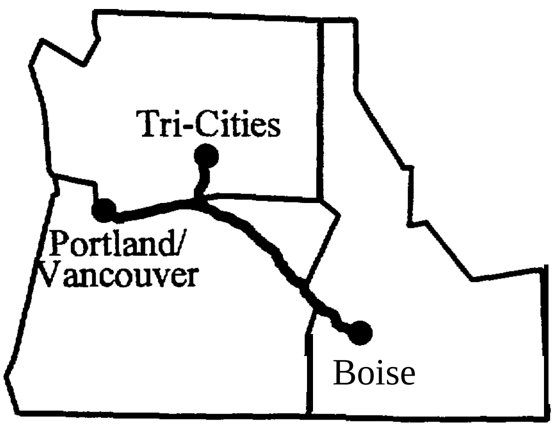
ITS Communications Assessment
Technical Memorandum
January 1997

Portland/Vancouver to Boise ITS Corridor Study



Prepared for:
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In Cooperation with:
Federal Highway Administration

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84ITS130 WPD

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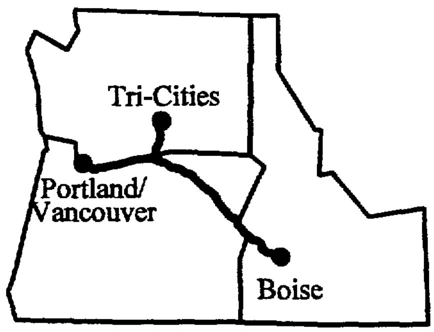
1.0 PROJECT OVERVIEW

Intelligent Transportation Systems (ITS) (formerly Intelligent Vehicle Highway Systems [IVHS]) is the application of advanced information processing, communications, vehicle sensing, and traffic control technologies to surface transportation systems. All highway and transit modes, as well as airport access, navigable waterway, and rail, can be included in ITS applications. The objective of ITS is to promote more efficient use of the existing highway and transportation network, increase safety and mobility, and decrease environmental impacts due to congestion.

The Portland/Vancouver, Washington to Boise, Idaho ITS Corridor Study consists of conducting an Intelligent Transportation System corridor study and developing recommendations for deployment of ITS and appropriate communications technologies along a multi-state, intercity corridor. The corridor limits are defined as follows:

- Interstate 84 from I-205 in Oregon to a point 20 kilometers east of Boise, a distance of 706 kilometers (439 miles).
- Interstate 82 from I-84 in Oregon to I- 182 in Tri-Cities, Washington, a distance of 66 kilometers (41 miles).
- State Route 14 from I-205 in Washington to I-82 in Washington, a distance of 282 kilometers (175 miles).
- Union Pacific and Burlington Northern Santa Fe Railroads
- Columbia River Waterway



As mentioned, a primary purpose of this project is to develop recommendations for the implementation of appropriate ITS technology to address corridor transportation needs over the next 20 years. The study focuses on specific applications of Advanced Traffic Management Systems, Advanced Traveler Information Systems, Commercial Vehicle Operations, and Advanced Rural Transportation Systems technologies, with an emphasis on providing implementation guidelines that will facilitate the integration and expansion of future ITS components within the corridor.

The planning effort also investigates ways to provide traveler information for various modes. The information, including, but not limited to, current roadway congestion, weather conditions, incident information, and construction information, will be used by travelers to make informed choices regarding mode, route, and time of departure.

The study also investigates the surveillance and communications requirements of traffic management systems and traveler information dissemination. These requirements include incident detection, demand management techniques in urban areas of the corridor, and traffic flow monitoring.

A final purpose is to develop communication recommendations that take into account Idaho Transportation Department (ITD), Oregon Department of Transportation (ODOT), and Washington State Department of Transportation (WSDOT) communication requirements in the corridor. Communication requirements across state borders will receive particular attention.

The ITS implementation and communication plan will be developed for the following time frames:

- Short Term: The first period will encompass the interval from 1997 to 2002. The focus will be on the development of a detailed tactical plan that identifies specific projects and programs to be implemented.

- Medium Term: The second period will include 2003 to 2007. For this time frame, the study will address emerging trends and issues and will recommend steps that ITD, ODOT, and WSDOT should take to prepare for anticipated changes in the transportation operational environment.

- Long Term: The final period will be from 2008 to 2017. The plan will recommend a strategic approach to addressing long-term concerns.

The study is divided into seven major work elements:

Work Element 1 – Assess Transportation Needs

This element generally consists of gathering data on transportation and traveller information needs and deficiencies in the corridor and identifying the magnitude of the problems.

Work Element 2 - Identify Corridor ITS Applications

Work Element 2 involves using the US DOT's user services categories to identify which ITS applications have the potential to address corridor needs.

Work Element 3 - Recommend ITS Strategies

This work element will identify ITS strategies that have a clear potential to meet corridor needs. Items associated with individual strategies such as benefits, costs, implementation barriers, technology requirements, and funding will be addressed.

Work Element 4 - Develop Corridor Plan

This element will identify specific projects and programs to be implemented. Short term projects will be developed in sufficient detail to allow them to be included in DOT and other funding and construction programs in the three states.

Work Element 5 - Assess ITS Communications Needs

Work Element 5 will identify the communication characteristics of various ITS field components and make recommendations for a communication system.

Work Element 6 - Conduct Outreach Effort

This work element contains the projects public involvement and outreach program, including stakeholder interviews, general media releases, targeted media kits, workshops, and stakeholder presentations.

Work Element 7 - Prepare Final Report

Work Element 7 will consolidate the results of previous work into a final action plan.

Technical Memorandums will be prepared for each work element, except the outreach effort. Recommendations of the public outreach will be incorporated into the other technical memorandums.

2.0 APPROACH TO WORk ELEMENT 5

This Technical Memorandum, covers the Assessment of Intelligent Transportation System (ITS) Communications Needs and Recommendations associated with the Portland/Vancouver to Boise ITS Corridor. This report is provided in compliance with Work Element #5, "Assess ITS Communications Needs and Provide Recommendations". It is built on information collected, analysis conducted, consensus derived and associated reports from other Work Elements including:

Work Element # 1: "Assessment of Corridor Transportation Needs as Documented in Technical Memorandum Number 1"

Work Element #2: "Identification of Corridor ITS Applications Which Meets Corridor Needs, as Documented in Technical Memorandum Number 2"

Work Element #3 : "Recommended Corridor ITS Strategies as Documented in Technical Memorandum Number 3"

This document translates the ITS Strategies Recommendations Communications needs into a communications architecture and recommended communications technology standards with phasing in accordance with corridor ITS Strategies.

2.1 Scope

This Technical Memorandum analyzes the communications needs for the corridor by considering ITS field device deployment requirements to meet ITS service requirements and the associated data rates and geographic deployment locations associated with the field devices as defined in Work Element #3, Recommended Corridor ITS Strategies. Communications requirements from operating center-to-field devices, operating center-to-operating center as well as from operating center-to-supporting agencies are included. Information source and destination routing is established with data rates, type of data (digital or multimedia), responsiveness and time resolution requirements defined.

A high level review of state-of-the-art in communications is included for Local Area Networks (LAN), Metropolitan Area Networks (MAN) and Wide Area Networks (WAN). Vehicle-to-infrastructure wireless communications technology is included as well as wireless technology which supports LAN, MAN, and WAN deployment. A projection of communication technology options for the mid- and long-term phases of the project are included.

Where information exists on existing communications infrastructure, it will be considered in a final recommendation of communications architecture. Where new communications infrastructure is recommended, it will be identified.

Federal Highway Administration (FHWA) has developed a National Architecture which will be considered. This architecture is in a standards process. It is believed that the standards process will result in a highly flexible architecture built around National and International communications standards which are independent of application (such as ITS), but support interoperability through use of standard communications devices such as bridges, routers, switches with brouters and Nationally recognized network management standards. The standards process will most likely focus on applications layer message structures and substructure standards for ITS which allow any ITS information received from any source to be identified and processed.

Modem communications technology is highly flexible supporting "virtual" applications standards to be implemented over very wide areas. The World Wide Web of the Internet is an example of the capability of modem communications. Information can be sent many miles over a variety of network standards and equipment and responsively reach its destination. Highly rigid architectures are becoming part of the past era of communications with highly flexible architecture becoming the standard for the future.

After requirements have been converted into information exchange parameters, technology and architecture have been reviewed, consideration has been made for use of existing communications infrastructure, the recommended network configuration(s) will be provided with reasons for selection. Approach to evolving the network to meet mid- and long-term projected requirements are discussed.

This being a planning document, no detailed design is included. Any cost information is considered to be budgetary for pianning and representative of typical acquisition, installation, tests, and operational cost. Unique problems impacting installation cost, other than general terrain, are not included in budgetary cost estimates.

The last section provides a summary of findings and recommendations related to communications.

Communications technology included in this study is derived from Kimley-Horn and Associates, Inc.'s NCHRP-3-51 Research Program entitled "Communications Mediums for Signal, ITS and Freeway Surveillance Systems", with the final report dated June, 1996. It represents two years of research on advanced communications technology applicable to ITS as funded by the National Research Council, Transportation Research Board. It is further based on Kimley-Horn and Associates, Inc.'s National design and deployment management experience with ITS Traffic Signal, Freeway, Transit Operations, Toll Operations, and CVO automated inspections stations.

2.2 Communications Terms and Categorization as Applied to Metropolitan and Rural Intelligent Transportation System Needs

Three terms are utilized in this Technical Memorandum:

- Local Area Network (LAN) refers to a local network, typically within the Freeway or Traffic Operations Center which provides high speed, flexible communications between equipment such as servers, workstations, and external communications adapters such as bridge/routers.
- Metropolitan Area Network (MAN) refers to a communications network which integrates distributed computer and communications equipment located at various geographic

locations within a metropolitan area. Typically considered to be a 50-mile radius of the center of a metropolitan area.

- Wide Area Network (WAN) refers to a communications network which integrates widely separated computers and communications equipment such as metropolitan area-to-metropolitan area. The term is applicable to statewide, National and International communications.

Typical LANs include ETHERNET and TOKEN RING. ETHERNETs, per specification, have a limited operating distance due to timing constraints. TOKEN RINGS can be extended into MANs. A fiber optic version of TOKEN RING referred to as Fiber Data Distribution Interface (FDDI or "Fiddie") is a commonly used MAN. In fact' FDDI is commonly utilized for both LANs and MANs. FDDI has both a terminal and distance limitation with maximum distance limited to 100 Km with 500 terminals.

WAN technology commonly utilized includes:

- Synchronous Optical Network (SONET)
- Satellite Communications
- Leased Services from Long Distance Service Providers including:
  - Integrated Services Digital Network (ISDN)
  - Frame Relay Service
- Internet/World Wide Web

The term network is utilized to describe an integration of a number of devices which send and receive information over a common medium. Each has a unique address and protocol associated with the network or network routing plan as defined by a network manager. Usually a network includes optional routing paths. Network technology applies to LAN, MAN, and WAN applications and is applicable to all physical layer mediums including wire, fiber and wireless. The term "Packet Network Radio" also called "Packet Radio", includes a routing protocol facilitating transfer of information over various link segments from sender to receiver. Thus a "network" is characterized by flexibility, reliability, and modular expandability.

The term "link" or "circuit" has classically been utilized to define a fixed path communication, either point-to-point or master station to supported slave stations. The classical interconnect of traffic signal controllers to a master which polls and manages communications with slave devices (i.e. field traffic controllers such as NEMA TS-1, NEMA TS-2, 170 or 179 types) is an example of a "link". The master plus all assigned slaves form the "link" or "circuit".

Links can also be associated with wireless communications. A Supervisory Control and Data Acquisition (SCADA) communications subsystem may utilize a master station to poll and collect data from field slave stations. Microwave stations are called "links" because one is directly linked to another in a "send-receive" sense. The radio frequency (RF) microwave link is point-to-point; however, when taken in total context, the multiple microwave transceiver sites may form a network with the addition of network electronics. For example, SONET microwave can seamlessly support the extension of an optical SONET network.

Transceiver is a term utilized in wireline, optical, and wireless communications equipment. The term implies that the device includes both transmitting and receiving circuitry. There can be an Optical Transceiver (OTR), Microwave Transceiver (MWTR), Radio Transceiver (RTR), and wireline modem transceiver. Typically a communications path is from transmitter-to-receiver. This path, when implemented alone is called "simplex". If communications devices on both ends of the "path" have transceivers, then duplex communications can occur (send and receive simultaneously). However, there may be reasons that simultaneous sending and receiving cannot occur simultaneously. Thus "half duplex" communications results (i.e. transmit in one direction, then reverse directions). Reasons for using half duplex communications includes:

- Master polling on the network with only a single response allowed to prevent interferences.
- A common medium or frequency is utilized not allowing bidirectional, simultaneous communications. A radio where the transmitter and receiver are both on the same frequency is an example.

Protocol is the standard supporting network and link operations. It defines the "rules" for communications. To communicate, both the transmitting station and receiving station must operate with a common protocol. With today's technology it is possible to implement multiple protocol links and networks. Adaptive techniques are utilized to "automatically" find a common communications language. This is similar to adaptive wireline modems which determine the appropriate data rate for reliable communications on a link. Obviously, adaptive technology is more expensive than fixed protocol communications devices. Typically, National standards define basic protocol; applications layer protocol is usually application specific, with the National Traffic Control ITS Protocol (NTCIP) emerging as the National Standard for Communications with field controllers associated with ITS applications including signal control, incident detection, ramp metering, variable message sign and closed circuit TV (CCTV) control. NTCIP protocol development plans include the addition of remote weather station protocol.

The term bits per second (bps) is utilized to define data rate. The term baud rate is similar to bit rate, but includes a consideration of modulation. For planning purposes they can be considered to be the same. Modulation is a term utilized to define how information is converted to a signal "understood" by the transmitter and receiver associated modulator and demodulators. Some common modulations include Frequency Shift Keying (FSK), Phase Shift Keying (PSK), Differential Phase Shift Keying (DPSK), Phase Amplitude Modulation (PAM), and Pulse Frequency Modulation (PFM). Modulations relate to bandwidth utilization efficiency or bits per Hertz (Hz) of bandwidth. Modulations also relate to communications reliability in the presence of noise. For a given modulation, bit error rate is related to signal-to-noise (S/N) ratio. Some modulations are much more susceptible to noise and are thus more applicable in a low noise medium such as fiber optic communications. Typically an "effective" S/N of 13 to 15 dB is required to achieve an acceptable bit error rate. (The term "effective" relates to actual received signal level plus processing gain versus noise where processing gain is achieved by use of some of the advanced modulation technologies.)

Modulation is thus the process of converting information, such as a digital bit, to a signal to be transmitted over the medium (wire, fiber or air) to a receiver. The demodulator takes the modulated signal and converts it back to its original form (i.e. a digital bit in the example).

Compression is a term utilized to decrease the volume of information to be transferred without loosing the basic content or representation of the information. Data, voice, video, and facsimile (FAX) may be compressed. The compression device is typically called a codec transmitter; the decompression device is typically called a codec receiver. Information is compressed to conserve bandwidth of a communications link or network and to conserve information storage. Information is decompressed for presentation (visual or audio) and for further processing. Video is typically a prime candidate for compression and decompression since one uncompressed frame of standard Closed Circuit Television (CCTV) video will contain over 1.31 million digital bits and there are 30 frames per second or approximately 40 million bits per second.

Within communications there are several technologies which extend distances. For wireline, line amplifiers are utilized. For optical, typically repeaters are utilized; however, optical amplifiers are available. For wireless, repeaters are utilized. Repeaters receive a signal and retransmit the signal with a small delay. For optical, the repeating delay may be on the order of one microsecond; a slightly longer delay may be encountered in wireless repeaters. The advantage of a repeater is that it launches the signal at its original transmission power. Thus, if repeaters are placed at points where S/N is high, no deterioration of the signal occurs. For amplifiers, noise as well as signal are amplified. Thus it is important to manage use of amplifiers at points along the communications path where noise does not degrade performance.

Like a line amplifier, loss of a repeater will break the link unless an alternate path is provided. For this reason, repeaters are typically configured in fault tolerant network configurations (rings or branch links double interconnected into the main communications network backbone).

One major difference in wireline and optical or RF links are that loss of a wireline modem generally will only impact communications with the attached controller. Loss of an optical transceiver or RF repeater can cause loss of communications with ail down-link devices unless some form of fault tolerance is provided in the design.

2.2.1 Open Systems Interconnection (OSI) Standards

The Open Systems Interconnection (OSI) has developed a standard for layers of communications which have been converted to International Standards Organization (ISO). **Table 2.2.1-1** summarizes the seven communications layers. The physical layer, Layer 1, is the electrical, optical or RF interface. Layers 2 and 3 are the data link and network layers. To transition from a link to a network, Layer 3 protocol is required. Routers are devices which utilize a standard protocol at Layer 3, such as Internet Protocol and provide information routing utilizing the IP address.

Table 2.2.1-1
International Standards Organization
Open Systems Interface Model

Layer Number	Name	Functions Provided	Typical Protocols
7	Application	Application specific	ITS
6	Presentation	Data formatting, encryption and description	DES
5	Session	Negotiation and establishment of sessions	Courier, Netbios
4	Transport	Provisions for end-to-end reliable delivery	TCP, SPP
3	Network	Routing of information across multiple network segments	IP, IPX, IDP, Routers
2	Data Link	Transfer of units of information, framing, and error checking	IEEE 802.3, 802.4, 802.5, Bridges
1	Physical	Transmission of data over a communications medium	EIA 232, 422, 485, Wiring

For communications to effectively occur, compatibility at all layers are required or else a transition must occur. Bridges can provide transition to the data link level; routers service the network layer.

Within communications standards there are many substandards that impact interoperability at various OS1 layers. For this reason it is highly risky to specify communications at its top level specification. All subspecifications which provide the exact configuration desired must be specified. Otherwise incompatibility will exist which may impact communications. For instance, the Institute for Electrical and Electronic Engineers (IEEE) and joint American National Standards Institute (ANSI) standards for ETHERNET as defined by IEEE/ANSI 802.3 have subspecifications from 802.3a to 802.3u, all defining variations impacting physical and link levels.

2.2.2 Network Management

Network management is perhaps the most important element of a modem communications system. As its name implies, it supports management of the network. Other very important functions such as supported by Simple Network Management Protocol (SNMP) include:

- Using Management Information Base (MIB) supports automatic network configuration
- Using MIB messages as part of network management protocol provides real-time monitoring of network performance and failures.

- Using a standard network management software package such as OpenView TM, provides a graphical presentation of the network configuration, performance, and operational status.

A major feature of network management, such as SNMP is the ability of most standard communications devices to achieve interoperable compatibility through exchanging information on how each device is configured and how it communicates. Without network management, a large distributed system would be very difficult to maintain.

Common Management Interface Protocol (CMIP) which-is a subset of Common Management Information System Element (CMISE) standard is emerging in the SONET and Personal Communications Service (PCS) in support of network management or Operations Service System (OSS). OpenView TM network management software supports both SNMP and CMIP.

2.2.2.1. Remote Monitoring (RMON)

RMON is a MIB extension to SNMP that defines variables for managing and monitoring remote traffic. There are nine (9) groups of RMON MIBs which set the guidelines for how RMON agents monitor network traffic and how they forward information to a network management console. These most common groups supported by industry include statistics, history, alarm, host reporting and TOPN (reports on most active talkers on the network). RMON is very beneficial in complex networks where switching hubs are deployed. RMON extends the insight into network performance problem identification provided by SNMP and/or CMIP. RMON extends the network management capability by integrating remote network management devices (called probes) and providing a common MIB language for monitoring and remote management control.

2.2.3 Fault Tolerance

Fault tolerance is another technology which is being deployed in modem ITS systems. Life cycle cost savings of fault capability, especially with distributed systems, validates the increased initial cost. The ability to repair failures on a planned maintenance basis conserves maintenance staff and travel costs. Combined with automated built-in test and test reporting through network management functions, time to detect and isolate a failure is significantly reduced.

There are several types of fault tolerance. One involves network architecture where multiple communications paths are available. A classic configuration is a ring network with counter rotating or path switched capability. A broken fiber does not inhibit communications. Interworking rings and other configurations such as “STAR” interconnects support sustaining more than a single fiber (or communications path) break (or interruption).

Generally a ring topology provides adequate network reliability at a much lower cost than a STAR topology. Interworking rings generally are lower cost than STAR networks and can sustain multiple failures. Medium diversity (such as optical for one path and microwave for another path in a ring topology) can provide improved reliability of a network. Usually the cost of two mediums (fiber and microwave) are prohibitive unless there is an existing usable microwave tower structure.

The second type of fault tolerance is where electronics have hot standby modules. A module failure results in automatic switch over to the backup module. This is commonly called M+N redundancy where "M" is the number of common operational modules and "N" are the hot standby modules. M+ 1 fault tolerance is common for, quality communications equipment and results in very high availability communications networks.

There are few commercial standards for fault tolerance. Bellcore requirements such as GR-929-CORE, entitled, "Reliability and Quality Measurements for Telecommunications Systems" as well as TR-NWT-000332 entitled, "Reliability Prediction Procedures for Electronic Equipment" form a baseline for high availability communications network design. Availability requirements of 99.98% with Mean Time Between Failure (MTBF) of 90,000 hours are typical of quality telecommunications equipment.

It is important that reliability and maintainability be planned into a communications system. It does not happen without planning and appropriate specifications and validations.

2.2.4 Categorization of Communications Requirements

To better compare requirements with communications options, requirements will be categorized as:

Rural

- Infrastructure-to-field infrastructure
- Infrastructure-to-operating center infrastructure
- Infrastructure-to-vehicle

Metropolitan

- Infrastructure-to-field infrastructure
- Infrastructure-to-operating center infrastructure
- Operating center-to-operating center
- Infrastructure-to-vehicle

Infrastructure-to-field infrastructure includes communications from field controllers to node buildings along freeways. Infrastructure-to-operating center infrastructure includes field nodes to Traffic Operations Center as well as other agencies to operations center communications. Infrastructure-to-vehicle communications includes all communications required to/from the vehicle with the Intelligent Transportation System (ITS) infrastructure. Infrastructure Operations Center-to-Infrastructure Operations Center includes all required communications to support interoperability between District-to-District and State-to-State Operations Centers.

Infrastructure-to-infrastructure implies no motion. Infrastructure-to-vehicle implies a form of wireless communications. Field infrastructure is differentiated from operating center infrastructure since field equipment must generally be environmentalized, complying with specifications similar to those associated with NEMA TS-2 field controllers. Bellcore equivalent specifications exist for outdoor equipment. Operating center equipment generally must comply with office environment standards or for the telecommunications industry Bellcore-specifications related to Central Office Terminal Equipment. Environmental specifications as defined by Bellcore (such as SR-3 166, "Requirements for Environmental Stressing Applied to Telecommunications Equipment" assure that equipment performs reliably within the environment for which it was designed to operate.

Infrastructure-to-vehicle communications is further classified as short range and long range. Long range covers many vehicles over a wide area and short range covers one or a few vehicles (depending on communications technology utilized) at or near a specific geographic location. Examples of long range communication from infrastructure-to-vehicle include mobile radio, satellite and radio data service; examples of short range communications includes toll tags and heavy equipment license tags (electronic). Sign post navigation system update links and traffic signal emergency preempt links.

