus an additional $0.002/character.[13]

The mobile terminals (i.e., in-vehicle units) include an antenna unit and an electronics unit. The antenna unit is approximately 29.2 cm in diameter, 17.1 cm in height, and weighs approximately 5 kg. The electronics section contains the acquisition receiver, the modulator, the demodulator, the error correction decoder, and the waveform synthesizer. This unit is 32.4 x 23.5 x 11.4 cm and weighs about 7.26 kg. A mobile terminal is priced at about $4000 without a display.[14] The system presently operates at Ku-band with GTE Spacenets' GSTAR-1 satellite. The GSTAR-1 satellite is geostationary and provides coverage of the continental U.S. and well into the Atlantic and Pacific oceans. An OmniTracs system is also being established on the EUTELSAT satellite over Europe, which could provide additional coverage over ocean areas outside the visibility of the GSTAR-1.

OmniTracs was not tested, because Qualcomm did not express an interest in participating.

5.4 GLOBALSTAR

Globalstar will provide similar services as Iridium and will operate in the L- and S-band frequency range. These proposed systems differ primarily in the detailed technical characteristics of the satellites and the orbits, with the objective of providing the cellular service at a lower capital cost. Also, each proposed system appears to have its own unique user terminal, which would include cellular compatibility. The Globalstar system has been proposed by a consortium of Space Systems/Loral and Qualcomm. In turn, Space Systems/Loral is jointly owned by Loral and Alcatel, Alenia, and Aerospatiale. This system would use a constellation of 48 satellites (optimized for worldwide coverage) at an approximately 1400-km circular orbit.[(15)] Because the system was not yet implemented, at the time of the study, it could not be included in this project's test.

On April 14, 1999, Globalstar launched four LEO satellites into space, bringing the total number of satellites successfully launched to 20. A constellation of 32 satellites is planned for service initiation in the third quarter of 1999. Ultimately, Globalstar will have 52 satellites in space by the end of 1999, including four in-orbit spares.

5.5 TELEDESIC

The Teledesic satellite network will provide global communications through a constellation of 840 LEO (700 km) satellites. The system is backed by Microsoft Chairman Bill Gates and founder of McCaw Cellular Communications, Inc., Craig McCaw. This system will provide high-quality voice-to-broadband channels. The system is planned to be operational by 2002. Because the system is not yet implemented, it could not be included in this project's test.

6. RECOMMENDATIONS AND NEXT STEPS

This section provides a summary and conclusions of the testing of satellite communications systems for mayday applications. Recommendations for the next steps in mayday systems development are also provided.

6.1 SUMMARY AND CONCLUSIONS

The following paragraphs represent findings from this satellite communications study as they apply to a *national* mayday system and to specific efforts ongoing in the mayday field.

- Satellite communications improvements over the next few years are a key element in the future viability of a rural mayday system. Cellular and other terrestrial-based wireless systems will continue to expand in rural areas where the traffic is sufficient to justify the investment. Cellular coverage can never be guaranteed, even after installation, because coverage is primarily a business decision.

- As measured in this study, satellite communications times are short enough to support an improvement in notification times to emergency responders. As low earth orbiting systems attain greater coverage, response times will continue to improve. Improvements in geosynchronous systems will not materially affect notification times, but will impact a vehicle's mayday configuration through the use of smaller, lighter, and cheaper antenna arrays as well as more affordable communications devices.

- Satellite voice and data modes, or a combination of the two, can play a future role in rural mayday systems. The preferred mode of operation will be driven by operational requirements and may change from region to region. Viable satellite systems to support these modes are available and will be even more readily available in the future. Mayday processing architectures are somewhat driven by data/voice considerations. Operational requirements that lead to a data or voice decision should be independent of communications carriers.

- The evolving mayday architecture must be flexible enough to accommodate improvements and changes in the wireless product offerings scheduled for introduction in the 21st century. The wireless industry is one of the most dynamic in the high-technology business sector and no architecture can afford to be dependent on a particular mode of communications. Overall, mayday functionality must look at communications as a transparent subsystem, with no significant difference between satellite and terrestrial systems.

- Satellite communications offerings are a private venture, and it is logical to conclude that services related to this mode of communications will be largely driven by the private sector. It is therefore even more of an imperative to develop a national mayday architecture that encompasses not only the private sector, but the specialized needs of the public safety community as well.

6.2 TECHNICAL RECOMMENDATIONS AND NEXT STEPS

Based on the completion of this study, results from ongoing mayday field operational tests, discussions with the study sponsor, and the current activities of the Multi-Jurisdictional Mayday Committee, the following paragraphs recommend next steps in the national mayday development effort. Wherever U.S. DOT is mentioned, it is assumed that FHWA is the action agency within the Department.

6.2.1 National Mayday Operational Requirements

Action: Develop formal operational requirements for a national mayday system incorporating both public and private participation. The national mayday system should incorporate hazardous material (HAZMAT) incident response requirements as part of a unified approach for all highway and rail users.