3.0 COMMUNICATIONS REQUIREMENTS AND EXISTING/PLANNED INFRASTRUCTURE

3.1 Communications Requirements

3.1.1 ITS Field Sensors and Electronic Signs

Based on earlier tasks, including ITS needs assessment and ITS deployment strategy, ITS field device deployment requirements are illustrated in **Figure 3.1.1-1** for the I-84 Corridor from Portland to Hermiston. The remaining segment of I-84 from east of Hermiston to Boise is shown in **Figure 3.1.1-2.**

There are four (4) ITS operations centers which are or will be primarily responsible for the rural ITS sensors and electronic messaging to travelers. These include the ODOT Traffic Operation Center (TOC) in Portland, the ITD TOC in Boise, and the Washington State DOT District TOCs in Vancouver and Yakima. The capabilities and status of these centers vary. These centers should be upgraded to accommodate management and control capability of the infrastructure segments indicated in **Figures 3.1.1-1** and 3.1.1-2. The communications requirements include interoperability between these centers to share corridor segment status associated with traveler advisory information and to coordinate any required joint support for incidents. A major objective for TOC interoperability communications is to assure that correct information is being distributed to travelers who may utilize several segments of the corridor(s), each managed by different TOCs.

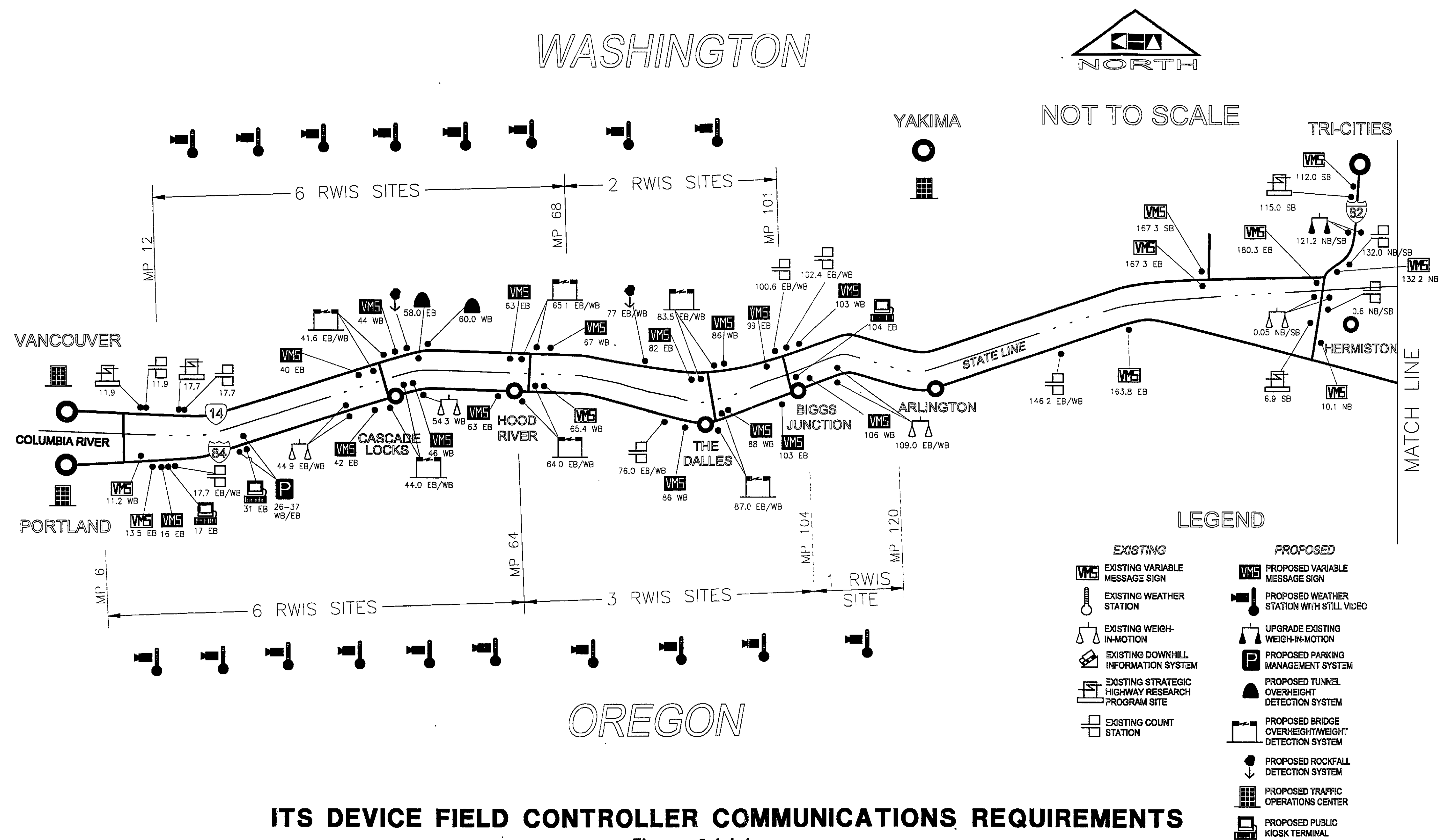
Table 3.1.1-1 summarizes the requirements for field sensors and electronic messaging to travelers, with associated TOC responsibility. **Table 3.1.1-2** includes two (2) categories of communications: real-time and periodic. These terms define communications requirements between the field device/controller and the TOC as follows:

Real-Time:

- Need to provide near continuous information
- Need to communicate at a specific time as defined by an event such as sensor activation
- Information resolution is seconds or 10s of seconds

Periodic:

- Time is not critical
- Information is gathered and distributed periodically
- Periodic timing is minutes, 10S of minutes or greater



ITS DEVICE FIELD CONTROLLER COMMUNICATIONS REQUIREMENTS

Figure **3.1.1-1**

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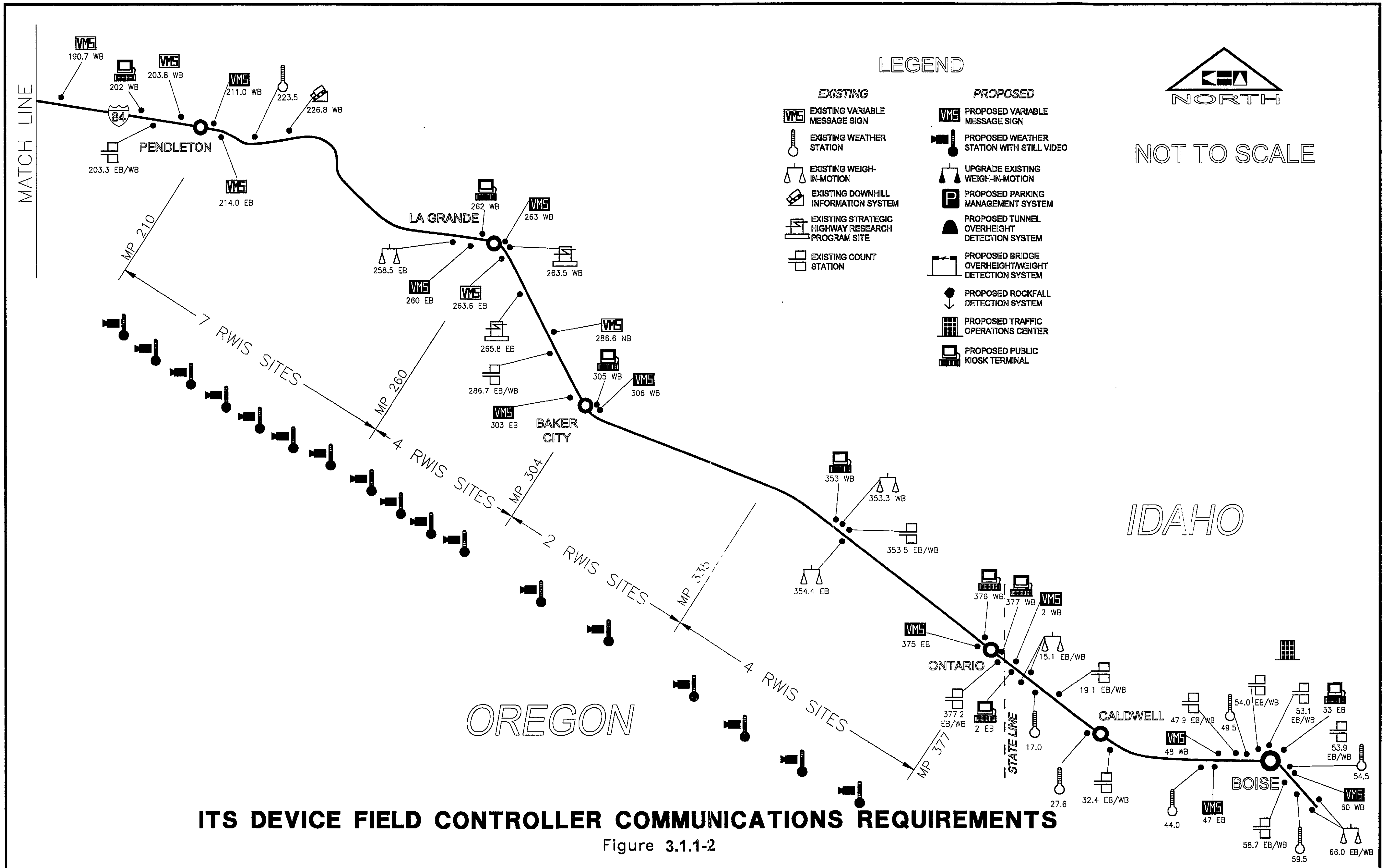


ITS DEVICE FIELD CONTROLLER COMMUNICATIONS REQUIREMENTS

Figure 3.1.1-2

File: 093009.00/i84its02.dwg

The functional application of the sensor may make it either real-time or periodic. For instance a weigh-in-motion station only utilized for statistical data collection or vehicle classification, number of cars (versus time), number of trucks (versus time), and perhaps statistics on number of over weight and weight compliant vehicles does not require "real-time" communications (assuming use of an intelligent controller with information logging capability). However, if the weigh-in-motion is to be utilized for enforcement, then the enforcement application requires real-time communications. **Table 3.1.1-2** summarizes application where real-time and periodic communications are appropriate.

Some of the existing sensors do not provide real-time, remote monitoring access. It is envisioned that the communications architecture supplies the ability to obtain any useful information that may be available from sensors to support real-time and traffic operations management. it is further envisioned that strategic highway research sites should include the ability to monitor the effectiveness of advanced sensors which may be deployed on a test basis and thus should be supported by communications.

Table 3.1.1-3 summarizes the basic communications load for field controller devices.

Table 3.1.1-1
Summary of ITS Field Sensors and Electronic Messaging Devices Complying with ITS Service Needs

Field Device	Typical Data Rate (bps)	Frequency		Number Integrated with TOC(s)				Total Devices
		Real-Time	Periodic	Portland TOC	Yakima TOC	Vancouver TOC	Boise TOC	
Road Weather Information Stations	2400-33.4K		✔	28		8	6	42
Variable Message Signs	2400-33.4K	✔		24	5	8	4	41
Weigh-in-Motion	2400-33.4K	✔		10	2		4	16
Bridge Vehicle Overweight Detection System	2400-33.4K	✔		6		6		12
Tunnel Vehicle Overheight Detection System	2400-33.4K	✔				2		2
Rockfall Detection System	2400-33.4K	✔				2		2
Count Station	2400-33.4K		✔	16	2	8	14	40
Down Hill Information System	2400-33.4K	✔		1				1
Parking Information System	2400-33.4K	✔		2				2
Strategic Highway Research Program Site	2400-33.4K	✔		3	1	2		6
Total				90	10	36	28	164

Table 3.1.1-2
ITS Device Application and
Impact on Communications Needs

Field Device	Real-Time Communications	Periodic Communications
Road Weather Information Station	Sensed hazard and warning	Predictive hazard and statistics
Variable Message Signs	Driver warning of impending hazard(s)	General safety reminders
Weigh-in-Motion Station	Enforcement and automated inspection	Statistical data gathering
Bridge Overweight Detection System	Immediate driver alert and potential incident alert to TOC	Statistical data gathering on occurrence
Tunnel Vehicle Overheight Detection System	Immediate driver alert and potential incident alert to TOC	Statistical data gathering
Vehicle Count Station	Congestion determination and management	Statistical data gathering
Rockfall Detection Station	Immediate driver alert and incident alarm	Road maintenance requirements information
Down Hill Information System	Driver alert and incident alarm	Statistical data gathering on hazardous activity
Parking Information System	Parking availability and directions	General information or parking areas
Strategic Highway Research Site	Remote monitoring of research activity which provides useful real-time corridor management information	Periodic data gather for research progress assessment

Table 3.1.1-3
Summary of Communications Needs per District Based on Table 3.1.1-1

TOC(s) Responsible for Rural Corridor Management	Field Controllers	Growth and Contingencies 30%	Total Controllers for COMS Plan	Data Rate (bps) (33.4 Kbps/site bank)	Equivalent T-I Channels*
Portland TOC	90	27	117	3.91 mbps	4.875
Boise TOC	28	8	36	1.20 mbps	1.5
Vancouver TOC	36	11	47	1.57 mbps	1.96
Yakima TOC	10	3	13	0.43 mbps	0.54
TOTALS	164	49	213	7.11 mbps	8.875

*Note: Computed based on a DS-0 per communications site and 24 DS-0 = 1 T-l

3.1.2 Kiosk Terminals

Part of the needs assessment and resulting ITS deployment strategy recommended the use of kiosk terminals to provide corridor status and other related travel information to travelers. There are a number of issues that apply to kiosk terminals including:

- Publicly owned terminals
- Privately owned terminals
- Centralized, privatized traveler information center for the region supported by public data input
- Centralized publicly owned regional traveler information center
- Publicly owned distributed but filly coordinated traveler information subsystems of corridor TOCs
- Privately owned traveler information center operating independently of the corridor TOCs

Basically, if traveler information becomes a sellable commodity, competitive private services will emerge. In any case the ITS architecture should consider emergence of competitive, privatized Integrated Traveler Information Services (ITIS). These privatized services may include:

- Yellow page services including directions, accommodation availability, and reservations
- Off main corridor directions and road conditions
- Specialized trip/route planning based on special access and/or membership codes (where payment is received)
- Specialized weather forecast and trip impact based on access code and prearranged payment
- Main corridor conditions as gathered by privatized sensors and aerial surveillance

The public information should include:

- Corridor status along major corridors including those associated with the study.

  - Hazard type location and impact on traffic flow caused by:

    - Weather related
    - Road damage and obstructions
    - Vehicle incident related
    - Special event related

  - Road construction warnings (location, lanes impacted, speed limits imposed)

  - Road closures:

    - Location, reason and estimated reopening
    - Detour information

  - Alternate routes available to improve travel time and/or route travel safety

- Yellow page location of Government facilities:

  - Welcoming Centers
  - Rest Areas
  - State and National Parks
  - Emergency Services
  - Camping Sites

- Areas along the major corridors where food, shelter and vehicle services can be obtained (symbols only - not specific advertisements for businesses).

- Status of parks and associated parking (if available):

  - Crowded conditions and available parking

Where privatized kiosk are offered, public sector ITS information should also be available to the private company supporting information distribution to travelers with communications service paid by the private company. Where privatized companies desire to share kiosk terminals, the advertising and profit benefits to the private company should be utilized to pay for deployment and operations cost.

Typically privatized kiosk are found at car rental offices, hotels, convention centers, airports and other locations where advertising achieves business results. There is a significant probability that private partners may be available to support integrated traveler information service cost offsets, especially at truck stops and major vehicle service and restaurant centers along the corridors.

Typically private companies are reluctant to invest in kiosk terminals in unprotected areas such as may be found at rest stops and in National and State park areas. The reason is that the terminals are vulnerable to vandalism and generally require more maintenance attention than justified by business benefits received.

Thus for this corridor, public kiosks are recommended at the locations presented in **Table 3.1.2-1.** Kiosk terminals recommended include the following capability:

- Color graphics presentations
- Local database storage and interactive access
- User friendly, touch screen communications with travelers
- Commercial vehicle driver or tourist dialog
- User presentations utilize graphical presentations with international (ISO) symbolic standards
- All graphical maps are locally stored with variable data communicated as overlays to minimize communications cost and user wait time
- Internet interface is utilized as the primary method of local kiosk terminal update with dial-up modem as the secondary interface

Table 3.1.2-1
Public Kiosk Terminals Recommended Locations

Facility	Route	Approximate Mile Marker	Priority
Oregon Welcome Station	I-84	337	1
Idaho Welcome Station	I-84	1	1
Park/Recreation Area, Oregon	I-84	31	1
Truck Stop (Idaho)	I-84	53	2
Ontario Area Truck Stop (Oregon)	I-84	376	2
Farewell Bend Truck Stop (Oregon)	I-84	353	2
Baker City Area Truck Stop (Oregon)	I-84	305	2
La Grande Area Truck Stop (Oregon)	I-S4	262	2
Pendleton Area Truck Stop (Oregon)	I-84	202	2
Biggs Junction Truck Stop (Oregon)	I-84	104	2
Portland Area Truck Stop (Oregon)	I-84	17	2

- Washington, Oregon and Idaho State DOT white pages would be accessible by touch screen selection providing extended traveler information.

The cost of providing kiosk terminal communications service utilizing Internet would be approximately $55 per month or **$7,260** per year for those shown in **Table 3.1.2-1.** Terminal cost for planning purposes is $10,000 per specially configured terminal or $110,000 for deployment of recommended kiosk terminals.

Surveys of truck stops indicate that the owners are willing to provide wall space for kiosk terminals as a service to truckers; however, they are not willing to pay a fee for rental use of the terminals. The truck stop owners have stated that their offering of full service to truckers is the incentive for truckers utilizing their facility. They do not believe that kiosk terminals with corridor conditions accessible will be a major contribution to business growth. Thus, deployment of kiosk terminals at truck stops will most likely require state funding.

By utilizing the Internet with an integration of all corridor segments' ITS information, and with interaction between user and terminal database and optionally Internet DOT page(s), the communications link cost can be minimized. Each terminal will be provided with a 33.4 Kbps V.34 (or perhaps emerging 56 Kbps modem announced by U.S. Robotics) dial-up modem with the terminal essentially being a multimedia Pentium PC packaged for rugged operations and with keyboard replaced with touch screen.

The user would not be provided with general access to Internet and could only access web pages relating to the corridor or traveled along the corridor.

It is recommended that one TOC provide the integrated rural corridor(s) traveler information update through TOC-to-TOC interoperability. The Internet with dial-up back-up communications does not preclude each TOC from updating a portion of the kiosk database associated with corridor segments for which they are responsible.

3.2 Existing Infrastructure Which Are Candidates for Supporting ITS Services

3.2.1 I-84 Microwave Backbone

Microwave technology is a very cost/effective means of supporting rural communications. The majority of the states have microwave stations integrated with VHF wireless radio supporting mobile communications with state police and public works (separate frequencies) vehicles. These microwave backbones, in some states, support emergency telephone communications from roadside-to-TOC (or designated emergency support center). For instance Florida and Louisiana utilize 75 MHz for roadside emergency communications.

Several states are upgrading their older microwave systems from the 2 GHz frequency band to the 6 GHz frequency band. This upgrade is being accomplished at no cost to the state since the 2 GHz frequency has been referred to Personal Communications Services (PCS) by the Federal Communications Commission (FCC). The states having the 2 GHz frequencies are trading them to PCS service suppliers in return for the upgrade. Florida DOT is an example of this upgrade.

Older microwave systems typically are analog. Newer microwave systems are digital. The newest digital microwave technology is known as "SONET microwave" since it can seamlessly extend a fiber optic SONET network utilizing microwave technology. SONET microwave's basic operating data-rate is OC-3 which is 155.52 Mbps. This supports 2016 DS-0 (telephone-voice) channels or 84 DS-1 channels. Modular expansion is possible. Interworking with DS-3 microwave is possible for branch circuits. The true benefits of SONET microwave are that international, open architecture standards apply and that standard interface multiplexers, brouters and switches may be utilized. Also standard subrate multiplexing can be utilized on DS-0 (64 Kbps) channels supporting multiple EIA 232 channels. The OC-3 microwave operating at the same frequencies currently utilized can support over 8000 full duplex EIA 232 channels (compared with 4809 of the existing microwave system). Since the major cost of the microwave system is the tower structure, upgrades of extended bandwidth and open architecture compatibility are recommended where older analog microwave capability exists.

Figures 3.2.1-1 and 3.2.1-2 illustrate the deployment of the current state microwave system along I-84. The equipment is older analog microwave operating in the 6 GHz frequency band and supporting 480 channelized EIA 232 channels with up to 9.6 Kbps capability. Equipment is supported by Harris Corp. Branch Service operates at 960 MHz and supports 12 EIA 232 channels. Currently 42% of the microwave network is being utilized offering a possible use of available channels for ITS applications.

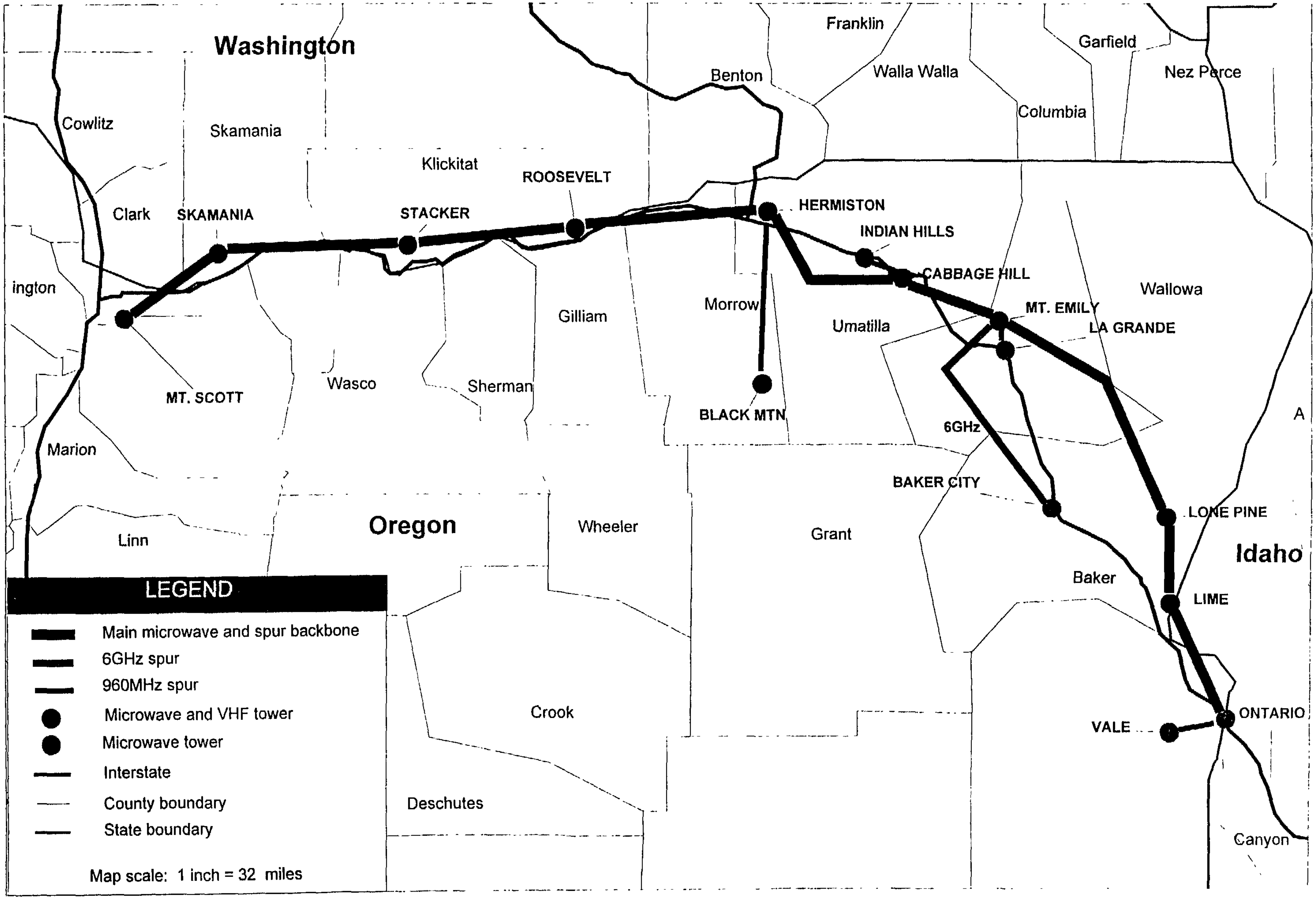
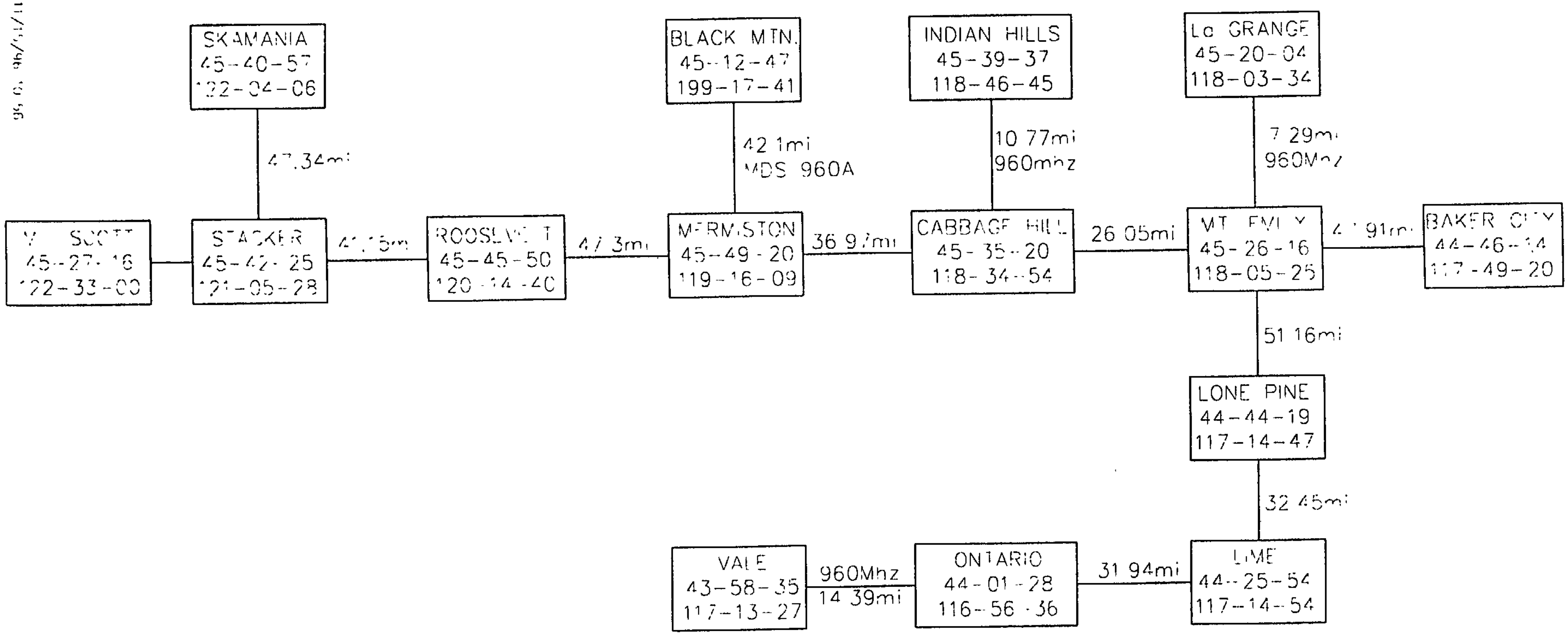


Figure3.2.1-1, Oregon Department of Transportation Microwave Tower Sites



ODOT MICROWAVE SYSTEM TOWER LOCATION AND CONNECTIVITY ALONG I-84

Figure **3.2.1-2**

The microwave towers have co-located 150 MHz mobile VHF communications with public works and state police vehicles. This coverage is excellent within perhaps a small area around mile marker 0 on I-84. This coverage is currently limited by terrain and tower placement The VHF wireless network does not support emergency roadside communications.

Figure 3.2.1-3 presents the microwave tower sites deployed along State Route 14 in Washington. The Skamania, Stacker Butte and Roosevelt microwave tower sites are owned by Washington State DOT and are shared with Oregon as shown in Figure 3.2.1-2. The microwave towers provide communications from the Skamania area to Yakima and are thus a candidate to support communications along a major portion of State Route 14.

3 2.1 1. Value of the Microwave Sites to Support Rural Corridor ITS

The microwave towers are valuable communications assets owned by the jurisdictions. They are characterized by:

- Reliable
- Low cost
- Full Corridor Coverage

The current microwave system is easily upgradable to SONET microwave which would provide 4.2 times the capacity of the current microwave system and seamless interoperability with any future SONET optical fiber networks to be deployed in either the Portland or Boise areas in support of Urban ITS and other state and city related functions. However, the current system has spare bandwidth that could support deployment of the recommended ITS services requiring narrow bandwidth communications.

The current microwave towers support mobile communications. Using a TERIM propagation model, the microwave tower sites were modeled based on use of 100 watt transmitters and 100 feet above ground level (AGL) digital radio antenna placements. A signal/noise margin accommodating adequate fade protection was incorporated. The model considered a 75 MHz digital radio operating frequency and 800 MHz operating frequency. **Figure 3.2.1.1-1** illustrates the coverage results at **75 MHz** and **Figure 3.2.1.1-2** presents the modeling results at 800 MHz which is commonly utilized for Supervisory Control and Data Acquisition (SCADA). The modeling results indicates:

- Digital wireless communications to the roadside is possible.
- 75 MHz digital coverage is possible except along a small section of I-84 around mile markers 54-64.
- 800 MHz does not support adequate coverage.

Figure 3.2.1.1-3 illustrates the use of the microwave backbone augmented with wireless digital service to the roadside. Staggered frequencies may be utilized between sites to avoid interference and to increase throughput. Multiple frequencies may also be utilized at a single site to enhance communications bandwidth to the roadside.

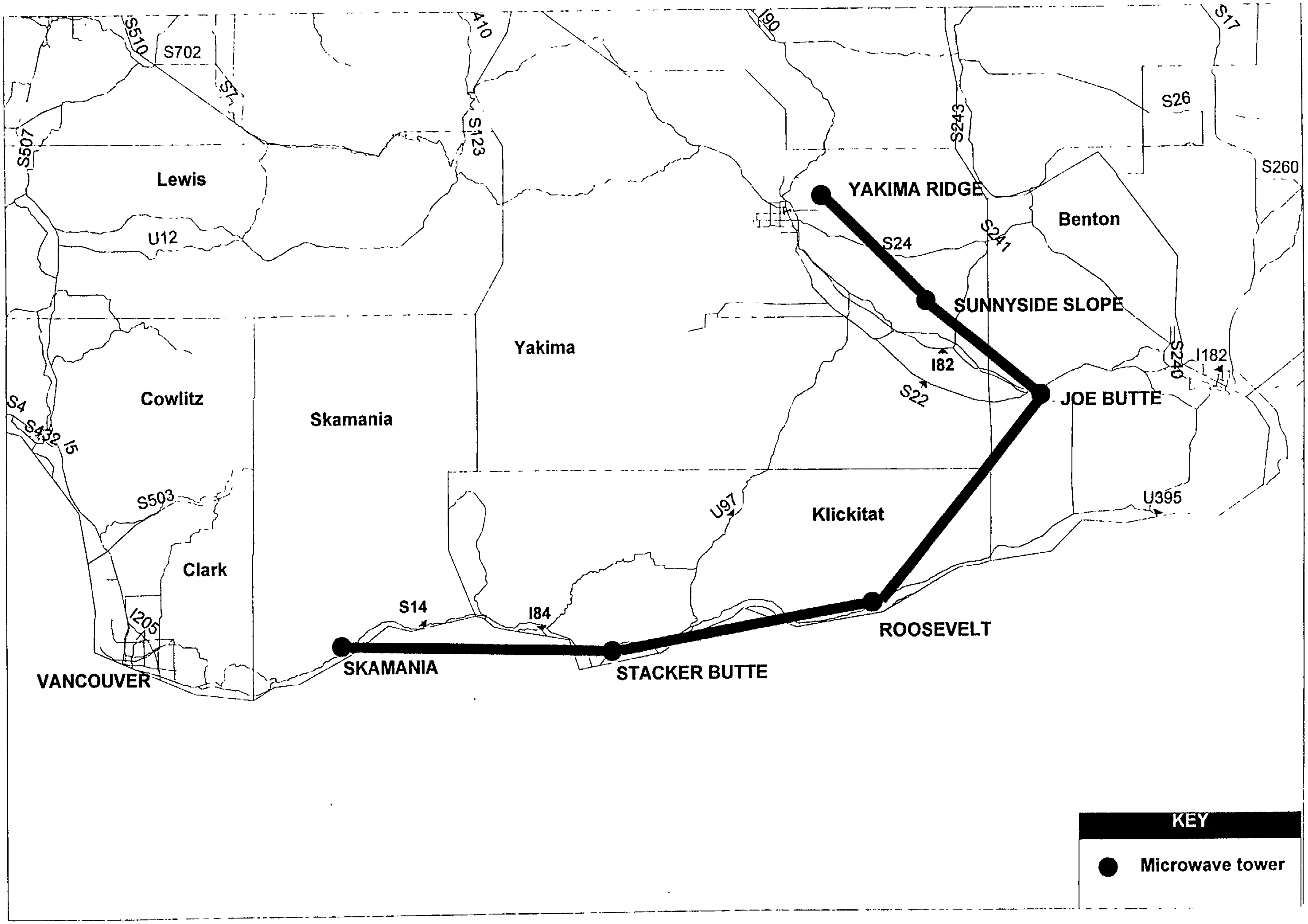
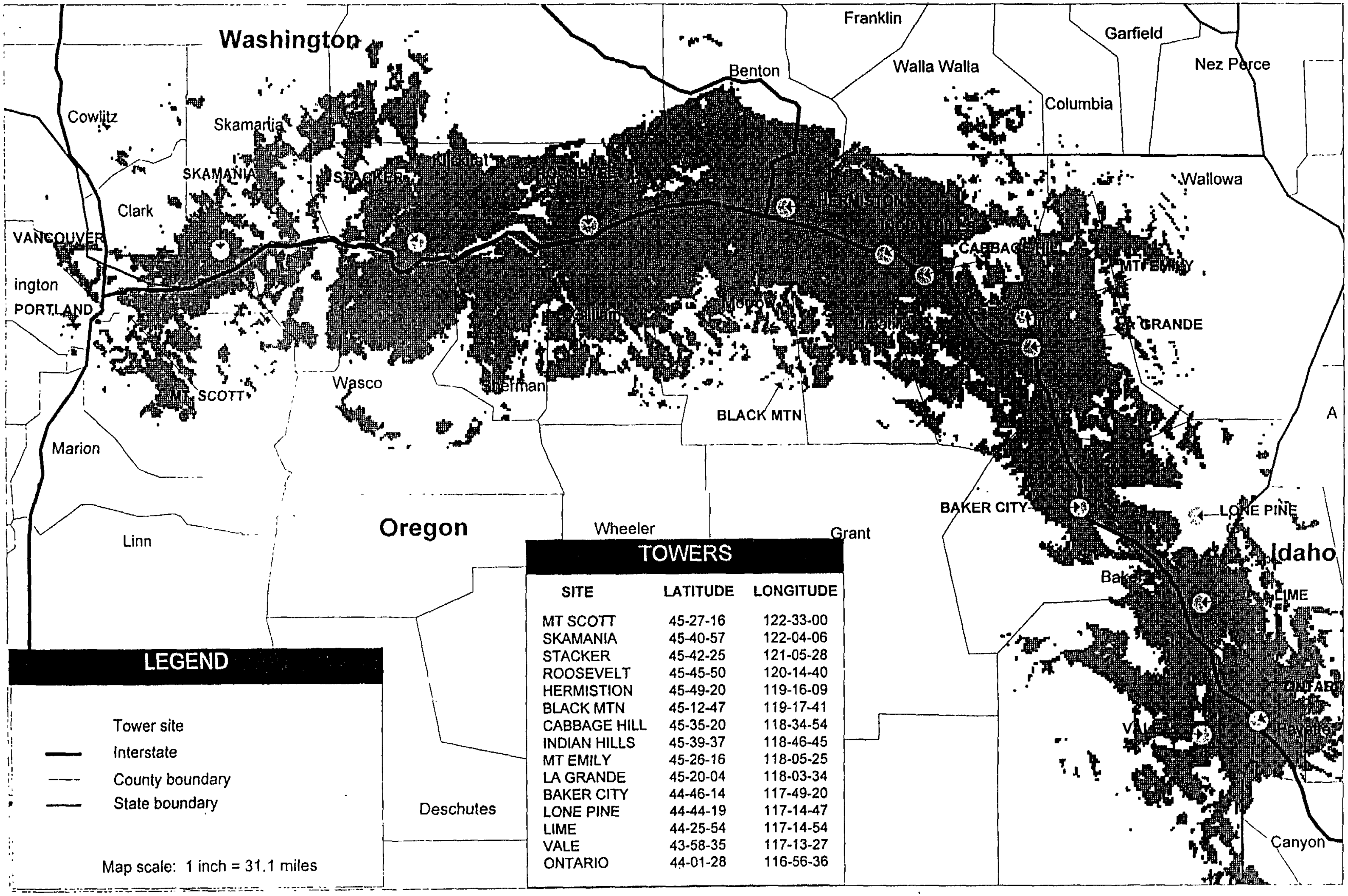
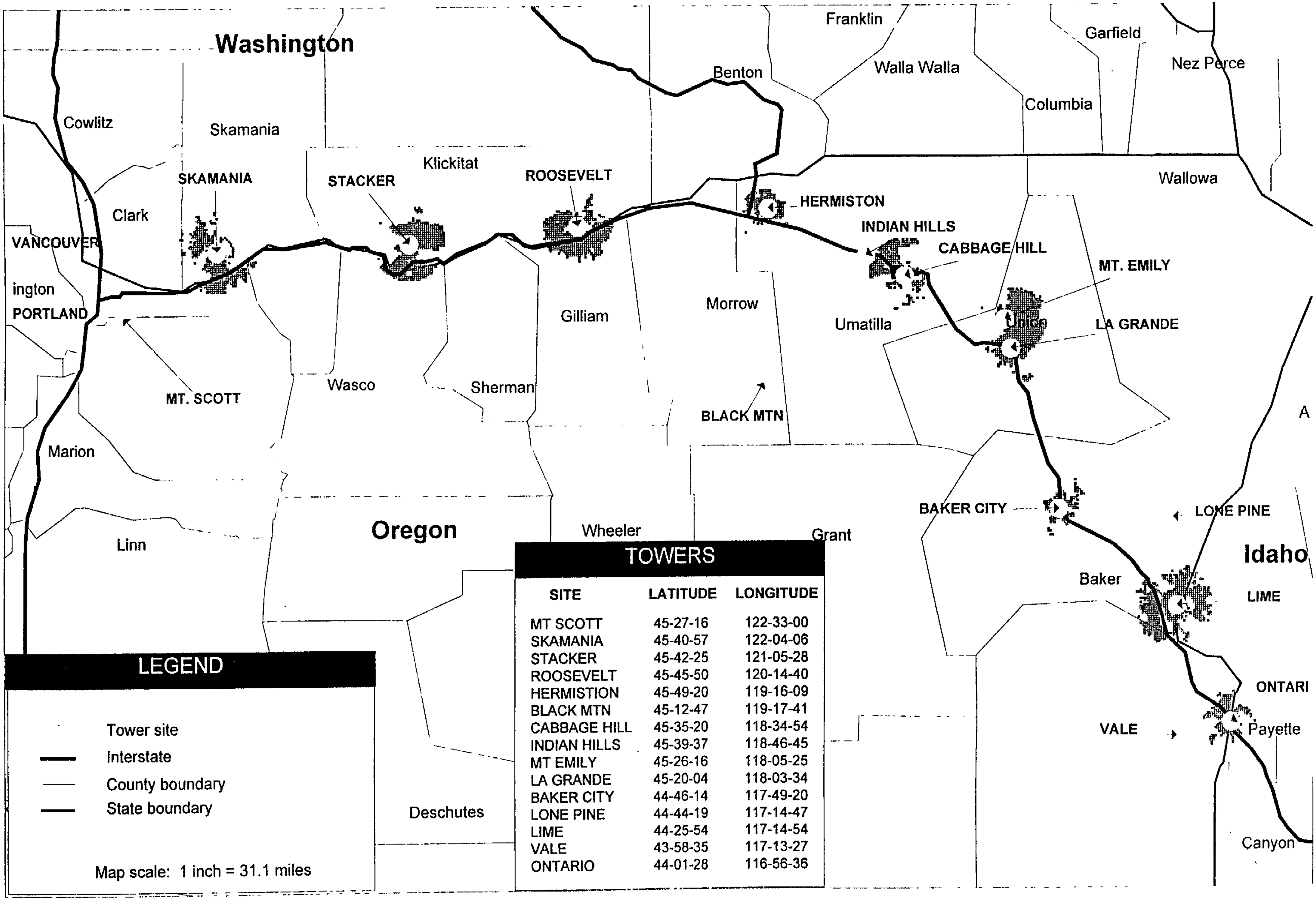


Figure3.2.1-3, Washington State Department of Transportation Microwave Tower Sites



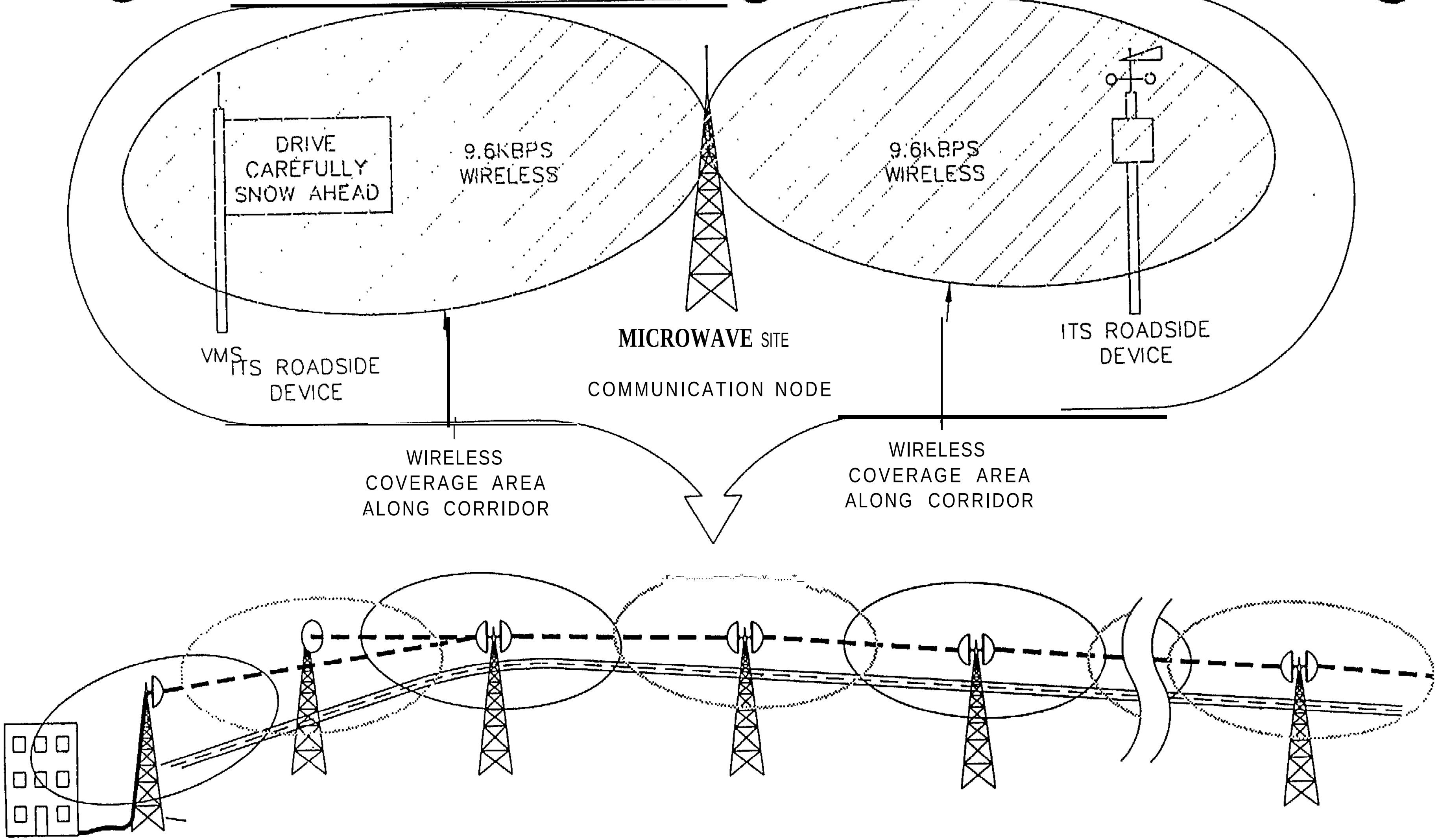
SITE	LATITUDE	LONGITUDE
MT SCOTT	45-27-16	122-33-00
SKAMANIA	45-40-57	122-04-06
STACKER	45-42-25	121-05-28
ROOSEVELT	45-45-50	120-14-40
HERMISTION	45-49-20	119-16-09
BLACK MTN	45-12-47	119-17-41
CABBAGE HILL	45-35-20	118-34-54
INDIAN HILLS	45-39-37	118-46-45
MT EMILY	45-26-16	118-05-25
LA GRANDE	45-20-04	118-03-34
BAKER CITY	44-46-14	117-49-20
LONE PINE	44-44-19	117-14-47
LIME	44-25-54	117-14-54
VALE	43-58-35	117-13-27
ONTARIO	44-01-28	116-56-36

Figure3.2.1.1-1, Modeled Coverage of 75 MHz Digital Radio Utilizing Microwave Towers



SITE	LATITUDE	LONGITUDE
MT SCOTT	45-27-16	122-33-00
SKAMANIA	45-40-57	122-04-06
STACKER	45-42-25	121-05-28
ROOSEVELT	45-45-50	120-14-40
HERMISTION	45-49-20	119-16-09
BLACK MTN	45-12-47	119-17-41
CABBAGE HILL	45-35-20	118-34-54
INDIAN HILLS	45-39-37	118-46-45
MT EMILY	45-26-16	118-05-25
LA GRANDE	45-20-04	118-03-34
BAKER CITY	44-46-14	117-49-20
LONE PINE	44-44-19	117-14-47
LIME	44-25-54	117-14-54
VALE	43-58-35	117-13-27
ONTARIO	44-01-28	116-56-36

Figure3.2.1.1-2, Modeled Coverage of 800MHz Digital Radio Utilizing Microwave Towers



EXAMPLE OF LOW SPEED DIGITAL WIRELESS INTERCONNECT WITH THE MICROWAVE BACKBONE COMMUNICATIONS NETWORK

Figure 3.2.1.1-3

Figure 3.2.1.1-4 provides a high level block diagram of interface **with Figure 3.2.1.1-5** illustrating a more detailed interface approach.