Discussion: With all the current activity concerning mayday systems, including this study, it is becoming more and more apparent that there is no agreed upon operational requirement for a *national* system. Whether or not the private sector leads the way in developing mayday capabilities, it is clear that a set of operational requirements are necessary that can be reviewed and agreed upon by the principal stakeholders in such a system. Without such agreed upon requirements, every effort in mayday development, whether standards, vehicle systems development, communications, or public safety community participation, will lack a clear sense of the issues and priorities that need to be addressed. Although one could argue that mayday systems should be left to the private sector, this choice of action ignores the compelling need to ensure interoperability across a wide spectrum of system providers and users.

6.2.2 National Mayday Architecture

Action: Develop a detailed mayday architecture that builds on the National ITS Architecture. The detailed architecture is distinguished from the operational requirements in that it includes a detailed description of the logical relationships between all components in the national mayday system. It would also include auxiliary components that might not appear in the operational requirements. This architecture should be developed with the assistance of (as a minimum) the U.S. DOT, the ITS America Emergency Management Task Force, the Associated Public-Safety Communications Officers (APCO), and the National Emergency Number Association. The architecture should seek to integrate mayday and HAZMAT user services requirements as well as the needs of both the public and private sectors. The national architecture should include requirements for both active mayday signaling and for passive systems that would send a signal without driver intervention.

Discussion: Development of a national mayday architecture is needed to provide additional guidance beyond that available in the National ITS Architecture. In particular, the public safety community does not see enough detail in the overall ITS architecture to provide any real support for system changes. A number of other activities are occurring that affect mayday systems; without architectural guidance, these activities might actually impede the successful deployment of a national mayday system. These include issues involving wireless 911 that are of paramount importance to the public safety community. We do not recommend the imposition of a rigid architecture, but rather an open and adaptable architecture that reflects the realities of public safety operations while leaving room for private sector innovation where appropriate.

6.2.3 National Mayday Standards

Action: Ascertain the development status of in-vehicle ITS data bus standards through the SAE IDB Committee and mayday message standards through the ISO J2313, TC204, and WG4. Mayday message standards are the unifying element between the ITS data bus and the fixed-site processing requirements and must be consistent with the national mayday architecture developed in Section 6.2.2. To this end, a U.S. DOT position on mayday message standards that meets the operational and architectural requirements articulated in Sections 6.2.1 and 6.2.2 should be developed.

Discussion: The in-vehicle data bus standards are being developed by the automotive industry, who will largely be responsible for their implementation. The mayday message standards, on the other hand, have the greatest impact on the public safety community, who will have to make system changes to accommodate these messages. WG4 is largely dormant at this time, which provides the U.S. DOT with an opportunity to exercise greater leadership on this issue. Development of mayday message standards is a key requirement for public safety community acceptance of a national mayday system in any form. It is also worth pointing out that mayday message standards are the unifying element between satellite and terrestrial communications systems.

6.2.4 Wireless Automatic Location Services

Action: The ongoing Federal Communications Commission (FCC) initiative to provide wireless communications location services is of central importance to this study. This effort should be closely watched for the impact on 911 systems nationwide. Specific approaches by the wireless industry should be evaluated for their impact on a national mayday architecture. U.S. DOT should provide inputs to the FCC on any issues affecting a national mayday architecture.

Discussion: The FCC has ruled that wireless service providers must begin implementation of location reporting capability with a gradual phasing in of increasing accuracy. The issue for public safety 911 centers is that this reporting must dovetail with existing landline 911 automatic location systems provided by telephone common carriers. This issue impacts mayday systems because these 911 centers have limited capacity to make changes for every new system being deployed. Satellite service providers may be affected if their service offerings include position determination independent of autonomous GPS.

6.2.5 Public Sector System Processing Requirements

Action: A concerted effort is required to examine the flow of information from the communications subsystem through the initial call answering center to the first responder agencies and the technical approaches to upgrading interagency interoperability. The goal would be to reduce dependence on telephonic notifications for interagency coordination as much as practicable. There is also a need to document the range of capabilities that exist within the public emergency response agencies.

Discussion: This is a key precursor to developing a national mayday architecture and should either be a direct part of that effort or precede formal development of the architecture. This could best be started by looking at the case studies of current mayday field operations tests (FOTs). Another source of information is through the Southern California Priority Corridor where a major effort is underway to define protocol and architectural implementation of interagency communications, particularly focusing on public safety agencies (law enforcement, fire, and emergency medical services [EMS]). The rural EMS agencies need to have a forum to articulate their specific needs and constraints. Automatic notification of incident information in real time is technically feasible and reasonably affordable, even for the smallest providers who have no other computer dispatch equipment.

6.2.6 Comprehensive Evaluation

Action: Coordinate approaches to rural emergency response through a comprehensive, real-world operational test using satellite communications, standard message sets, private and public sector service centers, and varying degrees of automated 911 systems. The events for this test would be synthetically generated, but would, in all other respects, conform to real-world constraints. This test would be unique because it would be designed and operated by the 911 community themselves to test the evolving mayday system architecture.