There are a number of options available to enhance operations. Tailored directional antennas may be utilized to improve performance. A number of roadside devices would be managed by the system. Typical poll-response is 400 msec allowing a number of multidropped controllers on a single link perhaps each being polled every 20 to 30 seconds.

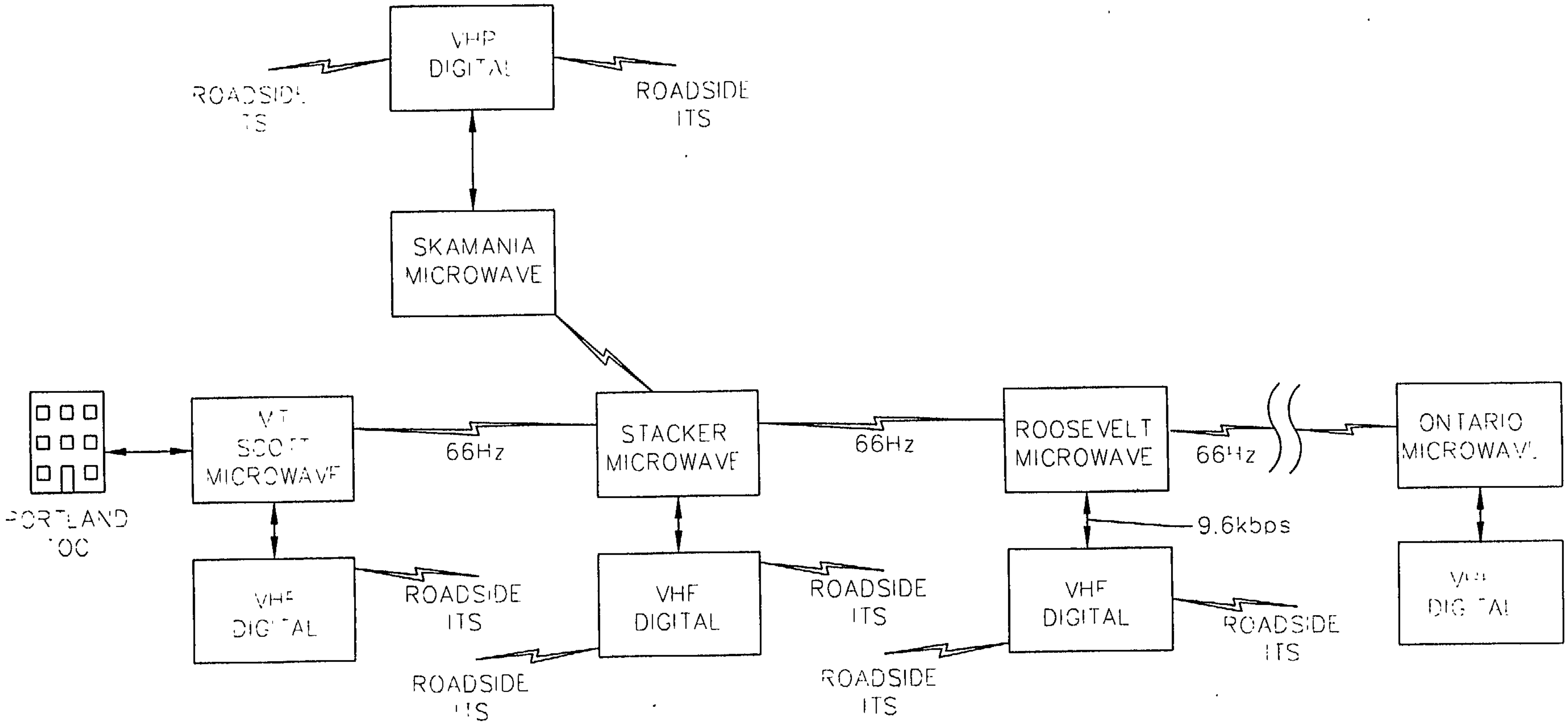
It is further possible to utilize solar powered transceivers and controllers in areas where it is difficult to interconnect with commercial power. The transmitter requires the majority of power. By prudently managing transmission and selecting a power conserving controller technology (i.e. CMOS solid-state devices) it should be feasible to achieve quick installation of field devices and controllers with an integral communications link. Of course this precludes the use of devices such as large variable message signs which consume a significant amount of power. It should further be noted that the US Department of Agriculture's SNOTEL System, which has been operational since the mid-1970's utilizing a communications technology referred to as Meteor-Burst, incorporates solar powered remote communications/controller terminals. In face the primary difference in the two (2) approaches is that the microwave link with digital wireless transceivers replace the meteor burst base station and in fact provide much more bandwidth from field to the central management facilities.

It should further be noted that a number of State DOTS are utilizing these roadside radios with solar power at the suggested frequency. These roadside radios with antenna cost under $3,000, which is significantly less than any alternate communications option.

The number of I-84 ITS controllers **(see Table 3.1.1-1)** associated with the Portland TOC would be 90. Assuming equal distribution of ITS controllers among 10 microwave sites results in 9 controllers per microwave tower. If the Ontario microwave tower site is utilized to cover part of Idaho, another 5 roadside sites could be covered. In any case the number of roadside controllers to be serviced per **Table 3.1.1-l** and the associated illustrations are, in most cases, well within the capability of a single transceiver.

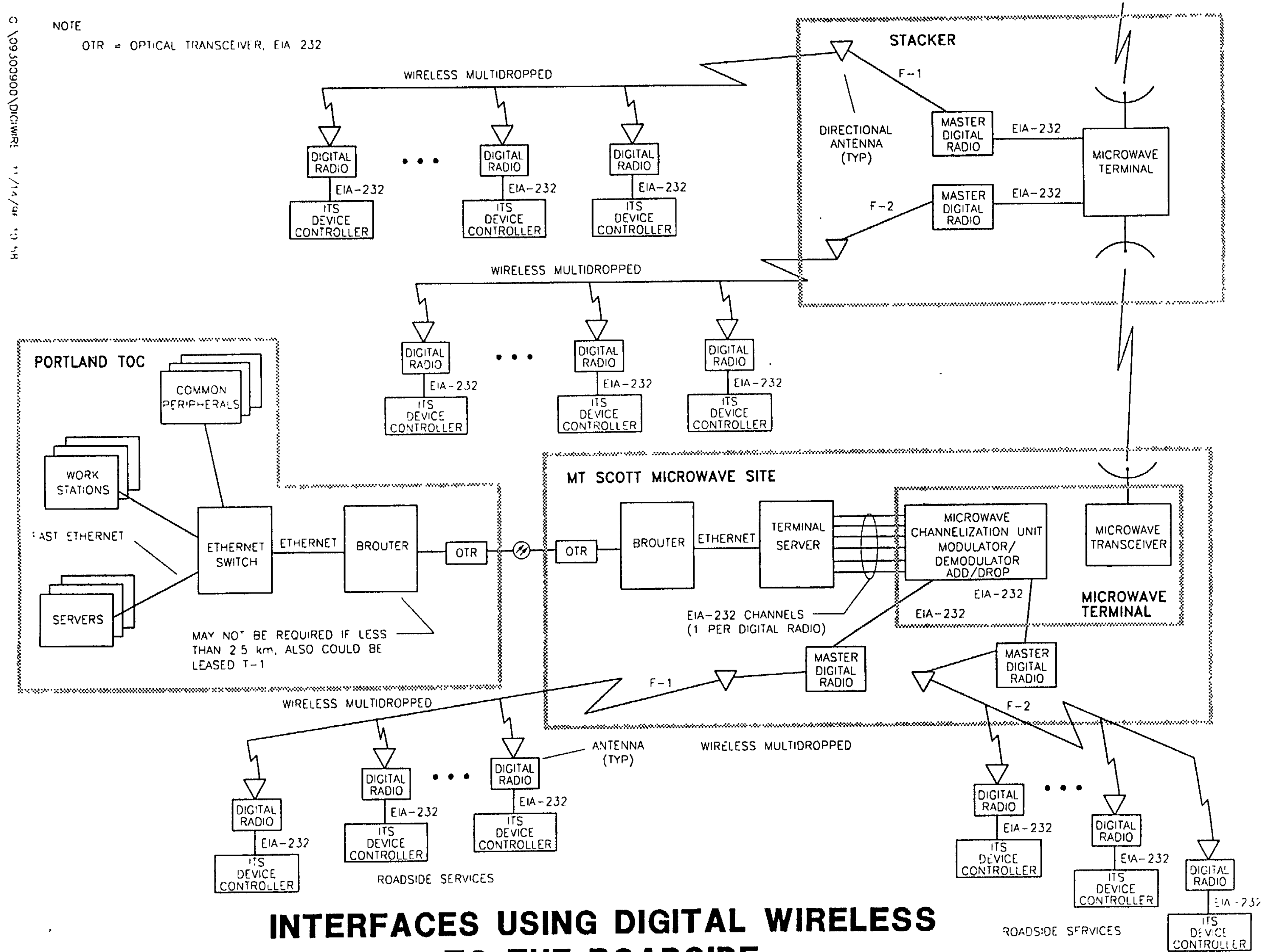
To summarize, ODOT and Washington State DOT have invested in a microwave backbone that covers a significant part of the ITS corridor. This infrastructure seems to be very usable for supporting deployment of narrow bandwidth ITS controller devices along the corridor in the density as defined by the early deployment plan's ITS service deployment strategy. The benefits of utilizing this infrastructure are:

- It is installed and has adequate available bandwidth.
- It is reasonably easy to accommodate an interface to a TOC (especially Portland).
- It can be accomplished at a reasonable cost.
- Based on experience of other states (including Florida DOT) reliable communications results can be achieved with this wireless approach integrated with a microwave backbone.



SYSTEM BLOCK DIAGRAM ILLUSTRATING INTERFACE OF THE DIGITAL WIRELESS LINK

Figure 3.2.1.1-4



INTERFACES USING DIGITAL WIRELESS TO THE ROADSIDE

Figure 3.2.1.1-5

It should be noted that additional analysis will be required to refine the design. However, no information obtained in this study indicates that objectives cannot be achieved. Modeling was accomplished with Omni (0 dBi) gain antennas. Use of tailored antennas (such as dB INCS 112 antenna) could provide up to 6 dB additional gain which would increase coverage, especially into Idaho. Similarly, where higher towers are available, coverage may be increased.

3.2.2 Idaho Transportation Department UHF' Wireless Network

Idaho has a Ultra High Frequency (UHF) mobile radio network operating in the 458 MHz band supporting public works operations and management. The system utilizes UHF repeater technology managed by burst tone selection. Radio frequencies are utilized in pairs and are activated by districts to minimize probability of interference. Odd numbered channels are utilized in odd-numbered districts and vice versa.

The radio signal from a vehicular radio or control station at a fixed office location is received at a mobile relay station, usually located on a mountain top and is automatically retransmitted on a paired radio channel to be received by the addressed mobile station or control station. Control and mobile stations send messages on one radio channel and receive on the second channel. Repeaters extend range between base stations and mobile stations. Several repeaters may be utilized in each district to achieve necessary coverage.

In order to select the particular mobile relay to be utilized, control stations and the mobile stations automatically apply a brief burst of a selected tone to the radio signal that is being transmitted. Only the mobile station which has been equipped to decode the selected tone burst will rebroadcast the signal. Tone selection is accomplished by the control station operator activating a switch on the control head of the communications equipment. Channel assignments are summarized in **Table 3.2.2-l. Table 3.2.2-2** summarizes locations of the sites.

Table 3.2.2-l
Communications Channel Requirements

District	Channel Number	Transmit Frequency (MHz)	Receive Frequency MHZ)	Use
1,3,5	1	453.150 .	458.150	
2,4,6	2	453.800	458.450	
5	3	453.150	453.150	Car-Car
4,6	4	453 .800	453.800	Car-Car

Table 3.2.2-2
Idaho Division of Highways Radio Stations

Call	Frequency	Location
		All District #3
KRE 319	453.800 453.150	Doe Point
KRE 320	453.800 453.150	District 3 Headquarters
KRE 321	453.800 453.150	Shafer
KRE 322	453,800 453.150	Snowbank
KRE 323	453.800	Boise Main Office
WSZ 42	45s. 150, .450	Doe Point
KVN 868	453.150, .soo	Cold Springs Ridge
KVN 869	453.150, .soo	Cinnabar Mountain
WSZ 43	45s. 150, .450	Snowbank Mountain
WSZ 41	45x.150	Highway District #3
KVR 959	453.150, .soo	Lucky Peak
KVR 960	453.150, .soo	Jackson Peak
DWT 646	453.150, .soo	Brundage Mountain
KXQ 798	453.150, .800	National Guard Armory, Boise
WAU 685	458.150, .450	National Guard Armory, Boise
		All District #2
KOA 819	47.20	Notch Butte
KUE 642	453.800	Albion Ridge
KUZ 870	453.150, .soo	Baldy Mountain Ketchum
KUZ 871	453.150, .800	Notch Butte
WSR 65	458.150 458.450	Notch Butte
KVN 870	453.150, .soo	Weigh Station, Bliss

Call	Frequency	Location
KVN 867	453.150, .800	Basin Butte
wsz 401	458.150, .450	Basin Butte
Ref.: Idaho Maintenance Manual; 5-401.62: Rev. Mav. 1975		

Use of the communications infrastructure should only be considered for reporting road work and conditions to the Boise Traffic Operations Center for preparation of corridor conditions and status reporting to travelers.

3.2.3 Leased Infrastructure

Both the State of Washington and the State of Oregon have an extensive leased communications service network. These networks generally consist of T- 1 (1.54 Mbps) and fractional T-l leased communications services. Through use of bridges and routes, virtual ETHERNETs and Token Rings have been established.

3 2.3 1. ODOT LAN/WAN

Figure 3.2.3.1-1 represents the ODOT Local Area Network (LAN)AVide Area Network (WAN). The system is composed of various communications technologies and mediums including:

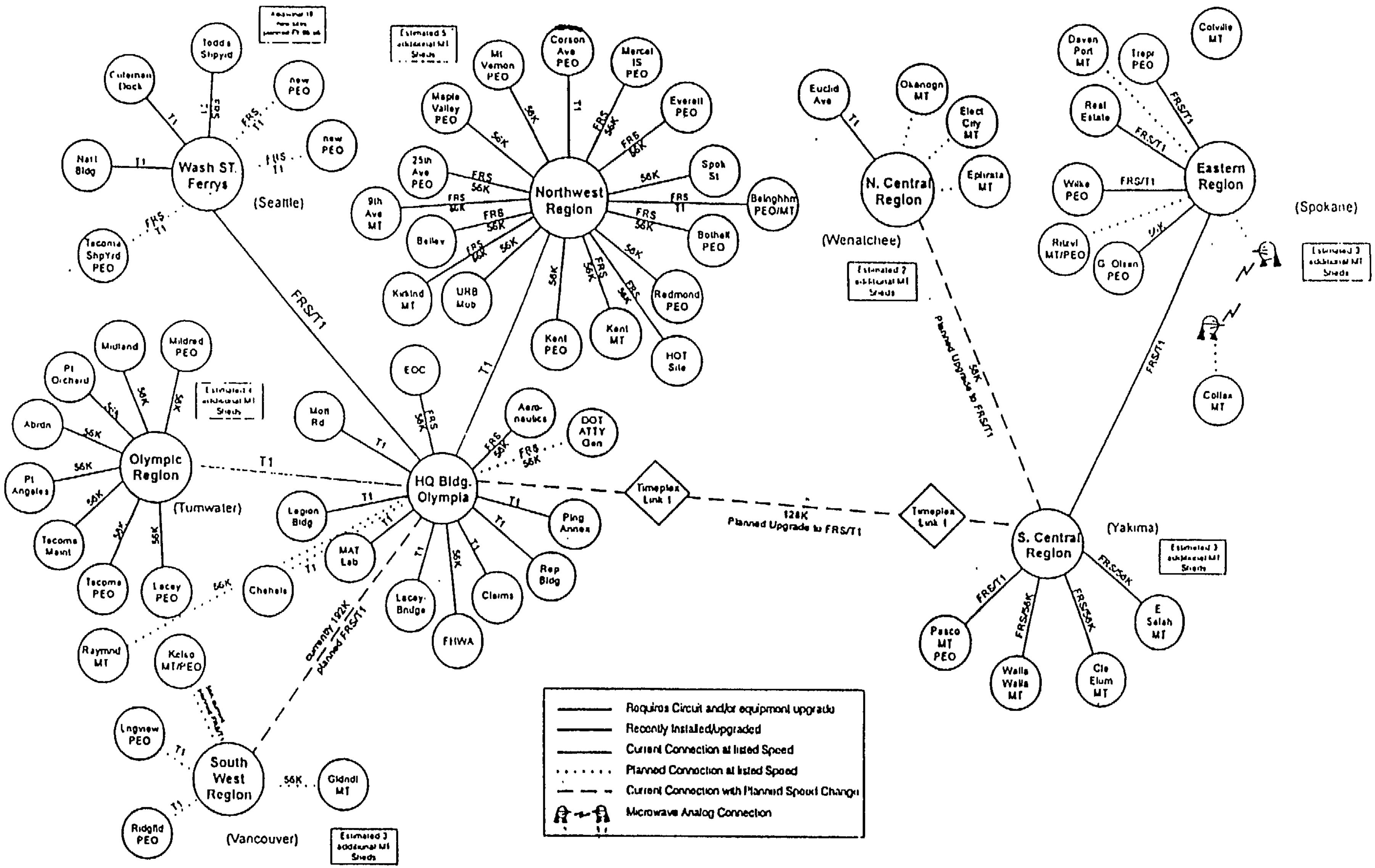
- Fiber Optic
- Copper Twisted Pair
- Leased Lines

Frame Relay, which is a packet switching service provided by the Local Telephone Companies (TELCOs), is utilized for information distribution. Some sites include routers and dedicated links (leased or owned) for virtual extension of LANs.

Communications is provided to all district offices. It is beyond the scope of this study to evaluate spare circuit capacity on each circuit branch which may be of use to supporting the implementation of recommended ITS services. The network is capable of supporting the gathering of corridor conditions, and construction and repair activity from associated district offices. It is further suitable for providing traveler related information to associated district offices for coordination. **(Figure 3.2.3.1-1** is located in the pocket at the end of the technical memorandum.)

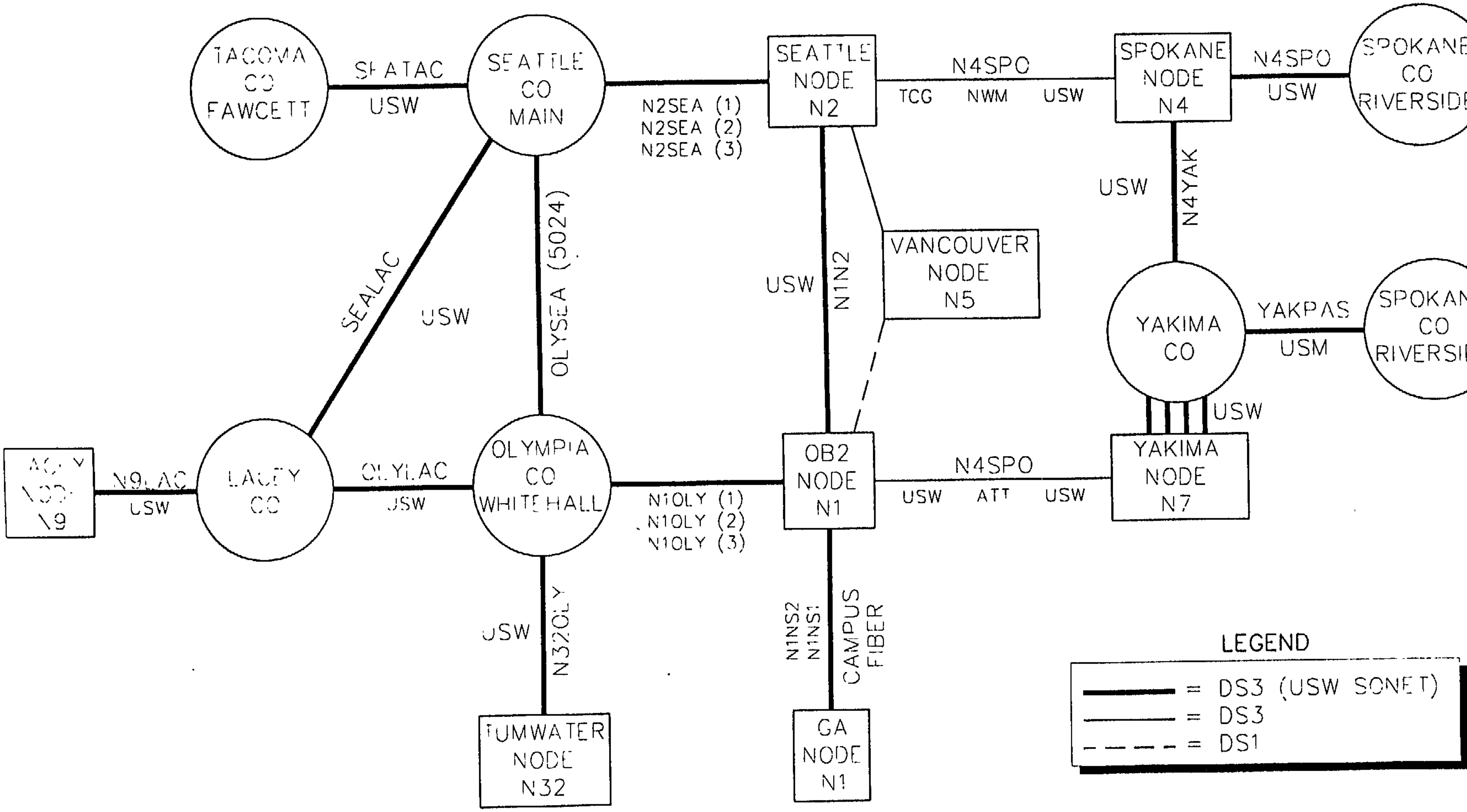
3 2.3 2 Washington State DOT Wide Area Network (WAN)

Figure 3.2.3.2-l illustrates the WSDOT WAN. The network is constructed utilizing leased digital services at 56 Kbps and T-l services of 1.544 Mbps between locations. **Figure** 3.2.3.2-2 illustrates wider band DS-3 (44.738 Mbps) service achieved through WSDOTs transition to SONET.



WSDOT WIDE AREA NETWORK (WAN)

Figure 3.2.3.2-1



WSDOT DIGITAL TRANSPORT COMMUNICATIONS BACKBONE ROUTE

Figure 3.2.3.2-2

Figures 3.2.3.2-l and **3.2.3.2-2** illustrate that there is an existing link between the Vancouver node and the Yakima node. This linkage can possibly support interoperability between the Yakima and Vancouver TOCs.

3.2.4 SNOTEL (Meteor Burst Communications Infrastructure)

Within the area is the U.S. Department of Agriculture (USDA) National Resources Conservation Service's (NRCS) SNOTEL system "SNOTEL" is derived from SNOW TELemetry, or the system which provides information to the NRCS Portland Center from sensors within the National Forest areas. SNOTEL communications with over 560 remote sites via two (2) master communications nodes and a Central Computer Facility (CCF) located in Portland.

The communications solution adopted by NRCS was to utilize meteor burst communications. Meteor burst communications is unique in that it can offer 24 hour a day communications over a 2000 Km distance with easy-to-operate, battery powered terminals, small antennas and no charge for satellite time nor leased communications links. The principle of operation is based on the fact that billions of tiny meteors enter the earth's atmosphere daily. These meteors provide reliable and predictable ionized trails capable of reflecting radio signals back to earth. They become "natures satellites" supporting earth-to earth communications over approximately a 2000 Km range. The limitation is that a slight delay is necessary in transmitting and receiving data as the system must wait for a suitable meteor trail. However, real-time data is not needed and when the amount of data being transferred is modest, meteor burst communications has a significant economic advantage.

Meteor burst communications technology is not new. It was first developed by the U.S. Navy in the 1940s for communicating with ships. The technology continued to be improved for U.S. Military and U.S. Coast Guard applications. In the mid-1970s the prototype development of SNOTEL began. Initial tests were very successful and the NRCS continued with the technology deployment and improvements. Deployment of the technology in other geographic areas including Alaska was sponsored by the U.S. Army Corp of Engineers.

Currently operating systems other than those sponsored by USDA and U.S. Department of Defense include:

- British Columbia, Ministry of Forest (300 remote units)
- Pakistan Water and Power Development Authority for monitoring forest associated with supplying water to the Tarbela and Mangela reservoirs and Kabul and Indus Rivers
- Argentina National Institute of Science and Hydrologic Technology's upper plains flood forecasting system
- China Dian Jian Koo Reservoir Project; water capacity management system
- Egyptian Ministry of Irrigation Water Management System (total Nile River system)
- Canadian B.C. Forest Service Protection Program

Thus there is no question that Meteor burst communications technology works. In fact Meteor Communications Corp. (MCC) of Kent, Washington is a world leader in deploying the technology. Scientific Radio Systems (NY), Napco International, Inc. (MN), IA Research Corp. (FL), Vaisala OY (Finland) and Hadron, Inc. (VA) are companies supporting Meteor burst technology. Thus competition exists for providing Meteor burst communications systems and equipment.

3 2 4 1 Overview of Meteor Burst Technology

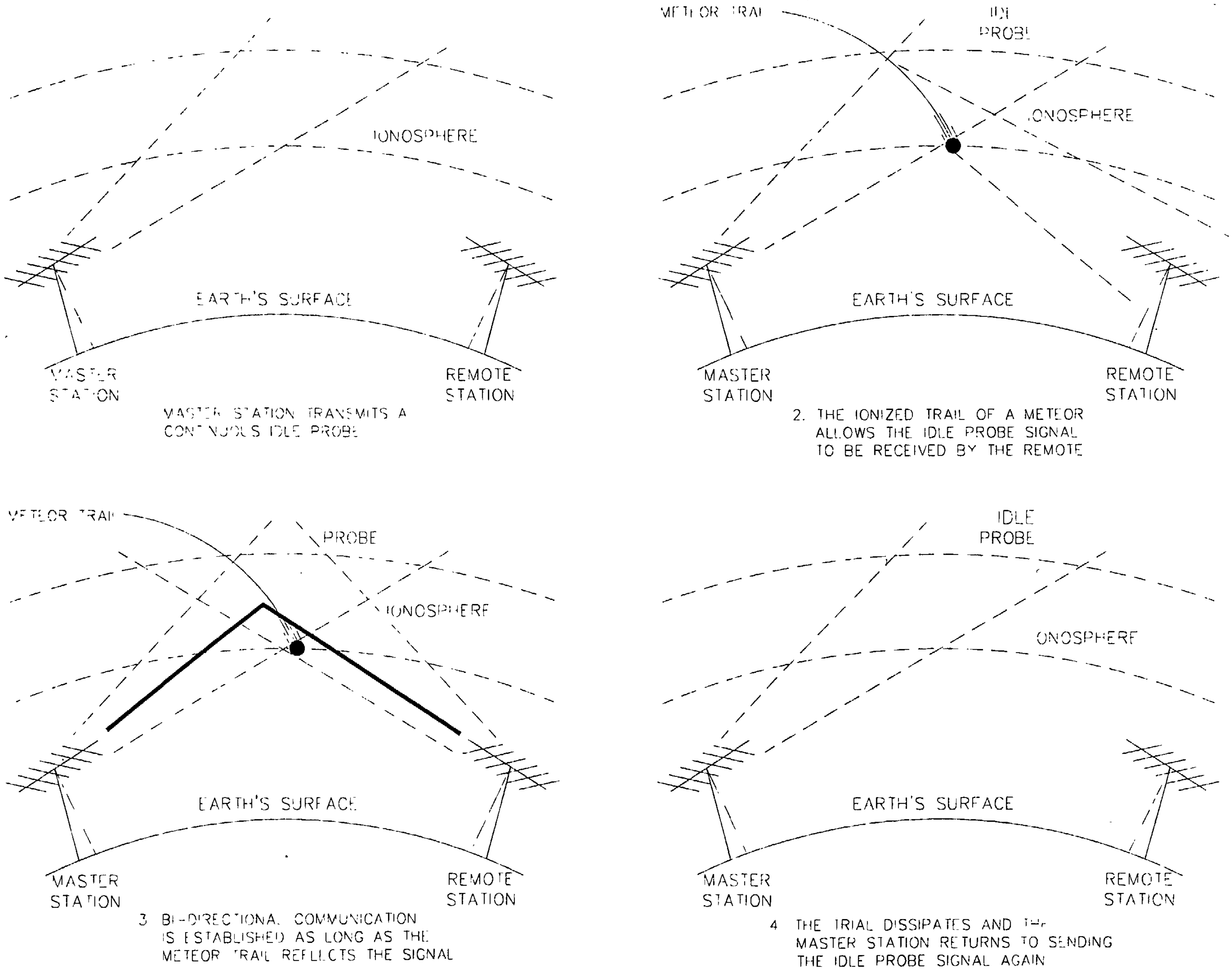
Meteor burst systems typically operate in the VHF frequency range of 30 MHz to 300 MHz. typical data rate supported is 9.6 Kbps. On an average, meteor trails occur every 60 seconds and last for an average of one (1) second. Thus the average throughput **is** 160 bps. While 160 bps is not fast in today's standards, it exceeds the 7.5 and 100 baud teletype data rates of the 1950's and 1960's.

There are approximately 10^{12} meteor particles entering the earth each day with a mass of 10^{6} grams. There are approximately 10^{8} meteors entering the earth's atmosphere each day each with an energy of 200 joules for a total of 20 billion joules of energy. It is these ionized meteor trails which provide a reflector of VI-IS radio signals. **Figure 3.2.4.1-1** illustrates the basic principle of the meteor burst communications. The master station's antenna is directed in a manner to meet communications geometry. Similarly, the remote antennas are positioned relative to the geometry of the master station and associated antenna pattern. **Table 3.2.4.1-1** summarizes typical base station and remote site communications equipment.

3 2.4 2 Meteor Burst Communications Applied to ITS

Meteor burst communications is very applicable to ITS rural applications where other communications technologies are either unavailable or too expensive. **Figure 3.2.4.2-l** illustrates how off-the-shelf meteor burst equipment (such as produced by MCC) could be applied **to** ITS. **Table 3.2.4.2-l** compares meteor burst with other communications technologies. Basically the MCC 545 remote RF modem/terminal supports an EIA 232 interface with an ITS controller. This technology would be very suitable for ITS field locations requiring periodic data collection, field database update and field control commands. Any ITS application where communications requirements can be serviced with fewer than 1000 bytes and communications contact cycles are in minutes rather than seconds are candidates. These certainly include:

- Remote weather stations (which are currently deployed with SNOTEL)
- Forest fire sensors which represent a hazard to the corridor (and would compliment the National Forest Service FireTel system)
- Vehicle classification and count sensors for corridor statistics



COMMUNICATIONS APPROACH UTILIZED BY METEOR BURST TECHNOLOGY

Figure **3.2.4.1-1**

Table 3.2.4.2-l
Comparison of Communication Systems

Type of System	Initial Cost	Operating cost	Frequency Range	Data Throughput Capacity	Communication Range	Antenna Size	Training Requirements	Overall Reliability	Other Characteristics
Public Switched Telephone Network (DS-0)	Very low to user <$I00	Depends on usage; very expensive for 24-hour-per-day connections	Currently 300-3000 Hz at subscriber loop (baseband signals)	Currently 33.2 Kbps	Virtually anywhere on Earth	Not applicable	Minimal; users are trained when teenagers	Very high	User has no control over operation of network
HF Radio	Moderate; depends	Low to moderate	3-30 MHz; modulation bandwidth limited to 12 kHz maximum, 3 kHz typical	1200 bps; higher rates of 2400 b/s to 4800 bps possible with very expensive terminal equipment	Typically 6000 km; under some conditions, range is worldwide	Depends on frequency and directivity; typically quite large	Can be very extensive; new systems for adaptive frequency control and automatic link establishment minimize training needed	Poor to moderate	Has often been the only means of communications after natural disasters
Satellite	Low (VSAT) to high	High	Generally, above 3 GHz	Moderate to high based on use cost	Above 10,000 km	Uplink (transmitting) antenna is 1 to 2 meters, downlink (receiving) antenna can be quite small	Can be very extensive	Generally high	Vulnerable to satellite failures
VHF Radio	Low to moderate	Low	30-300 MHz	To 19.2 Kbps	To 50 km; extended with relays	Small, but may need to be installed at the top of a tall tower	Moderate	Moderate to good depending on	Proven technology for mobile applications

Type of System	Initial Cost	Operating cost	Frequency Range	Data Throughput Capacity	Communication Range	Antenna Size	Training Requirements	Overall Reliability	Other Characteristics
Microwave	High	Low to moderate	Above 6 GHz	155.54 mbps	40-60 km between relay towers; overall, can be any length, but limited to contiguous land areas	Moderate antenna size, but typically mounted atop large relay tower	Usually used with telephone equipment; user training medium	Generally high if properly designed	Seamless SONET compatibility available
Cellular Telephone	Low	High	800-900 MHz	to 19.2 Kbps	Based on cell site coverage	For user - small	Minimal	Good depending on network design	Cell site coverage limits options
Meteor Burst	Low to Moderate	Low	Typically, 30-100 MHz	to 9.6 Kbps	2000 km; distance can be extended by relaying	Small	Moderate	Properly designed and installed, can be very high	Not real-time; messages are delayed a brief time ranging from seconds to a few minutes while waiting for a suitable meteor trail

Ref: Meteor Burst Communications, Artech House, Boston, 1990

It may be even possible through use of data compression technology and use of stored graphics maps to service remote kiosk terminals via meteor burst communications. These kiosk terminals would include a local database, updated remotely by the TOC on a periodic basis, to provide a dialog and associated traveler information to users.

To summarize, meteor burst communications is a technology generally unheard of but well-proven. It is operational in the Portland area and near **the I-84** corridor as shown in **Figure** 3.2.4.2-2. A partnership with NRCS may be possible to eliminate the need for another master station to support the ODOT Portland TOC. Even with deployment of a master station with remote terminals, meteor burst communications is still more economical than satellite, leased line or dial-up communications service. It is also a technology that can be quickly deployed. Thus it is a candidate to support some of the communication links.

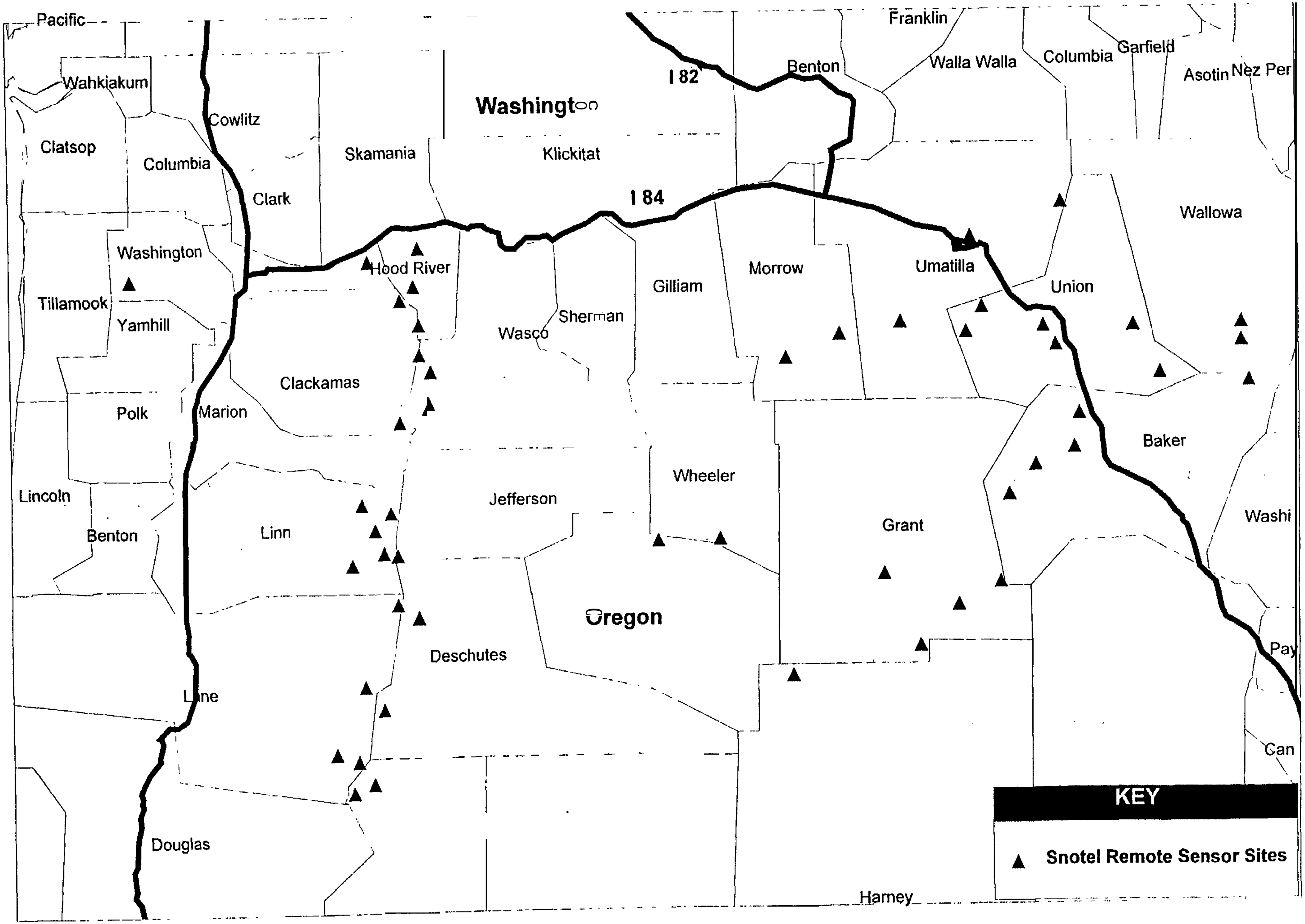


Figure 3.2.4.2-2, Meteor Burst Sites along I-84

3.5 Lease Services Which Are Candidates to Support ITS Services

3.5.1 Paging

Digital paging service provides a high speed data link to field devices (96.4 Kbps to 9.6 Kbps) with a response of 300 to 600 bps where two-way paging service is provided. Typically paging messages are limited to less than 500 byte messages from the field mobile paging device. Due to the low transmitter power output of the mobile pager, the response is limited to a lower data rate.

Paging is emerging in the digital cellular telephone market with digital paging displayed on the portable cellular telephone. This service is typically at 9.6 Kbps to 19.2 Kbps with data rate not limited and duplex communications supported. This, however, is classified under cellular telephone service rather than paging service.

A survey was made of paging service along the corridor which is summarized in **Table 3.5.1-1. Figure 3.5.1-1** summarizes the coverage.

Table 3.5.1-1
I-84 Corridor Pager Coverage Survey

WestLink: l-503-228-2255 ▪ One-Way Service ▪ No coverage between La Grande and Ontario ▪ In some of the remote areas communication is via numeric echo
Air-touch (formerly U.S. West): l-503-288-2370 ▪ One-Way Service ▪ No coverage east of Multnomah Falls near Portland
SkyTel: l-800-858-4338 • Two-Way Service ▪ No coverage outside of the Portland/Vancouver area
AT&T: 1-800-305-9494 ▪ One-Way Service? ▪ No coverage outside of the Portland/Vancouver area

Basically, WestLink is the only service supporting the rural corridor area. They do not support two-way communications. Thus paging becomes a candidate only for transmitting data from a TOC to rural controllers. Another communications medium would be required to receive data from a field controller. Furthermore, coverage is available only from Portland to La Grande.

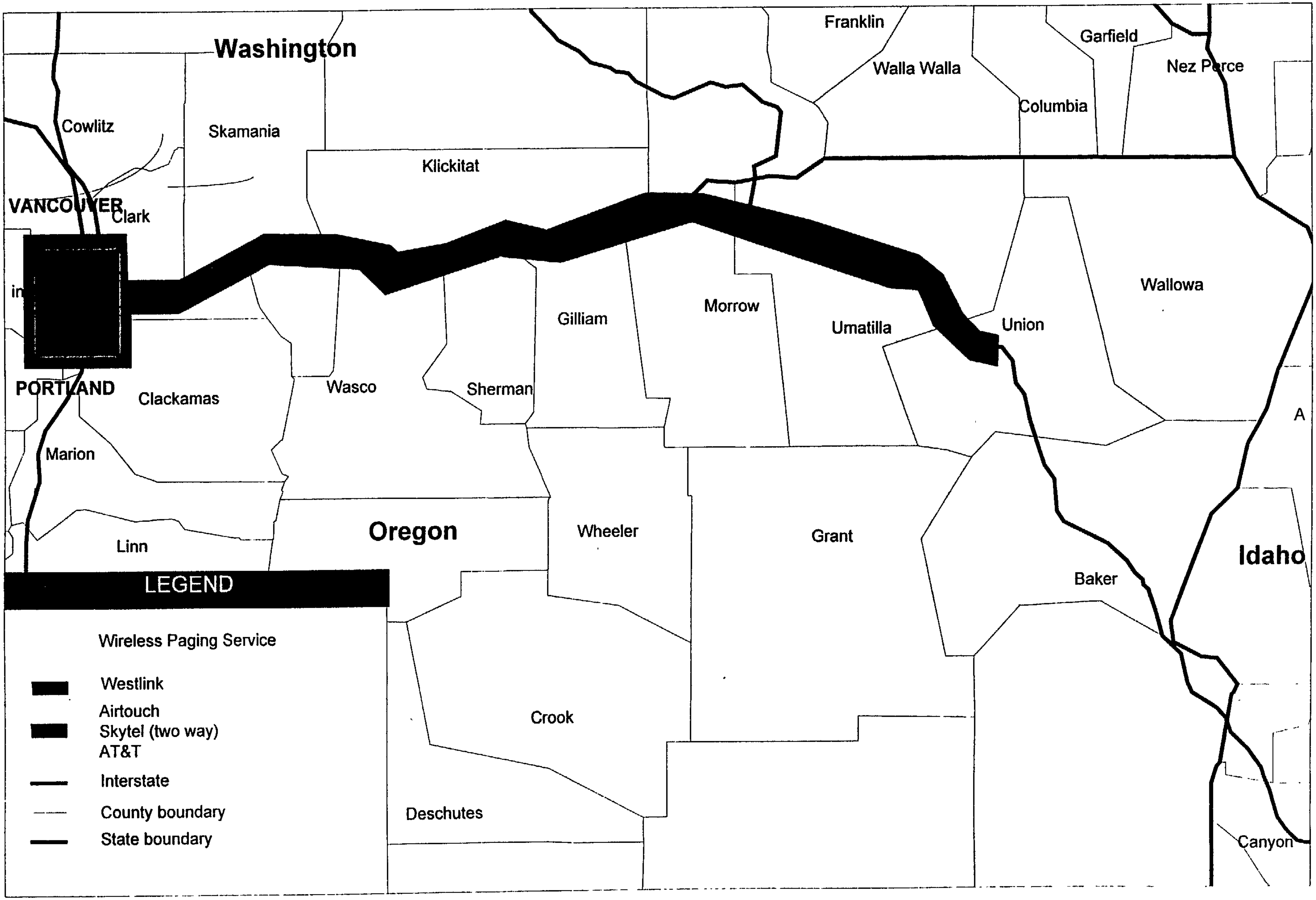


Figure 3.5.1-1, Corridor Digital Paging Coverage

Two-way paging is a communications candidate for urban Portland and Vancouver ITS applications. Benefits of using paging service include reasonably low cost ($20.00/month). Disadvantages are:

- Delays in access;
- Limited two-way capability, and;
- Not designed to support real-time operations; limited message lengths.

3.5.2 Cellular Telephone

The corridors are fully covered by cellular telephone service. **Table 3.5.2-l** provides an overview of the service suppliers and common service brand name. AT&T wireless service and Cellular One provide full brand name cellular service over the corridors of interest as shown in **Figure 3.5.2-l.** AT&T Wireless service provides coverage into Idaho from Ontario.

The current technology is analog voice operating under the Advanced Mobile Phone Service (AMPS) standard. Cellular Digital Packet Data (CDPD) standard upgrade to AMPS is planned by AT&T Wireless service. The AT&T CDPD capability is scheduled to be completed by the end of **1997. Table** 3.5.2-2 summarizes the two standards and **Figure** 3.5.2-2 illustrates the areas and time period when digital cellular capability is scheduled to be available.

AT&T Wireless service has the State contract for wireless service in Oregon and Washington. The State contract for analog voice is 14C/minute any time (no peak period pricing). The contract for digital service has not been negotiated since the service is not yet available.

According to AT&T Wireless service, the cell sites are of adequate density within the major urban areas to provide excellent communications service within a 35 mile radius of the center of major cities (including Portland, Vancouver and Boise). In the rural areas of I-84, a 3 watt mobile telephone provides good communications except for a few areas around La Grande and Baker City. The issue is terrain and density of cell sites which will be improved as communications demand increases in the rural area. In fact, Cellular One plans include deploying more cell sites in the future along the eastern portion of I-84. The low powered portable cellular telephones will encounter periodic areas along the rural corridor where communications may fade. Again, this is due to the lower density of cell sites requiring longer communications distances (thus three watts), terrain and foliage which attenuates the radio frequency signal.

AT&T Wireless service states that they offer emergency service calls free of charge to 911 and that coverage of the corridor is adequate to support "Mayday" communications via voice or digital cellular. AT&T Wireless services and Cellular One claim to offer speed dial access to weather and traffic/road conditions information via cellular.