Discussion: In previous field operational tests, the 911 community's input on test development and objectives has been limited in its scope. On the other hand, this community is not represented by a single unifying entity nationwide that can, on its own, come up with funding and a national mandate to proceed. The APCO and the National Emergency Number Association (NENA) represent different interests within this community and neither can claim to be a single stakeholder spokesperson. The U.S. DOT is in a position to provide funding to sponsor a comprehensive evaluation of emerging technologies and ways that these might be integrated into existing public safety 911 centers. This evaluation should focus on the integration of satellite and terrestrial communications, message standard development and testing, and the processing of the mayday message set within a representative set of operational 911 scenarios, including screening by private call answering centers. Suggested participants include the APCO and NENA organizations, a minimum of one or two state police agencies, at least one county or regional police agency, and several rural fire/EMS agencies. The test venue(s) chosen should include a representative sampling of different multi-jurisdictional arrangements. A HAZMAT carrier and a private answering service should also participate. This would be a multi-state evaluation and would not focus on in-vehicle equipment issues, which are largely within the purview of the automotive industry.

7. APPENDIX A – POSITION TECHNIQUES

The global positioning system (GPS) was developed by the U.S. military to provide highly accurate position, velocity, and time information to its military forces worldwide. It became fully operational in 1993 and uses 24 Navstar satellites. These satellites orbit the earth in a circular 12-h orbit at an altitude of 20,200 km and operate in the 1575.42-MHz L-band. Each GPS satellite transmits its position and the precise time of day. The GPS receiver on the ground receives and processes this information from the satellites to solve for the receiver's position (altitude, longitude, latitude, and time at position). The number of satellites in view at any one time from a given point on the earth will vary from 4 to 11. The accuracy of the position determination depends, in part, on the number of GPS satellites used to determine this information.

Different GPS devices can operate in different modes and have advanced tracking features. Many offer a dead-reckoning mode that allows the system to track its position with only one or two satellites in view. Once the speed and direction of the vehicle have been determined, position can be updated from fewer satellites or from special software and map databases. This feature is useful while a vehicle drives through canyons, between buildings, or in heavy foliage areas that temporarily block some of the satellites. The speed and accuracy at which the device determines its position can vary and are normally directly proportional to each other. Most devices can determine their position in 1 to 2 min after a cold startup with an accuracy error of several kilometers. Over time, the accuracy can increase to within 100 to 200 m. If not for timing errors introduced by the military, the 95-percentile horizontal position accuracy (latitude and longitude) would be 32.5 m. The military interjects random timing errors, called "selective availability," so the 95th-percentile horizontal position accuracy is 100 m. This means that 5 percent of the readings would be off by more than 100 m (or a short city block) from the true position. Differential GPS (DGPS) systems have been developed to compensate for the selective availability errors. These systems make the corrections needed for each satellite and are transmitted from a central base station on the ground. This base station has a precisely known location that is used in combination with the received GPS signals to solve for the errors. The needed timing corrections are then broadcast via radio. Commercial DGPS systems offer greater accuracy than raw GPS, but they have two major drawbacks. A second receiver is needed at the user location, increasing the cost of the equipment; and the DGPS service that maintains the base station and broadcasts the DGPS corrections charges monthly fees for services (except the U.S. Coast Guard), many of which are not offered in most rural areas or in all cities.

8. APPENDIX B – TEST-SITE LOCATIONS

Site 1: TransCore offices, 3500 Parkway Lane, N.W., Norcross, GA 30092. Area is surrounded by trees and has a six-story building to the south of the parking lot.

Site 2: Local Norcross shopping center. Area is highly elevated, with no trees and low buildings to the north.

Site 3: Valley north of Mountain City in northeast Georgia N34°55’49” by W83°25’37”. Area has mountains ranging from 20 to 30 degrees in line-of-sight elevation. Few trees in the line of sight to either of the satellite systems.

Site 4: Hillside north of Mountain City N34°56’39” by W83°25’03”. Area was on the north side of a small mountain, with a ridge line to the west and heavily treed. Test vehicle was on an incline of 20 degrees.

Site 5: Rural roadside along valley road north of Mountain City N34°55’36” by W83°26’32”. Large hill to the south and southwest 15 m from test vehicle. Heavy trees to south and west. Open to valley on north side.

Site 6: Rural roadside along valley road north of Mountain City N34°55’36” by W83°26’32”. On the other side of road from Site 3, against the hill. Vehicle was totally blocked from view to south and west.

Site 7: Rural mountain road north of Mountain City N34°55’48” by W83°24’25”. Area heavily treed with evergreens.

Site 8: Urban roadside Buford Highway in Norcross. Area was open to the east with few trees. Line of sight to following ORBCOMM satellite pass was across traffic and through power lines.

Site 9: Parking lot in urban location. Area was surrounded by two- to six-story buildings.

9. APPENDIX C – COMMUNICATIONS COVERAGE

9.1 TERRESTRIAL-BASED SYSTEMS

The range of terrestrial systems is limited by the line-of-sight (LOS) range from a base station or relay tower to the vehicle. Although the range can extend significantly beyond the radio LOS as the signal frequency is decreased, the antenna size must also be increased to permit effective transmissions. For this reason, cellular telephone and mobile data services employ 800 to 900-MHz frequencies, corresponding to antenna lengths of less than 30.5 cm. At these frequencies, the communications range from a radio tower is a function of tower height, irregularity of terrain features, and proximity of significant noise sources.