AMPS cellular will support digital communications utilizing analog modems. The new modems support:

- AMPS or CDPD Digital
- Adaptive Data Rate for AMPS (based on link signal/noise)

Table 3.5.2-l
Celhlar Telephone Service Overview

Service Area	Counties	A Carrier	B Carrier	Common Service Name
Portland MSA	Clackamas Multnomah Washington (in Washington State: Clark)	AT&T Wireless	U.S. West Cellular	AT&T
Salem MSA	Marion Polk	AT&T Wireless	U.S. West Cellular	AT&T
Eugene MSA	Lane	AT&T Wireless	U.S. West Cellular	AT&T
Medford MSA	Jackson	AT&T Wireless	U.S. Cellular	AT&T
Oregon Rural Service Area (RSA) #I	Columbia Clatsop Yamhill Tillamook	Crystal Corns; Managed by ATTWS	U.S. West Cellular	Cellular One
Oregon Rural Service Area (RSA) #2	Hood River Gilliam Wasco Wheeler Sherman Jefferson	AT&T Wireless	U.S. Cellular	AT&T
Oregon Rural Service Area (RSA) #3	Marrow Baker Umatilla Grant Wallowa Malheur Union	Blue Mountain Cellular	U.S. Cellular	Cellular One
Oregon Rural Service Area (RSA) #4	Lincoln Linn Benton	Point Communi-cations	U.S. West Cellular	Cellular One
Oregon Rural Service Area (RSA) #5	coos Curry Douglas Josephine	U.S. Cellular	Ramcell; Managed by ATTWS	Cellular One
Oregon Rural Service Area (RSA) #6A	Harney Klamath Crook Lake Deschutes	Point Communi-cations	U.S. West Cellular	Cellular One
Oregon Rural Service Area (RSA) #6B	Pacific Wahkiakum Lewis Cowlitz	AT&T Wireless	U.S. Cellular	AT&T
Oregon Rural Service Area (RSA) #7	Skamania Klickitat	AT&T Wireless	U.S. Cellular	AT&T

Note: MSA = Metropolitan Service Area
RSA = Rural Service Area
ATTWS = AT&T Wireless Service
A Carrier = per FCC; lower cellular band
B Carrier = per FCC; upper cellular band

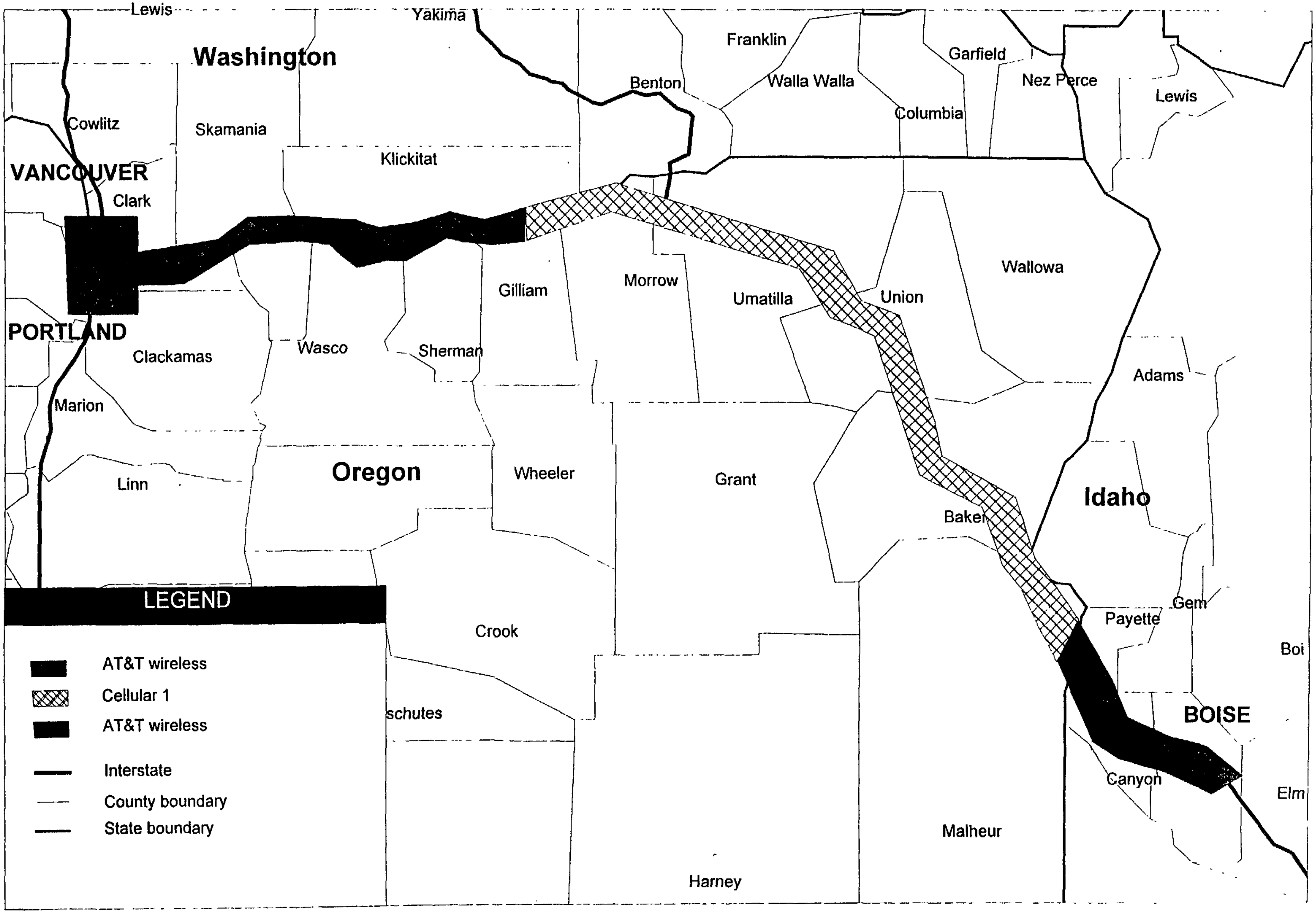


Figure 3.5.2-1, Corridor Voice Cellular Coverage

Table 3.5.2-2
Cellular Service Standard Along the Corridor

Standard	AMPS (Advanced Mobile Phone Service)	CDPD (Cellular Digital Packet Data)
Function	Voice (Analog)	Voice (Analog) and Digital Data
Frequency (MHz) Base to Mobile Mobile to Base	 **869-894** **824-849**	 **869-894** **824-849**
RF Channel Spacing (MHz)	30	30
Modulation	FM	Gaussian Minimum Shift Keying (GMSK)
Number of Channels	832	832
Channel Access Multiplexing	Frequency Division Multiple Access (FDMA)	FDMA
Multiuser Access	Data Sense Multiple Access (DSMA)	DSMA
Data Rate Kbps	300-9.6 Kbps (adaptive analog modem)	19.2
Digital Message Length (bits)	Variable	**24-928**

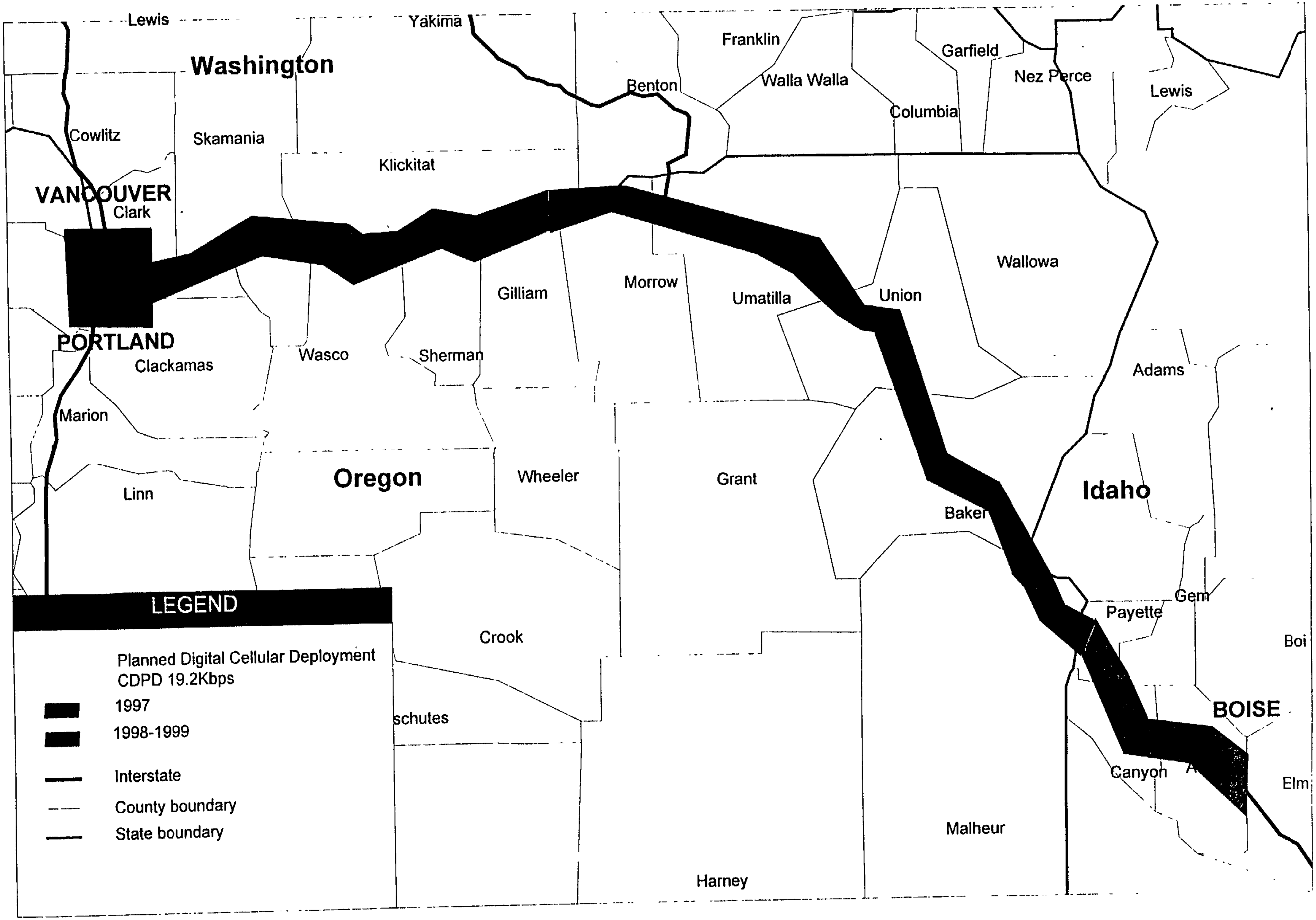


Figure3.5.2-2, Digital Cellular Service Plans (CDPD)

Highway Master (a commercial vehicle automatic vehicle location, status reporting and dispatching coordination service offered on a National basis) utilizes AMPS and analog modems.

CDPD service supports reliable digital data transmission at 19.2 Kbps with an effective throughput of 10 Kbps based on overheads and data message limits.

One issue which may arise is the conversion to digital voice. Currently there are two competing technologies:

- Time Division Multiple Access (TDMA) defined by IS-54 standard
- Code Division Multiple Access (CDMA) defined by IS-95 standard and supported by QualCom

A pseudo common standard between RSAs and MSAs exist along the corridor with both AT&T Wireless Service and Cellular One committed to IS-54. This is important since IS-54 and IS-95 standards are incompatible. This could, in the future, still provide a problem for National CVO operations coming from areas having IS-95 standard. However, there is development effort underway to provide an adaptive digital voice cellular telephone which will operate with either standard. The cellular telephone will obviously be more costly adapting to the two standards. Possibly this multiple standard technology will be in product form in the next few years.

In summary, AMPS is the current service; CDPD is anticipated to be added across the corridor in the next several years. The system(s) will ultimately be upgraded to digital voice with IS-54 being the leading candidate for Cellular One service. Analog digital modems effectively operate along the corridor at this time.

3.5.2.1 Potential Application of Cellular Telephone Service

There are numerous classical applications of cellular telephone to ITS. These include hazardous conditions reporting and traveler information request. Many cellular service companies provide speed dial capability for:

- 911 Emergency
- Weather Request
- Traveler Information Request

Some cellular companies are offering “yellow page” service to customers. **Table 3.5.2.1-1** provides an overview of cellular telephone service potential applications, both for digital and voice.

Advanced “Mayday” service has evolved through industry initiative. Car manufacturers, in an effort to enhance car sales, have added a capability to vehicles similar to the security systems in homes. The “Mayday” system includes:

- Sensors which automatically detect and report the seriousness of an accident.
- Ability of the vehicular computer to report the nature and extent of a mechanical or electrical problem.

- Manual ability to activate a specific Mayday report including robbery.

Table 3.5.2.1-1
Some ITS Applications of Cellular Telephone Service

	Cellular Voice	Cellular Digital
Public Works Vehicles Coordination	Yes	Yes
Motorist Assistance Patrol Coordination with TOC and Emergency Service Support	Yes	Yes
ITS Equipment Mobile Maintenance Crew Coordination with the TOC and Maintenance Operations	Yes	Yes
Hazardous Conditions and Incident Reporting by Travelers	Yes	Yes
Emergency Service Request by Travelers (Private)	Yes	Yes
Traveler Information Access by Travelers (Private)	Yes	Yes
Roadside Cellular Call Box (Public)	Yes	No
Integrated Sensor(s)/Controller(s) with Call Box ("SMART" Call Box)	Yes	Yes
Digital Cellular Link from TOC-to-Field Controllers	Yes (HAR only)	Yes
Probe Vehicles	Yes (manual)	Yes (if automated)
Commercial Vehicles Coordination with Dispatching	Yes	Yes (if automated)
Advanced ITS "Mayday"	Yes	Yes
"Yellow Page" Service Support	Yes	Yes (if automated)

The new "Mayday" systems are typically integrated with the Global Positioning System (GPS)/Route Guidance System of the vehicle thus automatically reporting vehicle identification and location along with the emergency problem. The communications linkage is cellular to a monitoring center which:

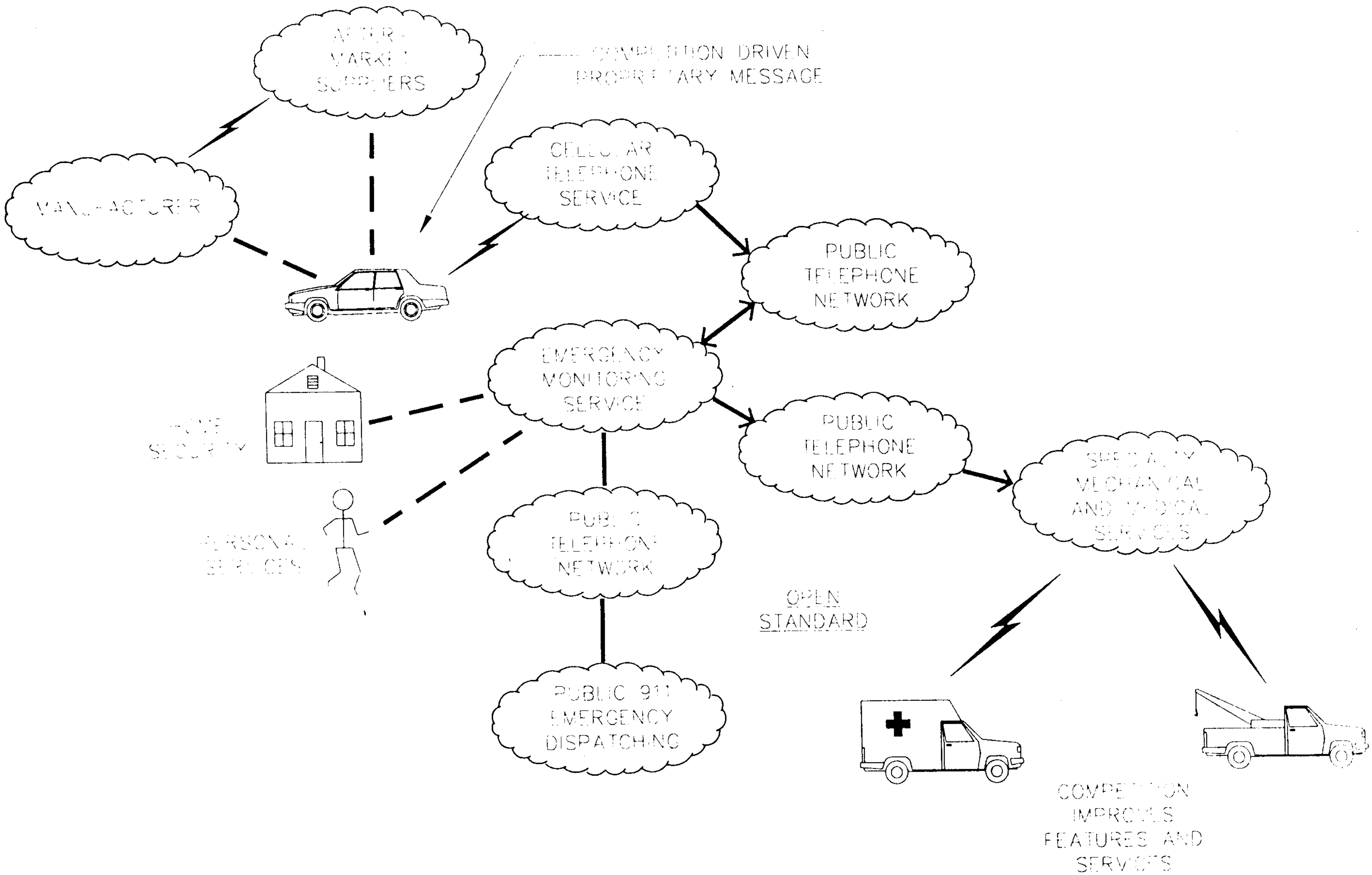
- Clears false alarms
- Directs the emergency to the nearest and correct emergency service supplier
- Monitors clearance of the emergency

Westinghouse Security supports the Ford Motor Company "RESCU" Mayday; General Motors, Inc. has selected Electronic Data Systems, Inc. as their clearinghouse. Other emergency monitoring companies include:

- CarCorp (ADT Security and Mobile Security Communications)
  - $700 for in vehicle system and $17.95/month around the clock monitoring fee
- OnCard (ATX, Inc.)
  - $695 to $995 for in vehicle system and $14.95/month monitoring fee
- AutoLink (Prince Corp.)
  - SkyTel two-way paging
  - $20/month

Figure 3.5.2.1-1 illustrates the emerging "Mayday" system architecture and communications links. It is anticipated that the trend will continue to grow for "Mayday" and related services. The trend will continue with:

- Car manufacturers setting their own standards and features to enhance sales.
- After market suppliers teaming up with service suppliers, adopting service supplier standards
- Service suppliers providing tailored monitoring services on a 24 hour/day, 7 days per week basis for a fee and:
  - Providing standard interface to 9 11 services
  - Providing tailored interfaces to car repair services based on vehicle type and manufacturer



EMERGENCY "MAYDAY" APPROACH

Figure **3.5.2.1-1**

This emerging trend is healthy because:

- It provides competition
- Promotes new business (service monitoring companies)
- Provides best service for users
  - Get the "right" maintenance service for their vehicle
- Offloads false alarm clearance by emergency service providers and TOCs
- Requires no special provisions by TOCs
  - Other than real-time coordination of verified incidents as a traffic information source

Figure 3.5.2.1-2 illustrates the results of a recent market research study related to consumer interest in traveler related services. The study included 10 focus groups conducted by Driscoll/Wolfe Marketing and Research Corp. The highest interest was designated a "7" with "0" representing little interest. Emergency monitoring or "Mayday" was considered to be very high. For this reason, good digital and voice cellular service should be encouraged along the corridor.

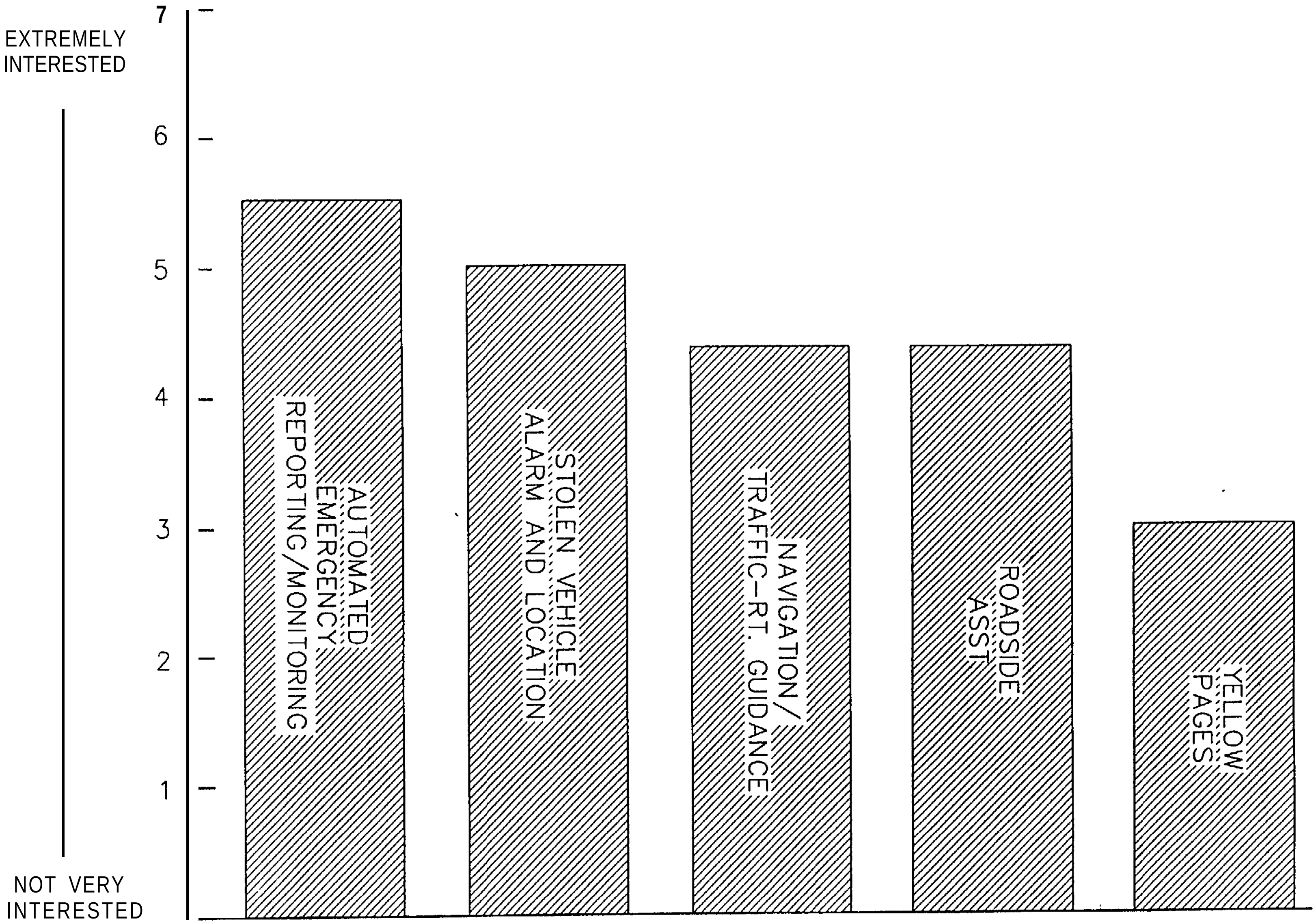
3.5.3 Private Data Networks (PDNs) and Personal Communications Services (PCS)

Private data networks, such as ARDIS, operate in the 800 MHz band with 45 MHz separation between transmit and receive frequencies. Older systems operated at 4800 bps per 25 KHz channel utilizing MDC-4800 protocol. New systems utilize RD-LAP protocol supporting 19.2 Kbps. Effective user data rate is 8000 bps. Base station power is 40 watts Effective Radiated Power (ERP) with portable units operating at 4 watts ERP. Modulation is Frequency Shift Keying (FSK) and frequency division multiple access is utilized. Transmission packet length is limited to 256 Kbytes.

MOBITEX was introduced by RAM Mobile Data in 1991 and covers 7500 or more cities and towns. MOBITEX operates in the 896-901 MHz band for transmit and base stations transmit at 932 to 940 MHz. Mobile units operate to 10 watts ERP and portable units operate to 4 watts ERP.

The IS-95 (CDMA) digital standard is designed to operate as follows:

Base to Mobile Frequency (MHz)	869-894
Mobile to Base Frequency (MHz)	824-849
RF Channel Spacing (MHz)	1.25
Channel Access	FDMA
Multiuser Access	DSMA
Modulation	4 PSK
Channel Bit Rate (Kbps)	9.6
Packet Length Bytes	256
Open Architecture	Yes
Service Coverage	All CDMA service areas
Type Coverage	Mobile



IN VARIOUS TRAVELER SERVICES

Figure 3.5.2.1-2

IS-95 standard is anticipated to be a major competitor in both PDNS and digital voice services.

The Federal Communications Commission (FCC) has reformed the 2 GHz microwave band allocating it to PCS applications. PCS spectrum is 1850 MHz to 1990 MHz. The FCC has allocated two (2) 30 MHz blocks (60 MHz) for PCS systems in each of 51 Major Trading Areas (MTAs) and one (1) 30 MHz and three (3) 10 blocks (60 MHz total) for PCS system licenses in 493 smaller (Base) Trading Areas (BTAs). By law the PCS licenses must have 33% operation in five (5) years and 60% in ten (10) years. These frequencies will be utilized to provide special communications services including microcellular communications.

No extensive survey was made of PDNs nor PCS networks because:

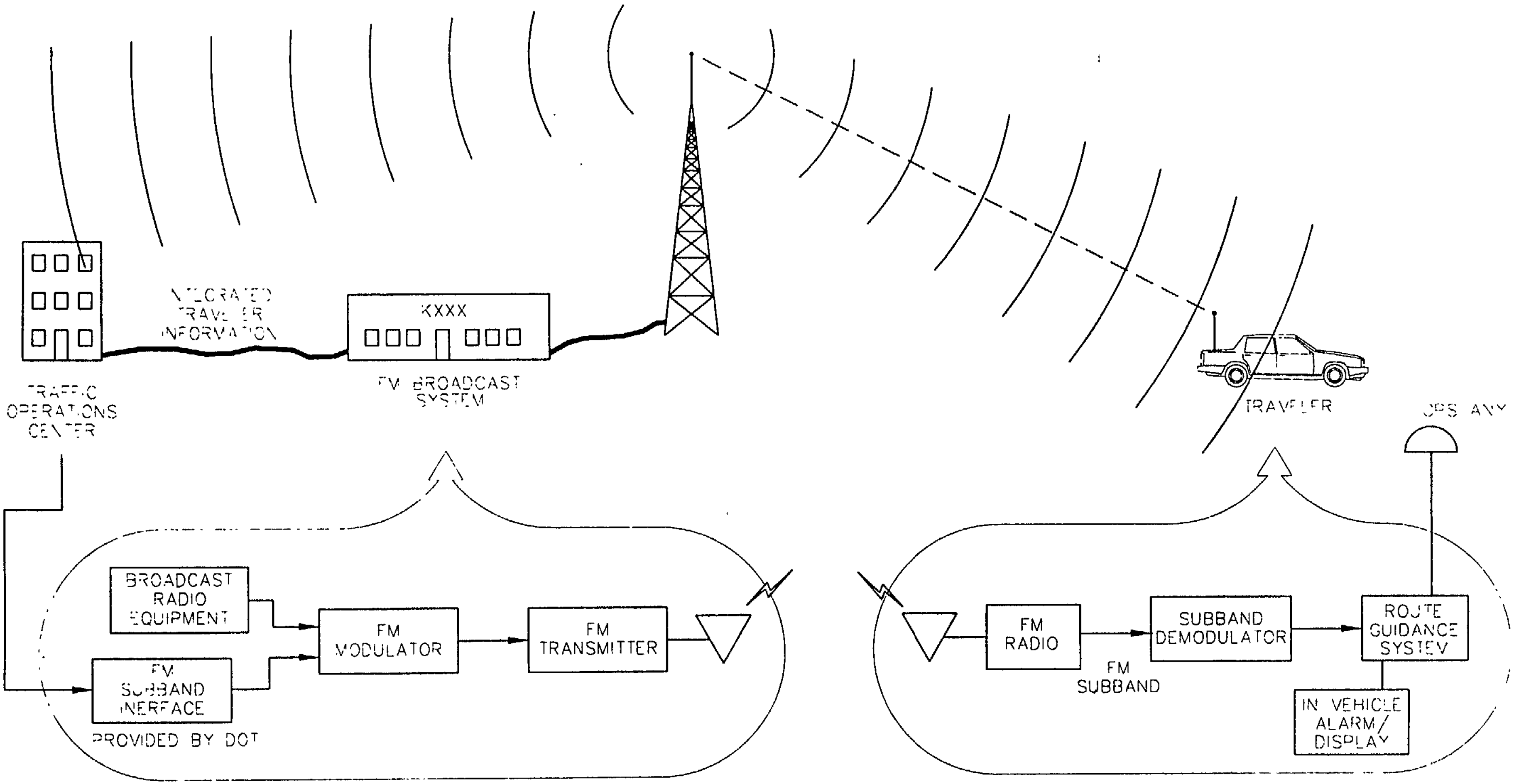
- PCNs are focused on urban areas
- PCS services are just emerging

Based on survey of primary cellular service providers, no PCN nor PCS services were identified along the corridor. The focus was on refinement of the deployed cellular network with evolutionary upgrade to digital.

3.5.4 FM Radio Station Coverage

FM radio provides a communications medium for infrastructure-to-vehicle communications. Classical use of FM radio stations are to provide voice messages related to traffic conditions. Some jurisdictions have purchased FM radio stations to provide wide area Highway Advisory Radio (HAR). Per FCC regulations, unlicensed HAR must be AM; therefore a licensed FM radio station is necessary to support traffic conditions broadcast via FM.

The new technology for ITS involves use of FM digital subband communications between infrastructure and the vehicle. Several cities including Seattle and Phoenix utilize FM digital subband for real-time distribution of corridor conditions information to vehicles. Some 1992 and newer vehicles are available with FM subband channel capability. The subband output is interfaced with the vehicle route guidance system. The results are that the route guidance system receives hazards location for driver warning, displayed and alarmed to the driver as the vehicle approaches the hazard. Thus time and distance from vehicle to the hazard are optimized for maximum effect on the driver and thus safety. The route guidance system further receives corridor travel time and congestion status; therefore, trip route planning can be optimized based on either minimum travel time or minimum travel distance. **Figure 3.5.4-l** illustrates the interfaces involved with FM digital subband communications, referred to as Radio Data Services (RDS) or Radio Broadcast Data Service (RBDS).



FM DIGITAL SUBBAND (RADIO DATE SERVICE)
SUPPORTING INTEGRATED TRAVELER INFORMATION SERVICE

Figure **3.5.4-1**

There are several RDS standards which have evolved from industry and a new standard developed by the FHWA and MITRE Corp. The FHWA standard was implemented for test by Scientific Atlanta Inc. The standards most freqeuntly displayed are industry standards which are compatible with production equipment. The FHWA standard provides higher performance and may be adapted by the manufacturers of car radios and route guidance systems.

There is little question that RDS will become the standard communications link from infrastructure- to-vehicle. The reasons are:

- Very low cost to the jurisdiction
- Compatible with standard vehicular equipment
- Supports GIS location of hazards thus making it effective for hazards warning
- Provides wide coverage as needed for vehicles traveling over medium and long distances
- Proven technology operating in Europe for over 15 years

RDS is capable of controlling radio frequency selection. The technology was developed originally in Europe so that a vehicle could automatically maintain the same program(s) as it transitioned through several countries (each with different broadcast frequencies). Thus it is feasible for RDS technology to automatically maintain contact with an FM channel supporting ITS during rural travel.

A survey was made of FM radio coverage along the corridor and is summarized in **Table 3.5.4-l.** Findings are:

- No single station covers the total corridor.
- An area between The Dalles and Hermiston has coverage problems.
- The best FM station covers 62% of the corridor.
- A minimum of three (3) station frequency changes will be necessary to cover the corridor.

Figure 3.5.4-2 illustrates FM radio coverage.

Another emerging application for FM digital subband communications is in support of automated vehicle location (AVL) applications utilizing GPS. High accuracy AVL is achieved by utilizing a navigation technique known as differential GPS. Basically the location of a vehicle is determined relative to a known fixed location as determined by GPS signal integration. The differential information is transmitted to vehicle navigation equipment utilized RDS. ACC-Q-Point (Magnavox and CVE Network Corp.) offers a differential GPS capability compatible with the Radio Technology Commission for Maritime Services RTCMS standard SC- 04 (differential GPS).

High accuracy (l-5 meter circular error of probability) GPS is more important to urban ITS due to the close proximity of streets and decision points. However, with the versatility of RDS, it should be considered as a communications resource for ITS projects.

Table 3.5.4.-1

FM Radio Stations Available in the I-84 Corridor

From Portland to Boise

	Cities												
FM Stations	Portland/ Vancouver	Troutdale	Cascade Locks	Hood River	The Dalles	Hermiston	Pendleton	Meacham	La Grande	Baker City	Ontario	Boise, ID	Tri-Cities, WA
87.7												■	
88.3	■	■	■										
89.1	■	■											■
89.5											■	■	
89.9	■	■							■				
90.1					■								■
90.3											■	■	
90.7	■	■								■			
90.9						■	■	■					■
91.3													■
91.5	■	■	■	■	■					■	■	■	
92.3	■	■	■								■	■	
92.5						■	■	■					■
93.1											■	■	
93.3						■	■	■					■
93.7	■	■	■										
94.1											■	■	
94.3				■			■						
94.5								■					
94.7	■	■	■										
94.9						■	■	■			■	■	■
95.3									■	■			
95.5	■	■	■										
95.7						■	■	■					■
95.9					■								
96.5									■				
96.9											■	■	
97.1	■	■	■			■	■	■					■
97.7				■	■								
97.9						■	■	■			■	■	■
98.3													■
98.5	■	■	■										
98.7									■				
99.1					■								

FM Stations	Portland/ Vancouver	Troutdale	Cascade Locks	Hood River	The Dalles	Hermiston	Pendleton	Meacham	La Grande	Baker City	Ontario	Boise, ID	Tri-Cities, WA
99.5	■	■	■								■	■	
99.9			■										
100.1									■				■
100.3	■	■	■								■	■	
101.1	■	■	■										
101.3													■
101.9	■	■	■								■	■	
102.1								■					
102.3					■								
102.7						■	■	■					■
103.3	■	■	■								■	■	
103.5						■	■						■
104.3											■	■	
104.5			■	■	■								
104.7								■	■	■			
105.1	■	■	■								■	■	
105.3								■					■
105.5				■				■					■
105.9											■	■	
106.5								■					■
106.7	■	■	■										
107.4													
107.5	■	■	■								■		
107.7						■	■	■					■
107.9											■	■	

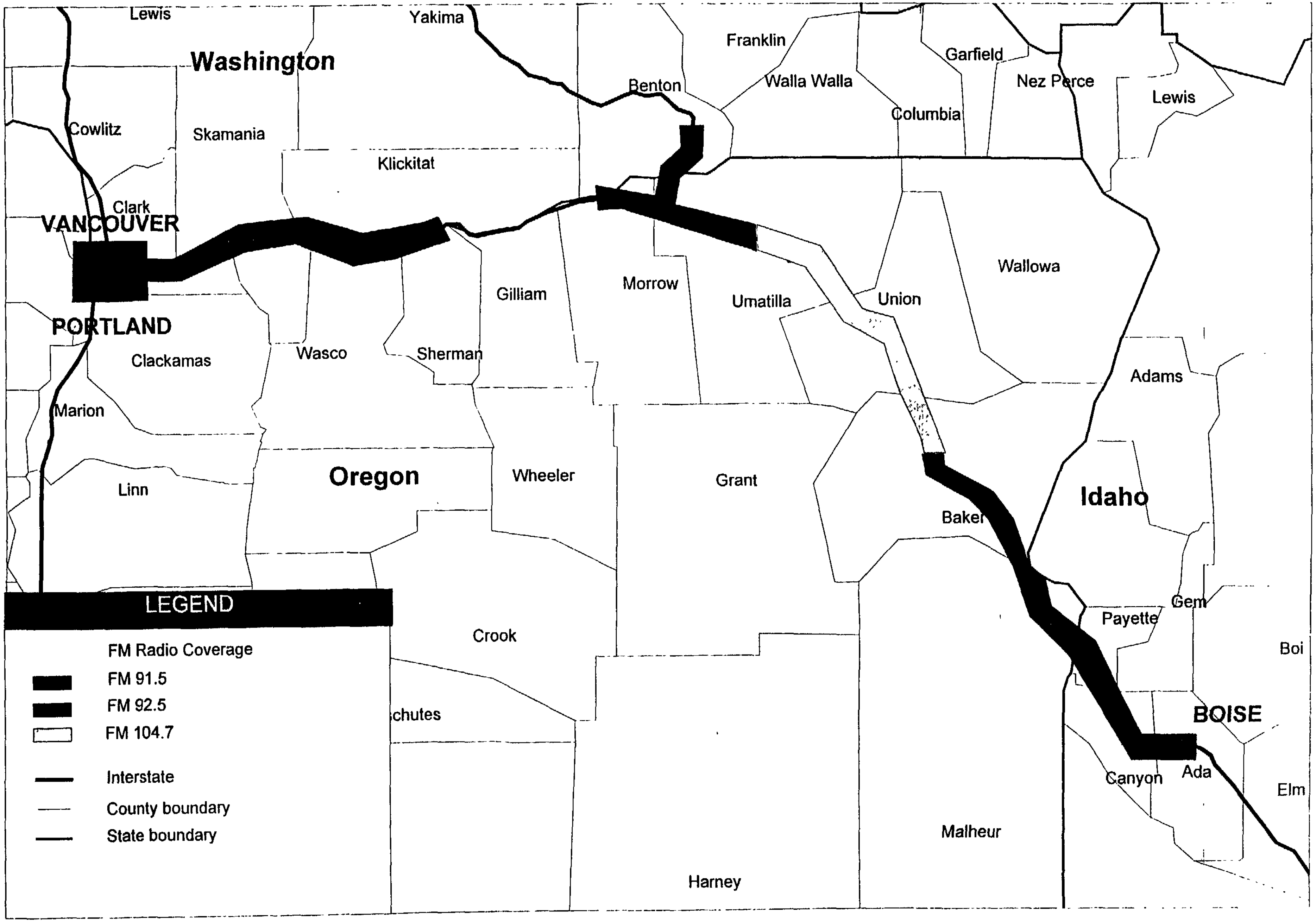


Figure3.5.4-2, FM Radio Coverage of the Corridor

3.5.5 Satellite Services

Satellite coverage of a corridor is very important to support commercial vehicle operations. Low orbit satellites are being developed to augment cellular telephone cell sites. With lower orbits, the lower power of cellular telephone transceivers can be received by the satellite.

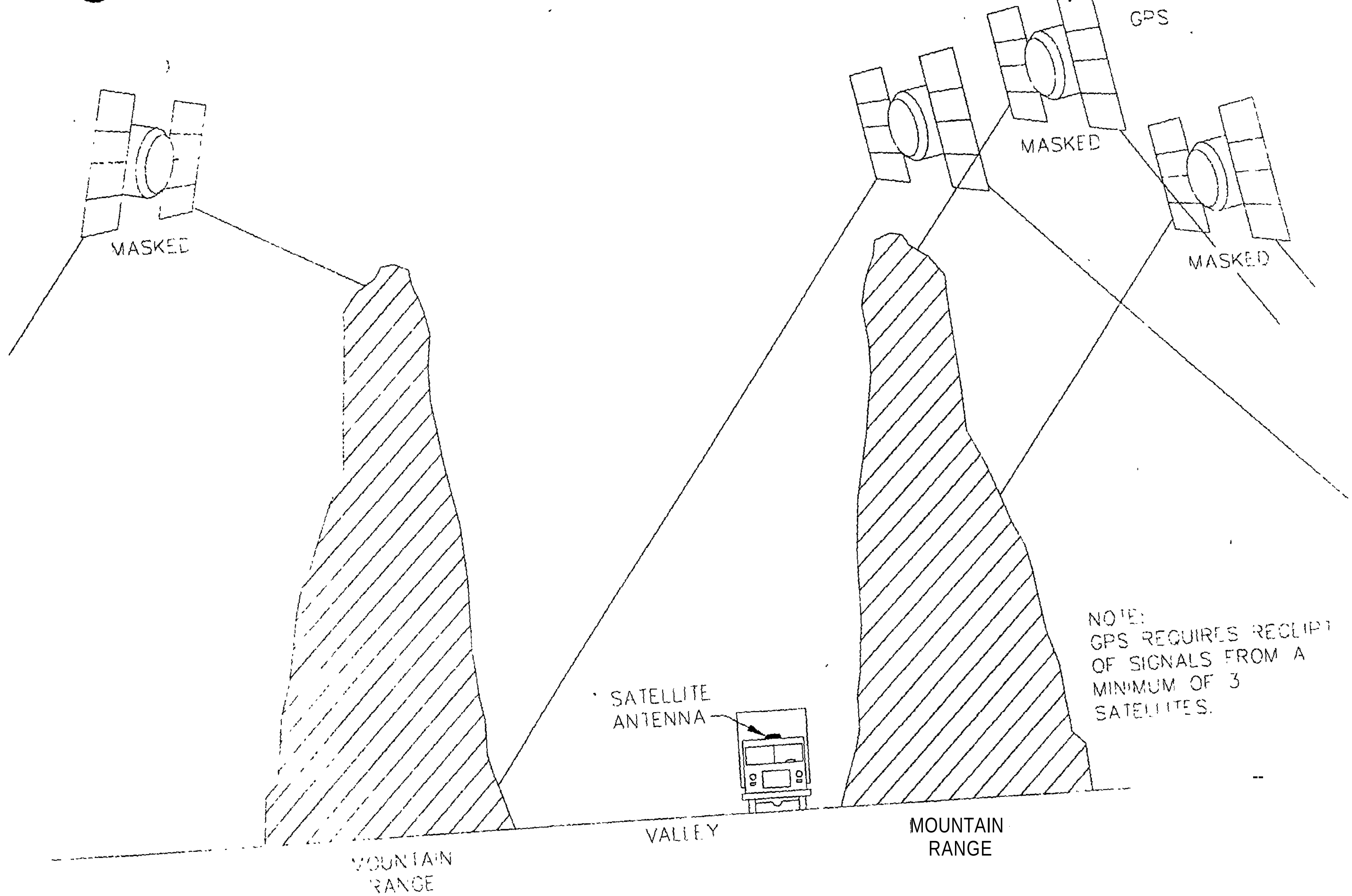
Currently satellites perform two (2) important functions along the corridor. These functions include:

- Global Positioning Satellite (GPS) coverage to support:
  - AVL enhancing commercial vehicle fleet management
  - Route guidance for commercial and private vehicles
  - "Mayday" automated location reporting
  - Automated tracking off police and emergency service vehicles along the corridor
  - Probe vehicle time/position reporting utilized for corridor traffic flow rate and volume estimates
- Communications between commercial vehicles and CVO dispatching related to vehicle/trip status and location and in support of messaging between CVO dispatching and drivers.
  - Also can support emergency vehicle AVL and Automated Vehicle Management (AVM) functions
- Station vehicle location support

In general, satellite coverage of the corridor exists. Terrain masking of radio line of sight between the vehicular antenna and the satellites may occur at various locations, especially in mountainous valleys as shown in Figure 3.5.5-l. Masking can also occur in urban areas caused by large building structures.

Several trucking companies interviewed utilize different satellite services:

- May Trucking
  - Utilize Rockwell manufactured vehicular satellite terminals and associated satellite communications services (Path MasterTM).
- Swift Trucking
  - Utilize .QualCom manufactured vehicular satellite terminal and associated satellite communications service.
  - Reports a few "dead spots" along the corridor as expected but generally full corridor coverage.



EXAMPLE OF TERRAIN MASKING OF SATELLITES

Figure 3.5.5-1

- Leprino Transportation Co. (fleet of 250 tractors and 350 trailers logging over 25 million miles per year)
  - Utilize QualCom manufactured vehicular satellite terminal equipment and OmniTracsTM communications service provided by QualCom

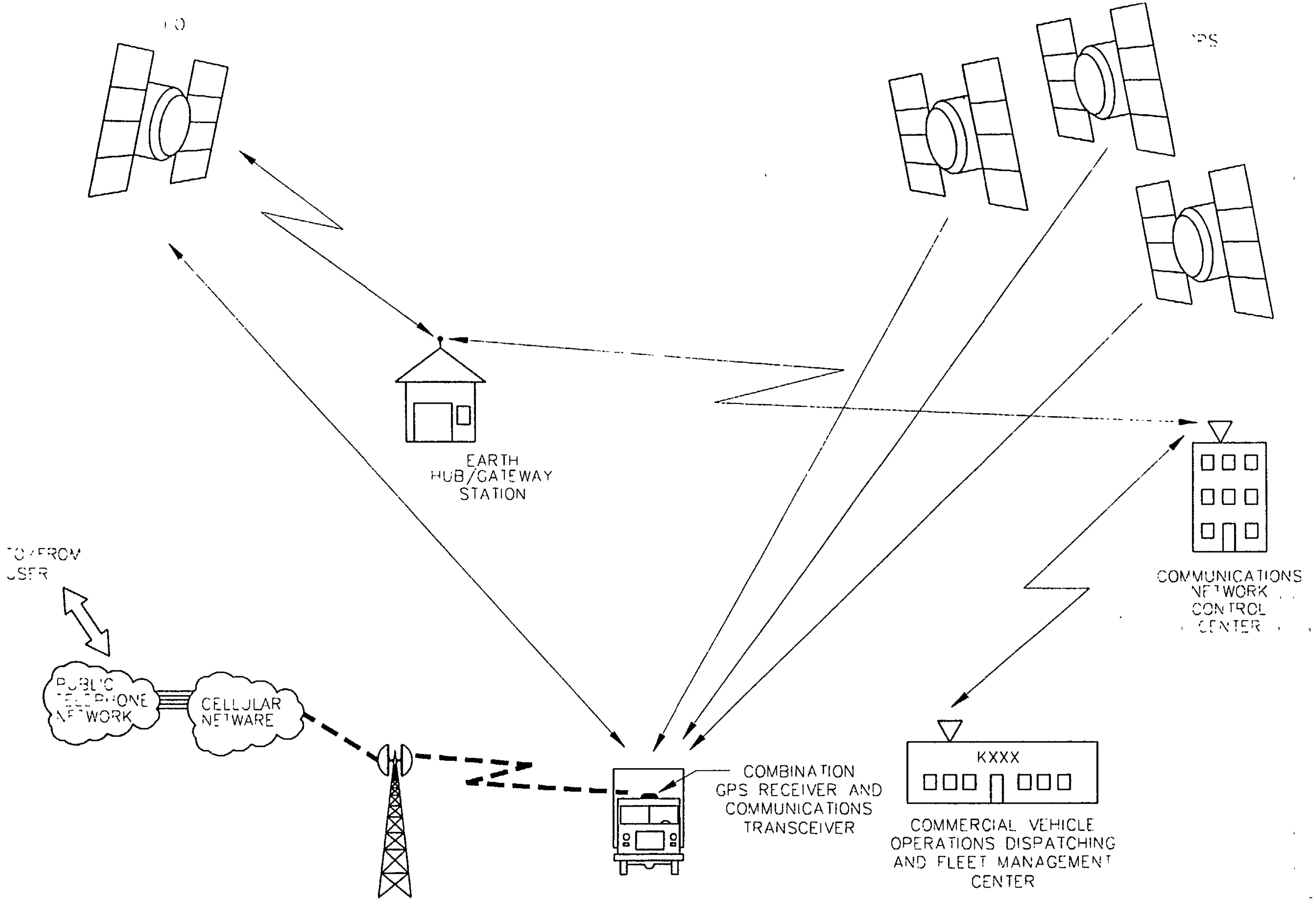
Robert Pritchard of the American Trucking Association Foundation (ATA) states that 40% of the major trucking companies now utilize AVL/AVM equipment within their commercial vehicles. ATA further indicates that the majority of major trucking companies utilizing AVL/AVM prefer satellite services at this time.