The direct and ground-reflected signal components traveling between the tower and vehicle typically provide the dominant signal contributions for LOS propagation. Under ideal conditions (smooth earth), the maximum possible LOS range is plotted versus tower height in Figure 9-1. For link ranges beyond the radio LOS (BLOS), the direct and reflected waves cannot propagate between transmit and receive antennas due to the Earth's curvature, prominent terrain features or buildings, and dense vegetation. Prominent path-interposed ridges that are many wavelengths in height may increase the propagation range, albeit with a significant shadow zone immediately behind these ridges. Urban canyons also serve as sources of diffraction, with the dominant propagation mode consisting of diffraction over the rooftops of adjacent buildings. For BLOS ranges, the received signal level (RSL) can be composed of intermittent diffracted, tropospheric-scattered, ducted, and surface wave modes. These BLOS modes are not relied on for the cellular land-mobile radio service. The net result of the myriad signal sources is the creation of an interference pattern over the earth's surface and

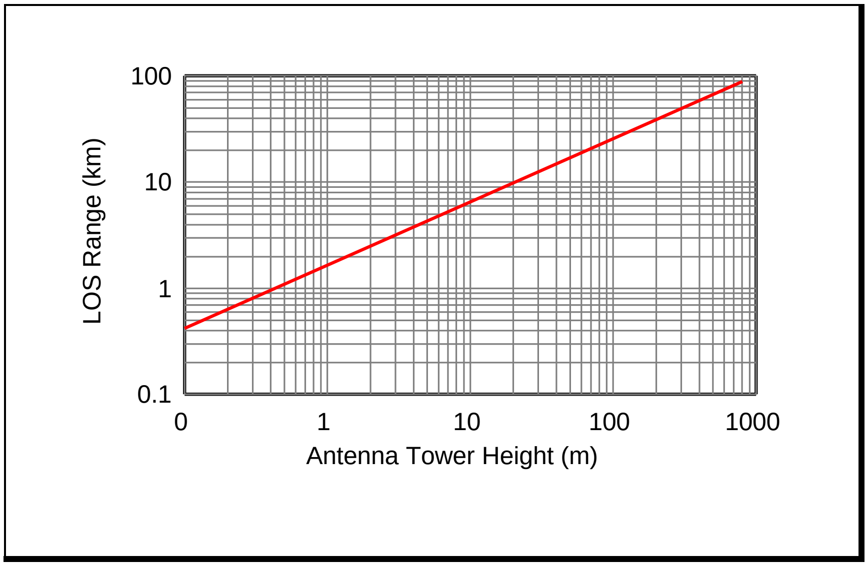

Figure 9-1: LOS Range Versus Tower Height

over and around path-interposed buildings. This pattern may be envisioned as the surface of a rough ocean with wave peaks and troughs corresponding to constructive and destructive interference, respectively. This effect explains the signal fading experienced during mobile telephone use in irregular terrain or at the fringes of the radio LOS from the nearest cellular tower. If a vehicle involved in an incident comes to rest in one of these troughs, then terrestrial communication with the vehicle will be unlikely. This effect may occur even in areas considered by cellular companies to be "covered," much less the vast portions of rural America that are not yet "covered." Although significantly increasing the surface area covered by at least one mobile-radio cell, particularly into rural areas, will greatly improve the performance of a rural "mayday" system, it cannot guarantee coverage at any location and at any time. The uncertainties in the propagation and noise environment guarantee that 100-percent location and time availability are virtually impossible in any practical radio system.

9.2 SATELLITE-BASED COMMUNICATIONS

The use of satellite communications to link the vehicle with the PSAP can eliminate some, but not all, of the coverage "holes" experienced in terrestrial systems. Currently, a number of geosynchronous orbiting (GEO) satellite services[16] are available that provide a "bent pipe" for the amplification and relay of signals between widely spaced points on the earth's surface. GEO satellites eliminate the need for a large number of radio towers to provide terrestrial mobile-radio coverage and otherwise eliminate many nationwide coverage problems. Nevertheless, they can suffer from terrain/building blockage and radio-link power budget limitations. In particular, the geosynchronous orbit of these spacecraft maintains the satellite's position in the sky relative to a fixed point on the earth at a distance of about 29,500 km from the earth's surface. As a result, the highest elevation angles for such GEO satellites are shown in Figure 9-2. Because the continental United States occupies latitudes from 25 to 50 degrees, these elevation angles will vary from as high as 55 degrees to as low as 25 degrees. There are many prominent terrain features and nearby roadways where the elevation angle to the terrain is blocked at angles in this range, particularly in the mountainous regions in the northeastern and northwestern United States. At a minimum, a GEO satellite system will not provide 100-percent coverage in these locations.

The free-space path loss suffered by a radio signal traversing this distance is plotted versus frequency in Figure 9-3. As the exhibit shows, the minimum GEO path-loss values exceed 160 dB at frequencies as low as 100 MHz. The use of simple low-gain omni-directional vehicle antennas at the vehicle, in combination with low transmit power, requires that a large SATCOM dish antenna be employed at the “fixed” end of the satellite link to achieve a usable link data rate. As a result, data from GEO systems must be retrieved from a suitable earth station via leased/dial-up lines and cannot be received directly at the PSAP dispatch point. This data access requirement can further delay emergency notification.

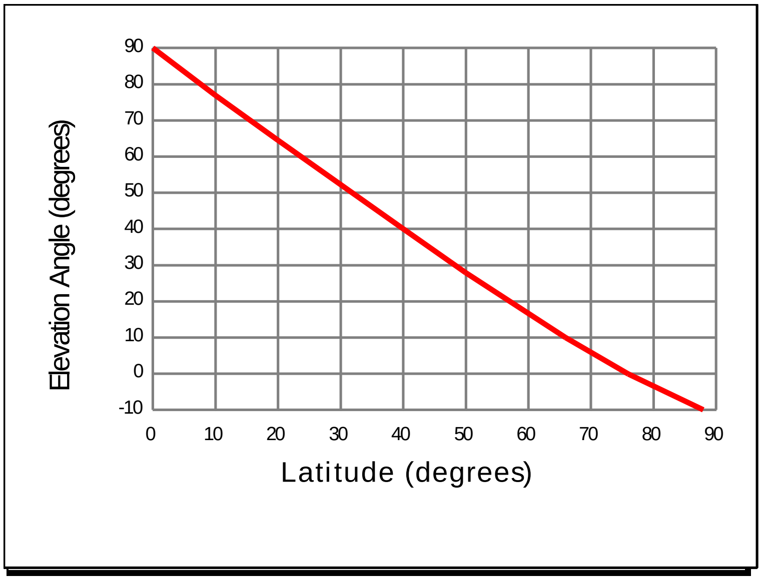

Figure 9-2: GEO Satellite Elevation Angle Assuming Southerly Bearing

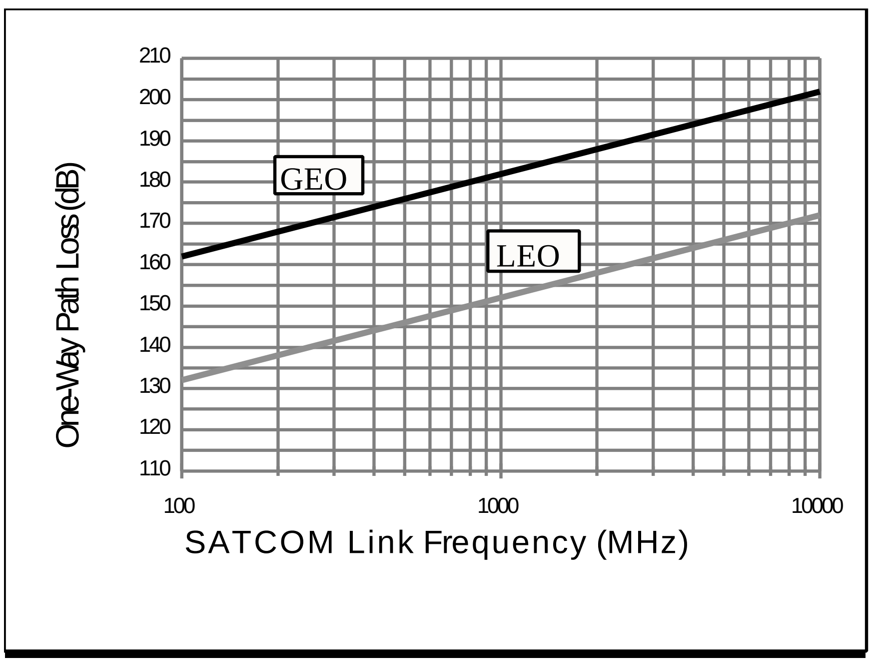

Figure 9-3: Minimum Earth-Space Path-Loss Values

If a low earth orbiting (LEO) satellite is employed at an altitude of 650 km, the resulting free-space path loss has decreased by about 30 dB (factor of 1,000) from the GEO value at the same link frequency. As a result, far less antenna gain and transmit power is needed at the vehicle, or the "fixed" site, to achieve an acceptable data transmission rate. Because the antenna gain requirement is reduced over a GEO system, the vehicle antenna can be made sufficiently small to mount it with the SATCOM electronics in a single ruggedized package. Moreover, the variety of orbits followed by satellites in the constellation will greatly reduce the effects of terrain and building blockage experienced with GEO satellites. At this altitude, however, a single satellite is forced to move well out of radio LOS with the United States for most of its flight in order to remain in orbit. Thus, proposed LEO systems employ a large number of satellites in a "constellation" designed to ensure that one or more satellites are always in view of any point in the U.S. or in the world. The complexities of managing these constellations, combined with the fact that LEO satellites receive and demodulate the incoming signal, require that all LEO-system communications be directed to a small number of designated ground entry points (GEPs). Terrestrial (or other SATCOM) links with these GEPs are then required to retrieve messages from the LEO system. Delays in data access from these sites will directly impact the success of the mayday system, but nevertheless may result in greatly reduced response times from those currently possible in remote rural areas. Both ORBCOMM and Iridium have fully functional constellations in service as of April 1999. These LEO systems will provide the essential communications component for realization of a nationwide mayday system. SATCOM systems are summarized in Table 9-1.

Table 9-1: SATCOM Systems

System	Coverage	Antenna	Frequency	Positioning	In-Service
ARGOS	Global	Whip	UHF	Yes	1999
INMARSAT-C	Global	Bifilar Helix	L-Band	No	1999
OmniTracs	North America	Medium Gain	Ku-Band	Yes	1999
GEOSTAR/LOCSTAR	Regional	Low Gain	L/S-Band	Yes	Defunct
AMSC	North America	Medium Gain	L-Band	No	1999
Iridium	Global	Low Gain	L-Band	Yes	Yes
GlobalStar	Global	Low Gain	L-Band	Yes	1999
CELLSAT	Global	Low Gain	L-Band	Yes	1999
STARSYS	Global	Whip	VHF	Yes	1999
ORBCOMM	Global	Whip	VHF	Yes	Yes

10. APPENDIX D – PATH-LOSS PREDICTIONS

10.1 GROUND-WAVE PREDICTIONS

Although several computer programs have been developed to predict path loss, many were derived from the measurements used by Okumura[17] for cellular-system design, rather than tactical radio-link planning. As a result, these programs typically require that at least one of the two antennas be elevated above ground to a height of several wavelengths. The second antenna is typically associated with a mobile unit and is therefore assumed to be close to the earth's surface (e.g., 3 m). Moreover, these programs often report only median (50^{th} percentile) values of path-loss, with little or no reporting of the distribution of expected path-loss values. Although deterministic for path-loss calculations that could support low antenna-height predictions, these programs require that a detailed terrain profile be input to the program. This terrain data may then be used to create a "model" of the desired propagation path using a variety of canonical shapes, such as knife edges or wedges. The objectives of the current study include only the consideration of "representative" terrain features, because preliminary design decisions must be independent of specific terrain paths and environments.

The only known computer program that purports to predict path loss for low antenna heights, while requiring only generic terrain input data, is the Irregular Terrain Model (ITM)[(.18] This model was developed as an empirical "curve fit" to measured data for a wide variety of terrain, climate, and frequencies ranging from 20 MHz to 20 GHz. It permits the user to model different types of radio service and describe the associated path-loss statistics. For example, the broadcast mode employed in this work allows specification of the percentage of locations (location variability) and time (time availability) for which the predicted path-loss values should not be exceeded. In addition, ITM includes a confidence value reflecting the dependence of path-loss values on the variability expected between different real-life system implementations along given radio paths. Because ITM does not require specific terrain inputs, model predictions should only be viewed as "representative" of like real-life situations and not the "answer" for any specific terrain path. This caveat is particularly important when considering the shadowing effects of close-in path-interposed obstructions such as prominent ridges. In this regard, the ITM model is not designed for urban or suburban path-loss prediction.

10.2 FOLIATED PATH-LOSS PREDICTIONS

Dense foliage along a radio path begins to have a significant effect as the radio wavelength approaches the dimensions of the wood and, if the frequency is sufficiently high, the leaves constituting the forest. In general, the relationship between the anisotropic dielectric constant of wood, the polarization of the incident electric field, the orientation of the wood grain relative to the incident signal, and the relative volume/area of the woody versus leafy portions of a forest complicates estimates of "through-the-woods" (TTW) path-loss prediction.[19] Figure 10-1 is a plot of incremental path loss (including spreading loss) for TTW propagation computed for softwoods and parallel grain orientation (|) for both horizontal (H) and vertical (V) polarization. These results show the empirically verified result that horizontal polarization is less attenuated than vertical polarization below about 500 MHz because the vertically oriented tree trunks dominate the volume absorption and scattering processes. Above 500 MHz, both polarizations are similarly attenuated as the randomly oriented branches and leaves dominate the area absorption and scattering processes. Measurement of path loss through surface vegetation[20] shows somewhat greater attenuation for vertical rather than horizontal polarization at frequencies as high as 10.2 GHz. This result was due to the predominance of the vertically oriented grain characteristic of surface vegetation.

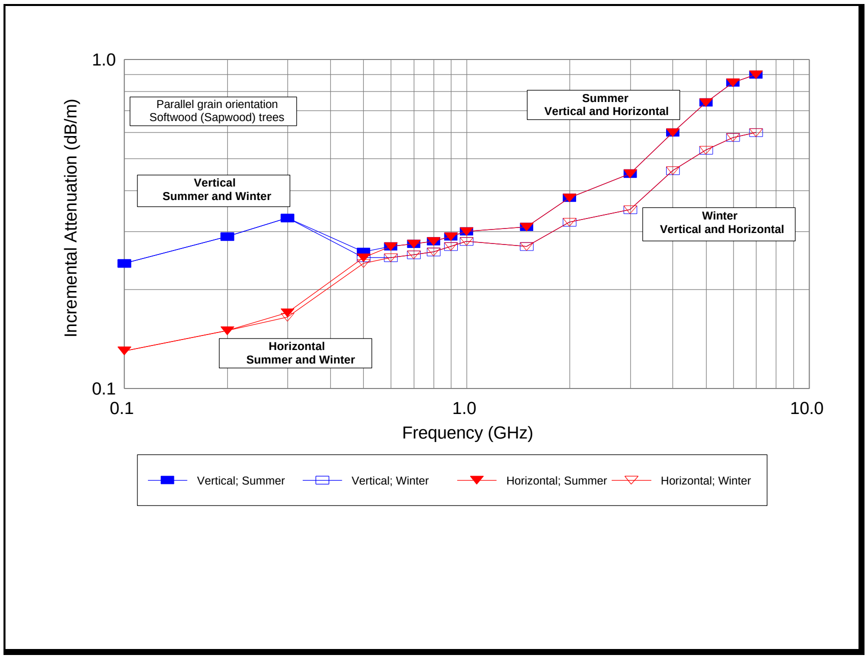

Figure 10-1: Incremental Attenuation Values for Trees

It is evident from inspection of the TTW values shown in Figure 10-2, which agree well with the measurements,[21] that TTW propagation alone would yield excessive attenuation if it were the only propagating mode. In addition to TTW propagation, however, diffraction over the tree tops is also possible. This "up, over, and down" mode occurs for propagation paths that have a low take-off angle to the top of a tree stand. The wave then propagates through the air-foliage boundary at the tops of the trees until descending to the receiver. As a result, the propagation path encounters far less vegetation and the overall path attenuation is significantly reduced.

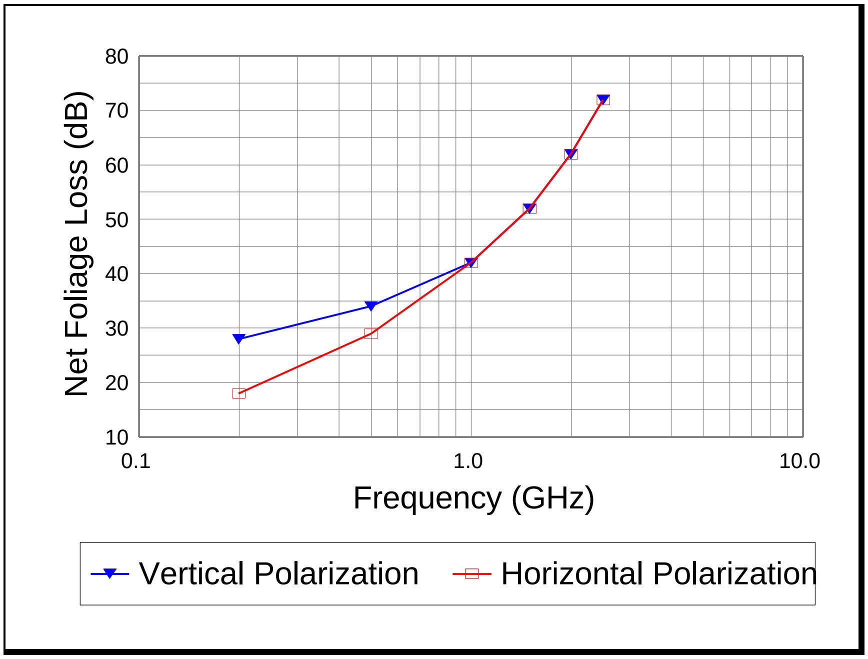

Figure 10-2: Additional Path Loss Due to Rain Forest

An empirical expression for foliage propagation[22] was used to compute path-loss values for a rain forest foliage path. The values plotted below 800 MHz correspond to measurements through the rain forest and include both the effects of TTW and lateral wave propagation, although the TTW contribution to the received signal at these ranges is negligible. The values above 800 MHz have been extrapolated from the empirical data provided in an interview with a satellite communications technical specialist.[9] The foliage path-loss values predicted using this expression (plotted in Figure 10-2) were then added to the ITM-computed values of path loss for hilly terrain. Note that the foliage loss plotted in Figure 10-2 is only a function of frequency. This result was stated in the same interview[9] to be due to the lateral propagation mode, which adds to the frequency attenuation, but not to the distance attenuation. In other words, the lateral wave is attenuated in distance as would be the ground wave without foliage.[23] It was also assumed that the entire path length was foliated, that is, the entire radio link was contained within the woods. Finally, these results were derived from measurements performed in a rain forest in India. Because the lateral wave-path loss increases with foliage conductivity,[24] a drier forest environment should lead to reduced TTW and lateral wave attenuation. Therefore, the path-loss values plotted in Figure 10-2 should be considered as an upper bound for foliage loss values expected in forested terrain, particularly for frequencies at or below 800 MHz. These values produce much less attenuation in forested environments than predicted by the exclusive use of the TTW mode in computing path loss as implied by reference.[25]

10.3 SUBURBAN/URBAN PATH-LOSS PREDICTIONS

The most well-known prediction tool for path loss in urban or suburban areas is Hata's[26] empirical model derived from measurements used by Okumura.[27] Because Okumura's measurements were intended to address path-loss issues for mobile radio in built-up areas, the minimum height for base station antenna towers employed in the measurements was 30 m. The mobile-unit antenna was at a minimum height of 1.0 m. Thus, Hata's empirical model is not valid for the 0.5-m and 1.0-m antenna heights required in this study. In fact, much of the cellular (900-MHz) path-loss prediction work, both empirical and theoretical, has assumed that at least one of the antennas was elevated above the local buildings. More recently, however, the advent of Personal Communications System (PCS) technologies requires the development of urban microcells with base station antennas far below building heights. A recent theoretical model[28] was developed to predict path loss for propagation over buildings for antenna heights above and below buildings. This model consists of three path-loss mechanisms 1/m free-space, diffraction from the rooftop of the last building before the receiver antenna, and diffraction from the transmit antenna over multiple buildings to the last path-interposed building before the receive antenna. This "Unified" model employs an infinite series containing Boersma functions developed in an earlier work[29] with accurate approximations for model results for outlying cases when computer precision limits the accuracy of the results. Typically, the approximations are needed as the elevation angle from the transmit antenna to the first building approaches 90 degrees.

The Unified model predictions for 50-m building face spacing and 15-m building height match closely with the Hata results for both small and large cities. This result is significant because Okumura describes the urban area as consisting of closely spaced three-to five-story buildings. Similarly, the Unified model predictions for a 5-m building height are within about 5 dB of the Hata results for the suburban environment. These results are reasonable assuming about 5 m per story. The 25-m results show a significant increase in loss over the Hata model results for lower building heights (three to five stories).

11. APPENDIX E – ENDNOTES

[1] U.S. Department of Transportation, *National Program Plan for Intelligent Transportation Systems*, Final Draft, November 1994, p. 4.

[2] IVHS America, *Intelligent Vehicle-Highway Systems in the United States*, Report IVHS-AMER-92-3, Washington, DC, pp. 1-4.

[3] W.B. Garner, "Description of the AMSC Mobile Satellite System," Proc. *AIAA 13th International Communications Satellite Systems Conference,* March 1990, pp. 771-776.

[4] C. Kittiver, "Design of the American Mobile Satellite System," *Proceedings of the Workshop on Advanced Concepts for Mobile, Micro, and Personal Communications,* Jet Propulsion Laboratory, May 1991, p. 23.

[5] American Mobile Satellite Corporation marketing sheets provided by Dr. Charles W. Carpenter of AMSC.

[6] *AMSC MMS Mobile Earth Terminal Installation and Maintenance Guide*, 1996.

[7] ORBCOMM web site www.orbcomm.net.

[8] ORBCOMM marketing sheets.

[9] For purposes of this discussion, coverage is defined as the percentage of time that a particular point on earth will be in view of a satellite.

[10] INMARSAT is essentially the mobile counterpart of INTELSAT, which provides worldwide point-to-point satellite communications via large fixed stations.

[11] W.C. Melvin, "Communications Satellite (COMSAT) Corporation COMSAT Mobile Communications (CMC) Division Land Mobile Satellite Services (LMSS)," from the *Proceedings of the American Defense Preparedness Association Space Symposium*, Fort Monmouth, NJ, April 14-16, 1992, p. 43.

[12] Supra., p. 44.

[13] W.J. Ciesluk, L. Klein, P.A. Oliver, W.E. Schoonveld, "UHF Satellite Communication Enhancements and the Role of Commercial Mobile Satellites in Military Communications," from the *Proceedings of the American Defense Preparedness Association Space Symposium*, Fort Monmouth, NJ, April 14-16, 1992, p. 41.

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[17] Y. Okumura, E. Ohmori, T. Kawano, and K. Fukuda, "Field Strength and Its Variability in VHF and UHF Land-Mobile Radio Service," *Rev. Elec. Commun. Lab*., Vol. 16, 1968, pp. 825-873.

[18] G.A. Hufford, A.G. Longley, and W.A. Kissick, "A Guide to the Use of the ITS Irregular Terrain Model in the Area Prediction Mode," *NTIA* Report 82-100, April 1982.

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[20] F.T. Ulaby, A. Tavakoli, and T.B.A. Senior, "Microwave Propagation Constant for a Vegetation Canopy With Vertical Stalks," *IEEE Transactions on Geoscience and Remote Sensing*, Vol. GE-25, No. 6, November 1987.

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[22] R.K. Tewari, S. Swarpup, and M.N. Roy, “Radio Wave Propagation Through Rain Forests of India,” *IEEE Trans. Ant. Prop*., Vol. 38, No. 4, April 1990.

[23] *Ibid.*, p. 444.

[24] T. Tamir, “On Radio-Wave Propagation in Forest Environments,” *IEEE Trans. Ant. Prop*., Vol. Ap-15, No. 6, November 1967, p. 809.

[25] R. Yuan, et al. *Ibid*., pp. 2-5.

[26] M. Hata, “Empirical Formula for Propagation Loss in Land Mobile Radio Services,” *IEEE Trans. on Veh. Tech*., Vol VT-29, No. 3, August 1980, pp. 317-325.

[27] Y. Okumura, *Ibid.*

[28] L.R. Maciel, H.L. Bertoni, and X.H. Howard, “Unified Approach to Prediction Over Buildings for All Ranges of Base Station Antenna Height,” *IEEE Trans. on Veh. Tech*., Vol. 42, No. 1, February 1993.

[29] X.H. Howard and H.L. Bertoni, “Diffraction of Cylindrical and Plane Waves by an Array of Absorbing Half-Screens,” *IEEE Trans. on Veh. Tech*., Vol. 40, No. 2, February 1992.