Highway Master is an AVL/AVM service which started with the use of LORANC positioning and reporting via cellular telephone. GPS has been added as an option for AVL; however cellular telephone with analog modems are still utilized to support vehicle-to-dispatching center communications. Highway Master is utilized along the corridor based on interviews with Cellular One and AT&T Wireless.

Table 3.5.5-l illustrates the number of suppliers of in-vehicle equipment and associated services. **Figure 3.5.2-2** illustrates the communications links utilized to support AVL and AVM. **Table 3.5.5-2** summarizes typical cost of service.

Table 3.5.5-l
Examples of Satellite Navigation and Communications In-Vehicle Equipment Suppliers

Company	Vehicle Location and Communications Terminal Equipment Name (Trade Marked)	Country of Manufacture
America Mobile Satellite Corp.	Galaxy	USA
Arrowsmith Tech, Inc.	FleetCOM	USA
Buchner	Driver's Associate	Holland
General Motors	GuideStar	USA
Geofit, Inc.	VISAT	Canada
Magnavox, Inc.	GPS-DR	USA
Mazda	Satnav	Japan
Motorola, Inc.	TRAXAR	USA
NAVSYS, Inc.	TIDGET	USA
Navigation Systems International	Fleet-Trak	USA
NUKEN	VELOC	Germany
ORBCOM, Inc.	—	USA
Pulsearch	NavTrax	Canada
QualComm, Inc.	OmniTRACS	USA
Radio Satellite Integrators, Inc.	V-TRACK	USA
Rockwell	PathMaster	USA
STARSYS, Inc.	—	USA
Trimble	Fleet Vision	USA
Zetel, Inc.	NAUMATE	USA



COMMUNICATIONS UTILIZED IN ALM/AVM

Figure 3.5.5-2

Table 3.5.5-2
Typical Cost of AVL/AVM

Service	Service Name	Equipment cost ($)	Monthly Service Cost per Vehicle ($)
QualCom	OmniTRACS	3500-4000	70
American Mobile Satellite Corp.	Galaxy	2000	70
Highway Master	--	2000	100-200
OrbComm*	(LEO)	1000	70
STARSYS*	(LEO)	1000	70

*Not fully operational
LEO = Low Earth Orbit Satellite

4.0 OVERVIEW OF COMMUNICATIONS TECHNOLOGY

Discussed thus far in this report are communications requirements and existing communications infrastructure identified which may be candidates for meeting the communications requirements. This section provides an overview of other candidate communications technology.

One of the most important aspects of communications is adherence to the International Standards Organization's (ISO) Open System Interface (OSI) standards. These standards define 7 communications layers which must have compatibility for communications. **Figure 4.0-l** illustrates the OSI standards.

Networks usually utilize a topology as illustrated in **Figure** 4.0-2. Topologies such as STARS, rings and interworking rings adds to the fault tolerance of a network.

4.1 Current State-of-the-Art in Communications Technology

4.1.1 Local Area Communications Technology

It seems there is no area of communications technology that is growing more rapidly than LANs. In the early 1980s as PC technology was emerging, so were LANs. In the early 1980s, IEEE developed the 802.X standards which encompassed the basic concepts .of links and networks plus perfected the XEROX ETHERNET standard and IBM TOKEN RING standard. These emerged as IEEE 802.3 and 802.4 and 802.5 with the fiber version of TOKEN RING (FDDI) included in the 802.5 standard. IEEE 802.1 covers the basic standard for network architecture and addressing.

Since the early 1980s the standards for LAN technology have continued. **Table 4.1.1-1** provides a list of current standards for LANs and MANS supported by IEEE. The American National Standards Institute sponsors most of the IEEE 802.X standards.

Key IEEE standards include:

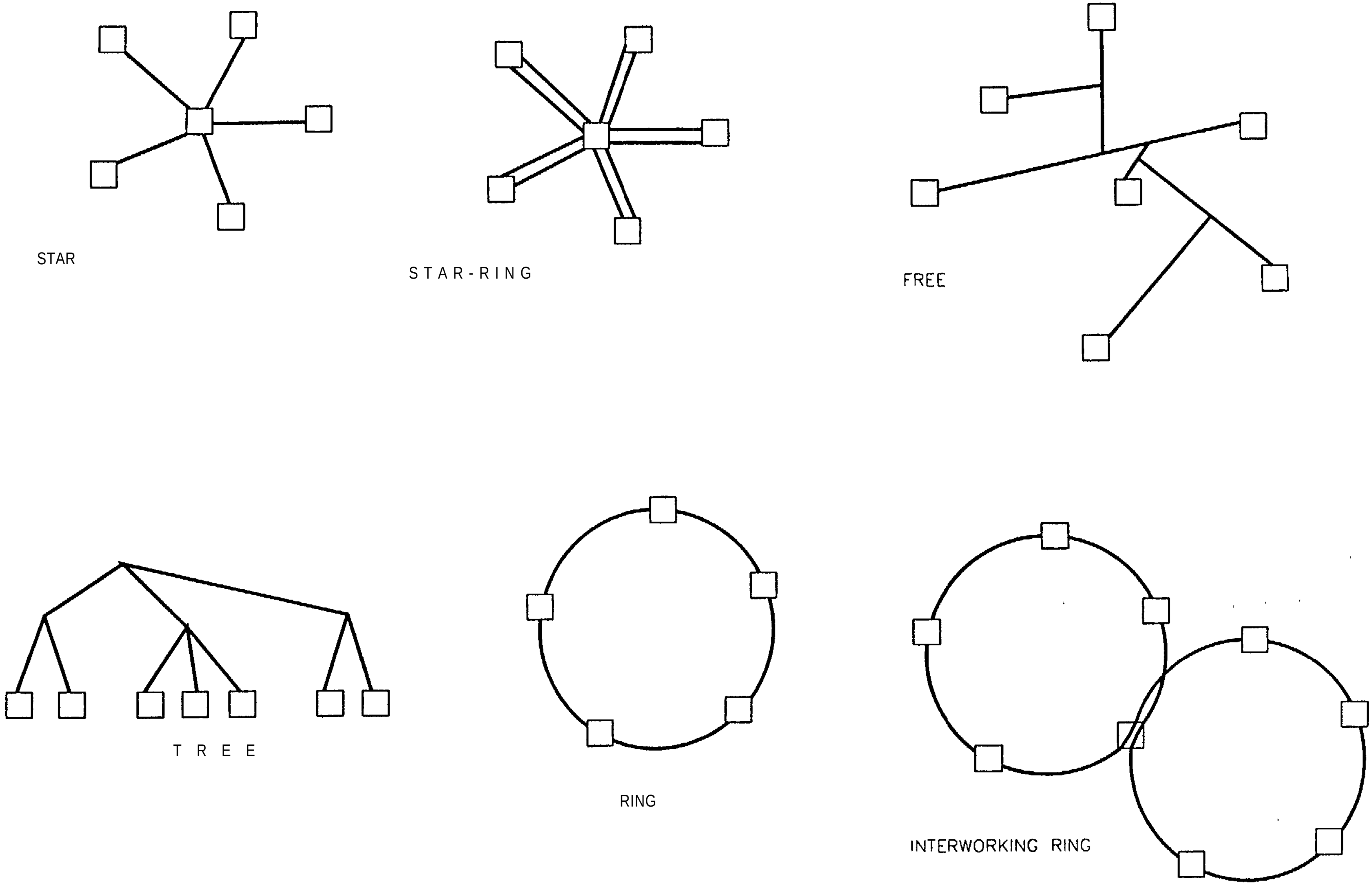
- 802.1 and 802.2: General LAN Architecture and Technology
- IEEE 802.3: ETHERNET
- IEEE 802.3d: 10BASE-T ETHERNET
- IEEE 802.3j: 10BASE-F (Fiber) ETHERNET
- IEEE 802.3u: 100BASE-T ETHERNET (Fast ETHERNET)
- IEEE 802.4: TOKEN RING
- IEEE 802.5: TOKEN RING
- IEEE 802.5j: Fiber Data Distribution Interface (FDDI) Using TOKEN RING
- IEEE 802.9: Isosynchronous ETHERNET
- IEEE 802.11: Wireless ETHERNET
- IEEE 802.12: 100 VG AnyLAN

	OSI LAYERS	TYPICAL TASK ASSIGNED	CONTROL NETWORKING REQUIREMENTS
7	APPLICATION	• USER SEMANTICS • FILE TRANSFER	• DATA OBJECTS • STANDARDIZED NETWORKING STRUCTURES
6	PRESENTATION	• DATA COMPRESSION • USER DATA CONVERSION	• NETWORKING STRUCTURES • DATA INTERPRETATION
5	SESSION	• SYNCHRONIZATION • DIALOG STRUCTURE	• AUTHENTICATION • NETWORK MANAGEMENT
4	TRANSPORT	• RELIABLE DATA TRANSFER • END-TO-END COMMUNICATION	• END-TO-END ACKNOWLEDGMENT • DUPLICATE DETECTION, AUTOMATIC RETRIES
3	NETWORK	• ROUTING, LOGICAL ADDRESSING • MAC - INDEPENDENT INTERFACE	• ADDRESSING, UNICAST, MULTICAST, BROADCAST • ROUTERS
2	DATA LINK	• MEDIA ACCESS SCHEME • ERROR CORRECTION AND FRAMING	• MAC, COLLISION AVOIDANCE/DETECTION • FRAMING, DATA ENCODING • CRC, ERROR CHECKING • TRANSCEIVER INTERFACE • PRIORITY • MEDIA TRANSCEIVERS
1	PHYSICAL	• PHYSICAL INTERFACE DEFINITION • TRANSCEIVER INTERFACE	

MAC = MEDIA ACCESS CONTROL
CRC = CYCLIC REDUNDANCY

ISO OSI STANDARD MODEL

Figure 4.0-1



TOPOLOGIES TYPICALLY USED IN NETWORKS

Figure 4.0-2

Table 4.1.1-1
Summary of Institute of Electrical and Electronic Engineers
Key Specifications Related to Local and
Metropolitan Area Networks

IEEE Standard	Title
802-1990	Standard for Local and Metropolitan Networks: Overview and Architecture
-802.1b-1995 (15802-2)	Standard for Local and Metropolitan Area Networks: LAN/MAN Management
802.1d-1993	Information Technology - Telecommunications and Information Exchange Between Systems - Local Area Networks - Media Access Control Bridges
802.1e-1996	Information Technology - Telecommunications and Information Exchange Between Systems - Local and Metropolitan Area Network: Part 4; System Load Protocol
802.1f-1993	Standard for Local and Metropolitan Area Networks: Common Definitions and Procedures for IEEE 802 Management Information
802.1h-1995	Recommended Practice for Media Access Control (MAC) Bridging ETHERNET Version 2.0 in 802 LANs
802.1k-1993	Supplement to IEEE Standard 802.1B-1992, Discovery and Dynamic Control of Event Forwarding
802.1p-1995	Standard for Local and Metropolitan Area Networks - Supplement to Media Access Control (MAC) Bridges: Traffic Class Expediting and Dynamic Multicast Filtering
802.2-1994 (8802-2)	Information Technologies - Telecommunications and Information Exchange Between Systems - Local and Metropolitan Area Networks - Specific Requirements Logical Link Control (Inclusive of 802.2a, 802.2b, 802.2d, and 802.2e)
802.2h-1995	Standard for Local and Metropolitan Area Networks - Supplement to Logical Link Control: Optional Toleration of Duplicate Information Transfer Format Protocol Data Units (IPDUs)

Table 4.1.1-1 (cont'd)

IEEE Standard	Title
802.3-1993	Information Technology, Local and Metropolitan Networks, Part 3 : Carrier Sensed Multiple Access with Collision Detection (CSMAKD) Access Method and Physical Layer Specifications
802.3-1991 (1802.3)	Conformance Test Methodology for Standards for LAN/MAN: Carrier Sense Multiple Access with Collision Detection (CSMA/CD); Access Method and Physical Layer Specifications and Attachment Unit Interface
802.361993 (1802.3d)	Supplement to 802.3-l 99 1, Type 1 OBASE-T Medium Attachment Unit, Conformance Test Methodology
802.3j-1993	Supplement to 802.3: Fiber Optic Active and Passive STAR-Based Segments, Type 1 OBASE-F
802.3k-1992	Supplement to 802.3-1993: Layer Management for 10 Mbps Baseband Repeaters
802.31-1992	Supplement to 802.3, Type 10BASE-T Medium Attachment Unit (MAU) Protocol Implementation Conformance
802.3p&q	Supplement to 802.3, Guidelines for Deployment of Managed Objects Format for Layer-Managed Objects and Layer Management for 10 Mbps Baseband MAUs
802.3t-1995	Supplement to Standard for Information Technology - Local and Metropolitan Area Networks - Part 3: Carrier Sensed ,Multiple Access with Collision Detection (CSMA/CD): Access Methods and Physical Layer Specifications: Annex for Support of 120 ohm Cables in 1 OBASE-T Simplex Link Segments
802.3u 1995	Supplement to Standard for Information Technology - Local and Metropolitan Networks - Part 3: Carrier Sensed Multiple Access with Collision Detection (CSMAKD): Access Method and Physical Layer Specifications, MAC Parameters, Physical Layer, Medium Attachment Units and Repeater for 100 Mbps Operation (100 Based ETHERNET)
802.4- 1990	Information Processing Systems - Local Area Networks - Part 4: Token-Passing Bus Access Method and Physical Layer Specifications

Table 4.1.1-1 (cont'd)

IEEE Standard	Title
802.4b-1992	Supplement to 802.4-1990: Enhancements for Physical Layer Diversity (Redundant Media Control)
802.5-1995	Information Technology - Local and Metropolitan Area Networks - Part 5: Token Ring Access Method-and Physical Layer Specifications
802.5b-1993	Supplement to 802.5-1992: Recommended Practice for Use of Unshielded Twisted Pair (UTP) for Token Ring Data Transmission at 4 Mbps
802.5c-1993	Supplement to 802.5-1992: Recommended Practice for Dual Ring Operations with Wrapback Reconfiguration
802.5j-1993	Supplement to 802.5-1992: Fiber Optic Station Attachment
802.6-1994	Information Technology - Telecommunications and Information Exchange Between Systems - Local and Metropolitan Area Networks - Specific Requirements - Part 6: Distributed Queue Dual Bus Access Method Physical Layer Specifications
802.6j-1995	Standard for LAN/MAN Networks: Supplement to Distributed Queue Dual Bus (DQDB) Access Method and Physical Layer Specifications: Connection Oriented Service on a Distributed Queue Dual Bus Subnetwork of a MAN
802.7-1989	Recommended Practices for Broadband Local Area Networks
802.9-1994	Standards for Local and Metropolitan Area Networks: Integrated Services (IS) LAN Interface at the Medium Access Control (MAC) and Physical (PHY) Layers (ISO ETHERNET)
802.9a- 1995	Standard for Integrated Services LAN: Integrated Services (IS) LAN IEEE 802.9 Isochronous Service with Carrier Sensed Multiple Access with Collision Detection (CSMA/CD) Media Access Control Service (ISO ETHERNET)
802.9d-1995	Supplement to IEEE 802.9; Integrated Services Local Area Network: Protocol Implementation Conformance Statement (PICS)
802.9e-1995	Standard for Local and Metropolitan Area Networks, Supplement to Integrated Services (IS) LAN Interface at the MAC and Physical Layers: Asynchronous Transfer Mode (ATM) Cell Bearer Mode

Table 4.1.1-1 (cont'd)

IEEE Standard	Title
802.9f-1995	Standard for Local and Metropolitan Area Networks - Supplement to Integrated Services (IS) LAN Interface at the MAC and Physical Layers: Remote Terminal Line Power for Integrated Services Terminal Equipment (ISTE)
802.10-1992	Standards for Local and Metropolitan Area Networks: Interoperable LAN/MAN Security
802.10b-1992	Standards for Local and Metropolitan Area Networks: Interoperable LAN/MAN Security: Secure Data Exchange
802.10e&f-1993	Supplement to 802.10-1992, Standard Data Exchange (SDE) Sublayer Management and Recommended Practice for SDE on ETHERNET
802.10g	Standard for Secure Data Exchange, Security Label
802.11	Standard for Local Area Network, Wireless ETHERNET
802.12-1995	Standard for Demand Priority Access Method Physical Layer and Repeater Specifications for 100 Mbps Operations (100 VG AnyLAN)
802.12a-1995	Standard for Local and Metropolitan Area Networks - Supplement to Demand - Priority Access Method, Physical Layer and Repeater Specifications for 100 Mbps Operations: Operations at Greater than 100 Mbps
802.12b-1995	Standard for Local and Metropolitan Area Networks - Supplement to Demand Priority Access Method, Physical Layer and Repeater Specifications for 100 Mbps Operations: Two Pair Balanced Cable Physical Medium Dependent (2-TP PMD); Medium Dependent Interface (MDI) and Link Specifications
802.12c-1995	Standard for LAN/MAN - Supplement to Demand - Priority Access Method, Physical Layer and Repeater Specifications for 100 Mbps Operations: Full Duplex Operation
802.12d-1995	Standard for LAN/MAN - Supplement to Demand - Priority Access Method, Physical Layer and Repeater Specifications for 100 Mbps Operations, Redundant Links

Table 4.1.1-1 (cont'd)

IEEE Standard	Title
802.14-1995	Standard for Interfacing Cable Television Over a Local Area Network
1327.1-1993	Standard for Information Technology - X.400 - Based on Electronic Messaging Interface

It is important that these standards be followed in procurement documents to assure interoperability. Some equipment have modified standards to achieve a specific performance capability; however, these equipment are not "open" in the sense that they are not fully compliant standards.

The American National Standards Institute (ANSI) has developed a companion set of standards for FDDI which include:

- ANSI X3.166: FDDI Physical Layer Specifications
- ANSI X3.148: FDDI Physical Layer Protocol
- ANSI X3.139: FDDI MAC Layer Specifications
- ANSI X3T9.5: FDDI Station Management Specifications

There is an on-going effort to develop an FDDI-II standard which operates at 155.52 Mbps and which supports Isosynchronous Operations required for voice and digital video. The problem with FDDI-II is that it provides little advantage compared with Asynchronous Transfer Mode (ATM) technology which, with an OC-3 transport (155.52 Mbps) has equivalent data rate and improved performance features.

Currently there is no significant competition between 10 BASE-T and 10 BASE-FL ETHERNET (twisted pair versus fiber). Fiber cost continues to decrease and solves noise problems on the LAN. FDDI has continued to be much more expensive (3 to 4 times) compared with ETHERNET. With the emergence of 100 BASE-T and 100 BASE-FL ETHERNET, data rate performance with FDDI has been achieved (except for distance). The 100BASE-FL interface is still significantly less expensive than the FDDI interface, and today, the cost of 10 BASE-T versus 100 BASE-T interface modules are insignificant. In fact, interface modules are now entering the market with 10/100 ETHERNET capability, adaptable both to standard and FAST ETHERNET. Also in competition with 100 BASE-XX ETHERNET is 100 VG AnyLAN (IEEE 802.12). According to Communications Systems Design Magazine, in an article by N. Westmoreland, Edition entitled "No Rest for the Weary" (Dec. 1995), 100 **VG AnyLAN** has 33%-40% of the market compared with Fast ETHERNET (100 BASE-T) and other higher performance LAN options such as ATM. However, with the lower cost of 100BASE-T and combination 10/100BASE-T interface modules, in 1996 ETHERNET expanded the margin leaving 100 **VG** AnyLAN around 30%.

ATM claims to support LANs, MANs, and WANs. It was originally specified by Bellcore under Broadband Integrated Services Digital Network Standards. The standards were refined by the ATM Forum. Bellcore specifications covering ATM include:

- TR-73585: "Asynchronous Transfer Mode Network Interface Specifications"
- GR-1113-CORE: "Asynchronous Transfer Mode Adaptation Layer Protocols"
- GR-2837-CORE: "ATM Virtual Path Functionality in SONET Rings - Generic Criteria"
- GR-2842-CORE: "ATM Service Access Multiplexer Generic Requirements"
- GR-284%CORE: "Asynchronous Transfer Mode Network and Element Management Layers, Generic Requirements"

ATM technology has the advantage over FDDI, ETHERNET, and 100 AnyLAN of:

- LAN/MAN/WAN compatibility
- Supports isochronous, multimedia
- Allows various priorities for data transfer supporting timing requirements of systems
- Optimizes communications bandwidth utilization for asynchronous, non-continuous data typical of that created by workstations
- Fully compatible with modem network routing and management technology

The disadvantage of ATM is that it is very expensive compared to ETHERNET and 100 VG AnyLAN and somewhat more expensive compared with FDDI.

Table 4.1.1-2 provides an overview of commonly utilized LANs. **Figure 4.1.1-1** illustrates the relationship of IEEE 802.3 standard to the Open Systems Interface (OSI) seven (7) layer standard. The more popular LANs are 10 BASE-T ETHERNET, 10 BASE-FL ETHERNET, 100 BASE-FX ETHERNET, 100 VG AnyLAN and FDDI. (Note FL and FX define fiber links). The trend is to utilize fiber interconnects in large centers to minimize line interconnect noise caused by electromagnetic interferences. Wire interconnects tend to be utilized in smaller centers because it is less expensive than fiber. However, the cost of fiber interconnect trend is downward. FDDI is more commonly utilized where campus extensions of LANs are involved or metropolitan area extensions are involved.

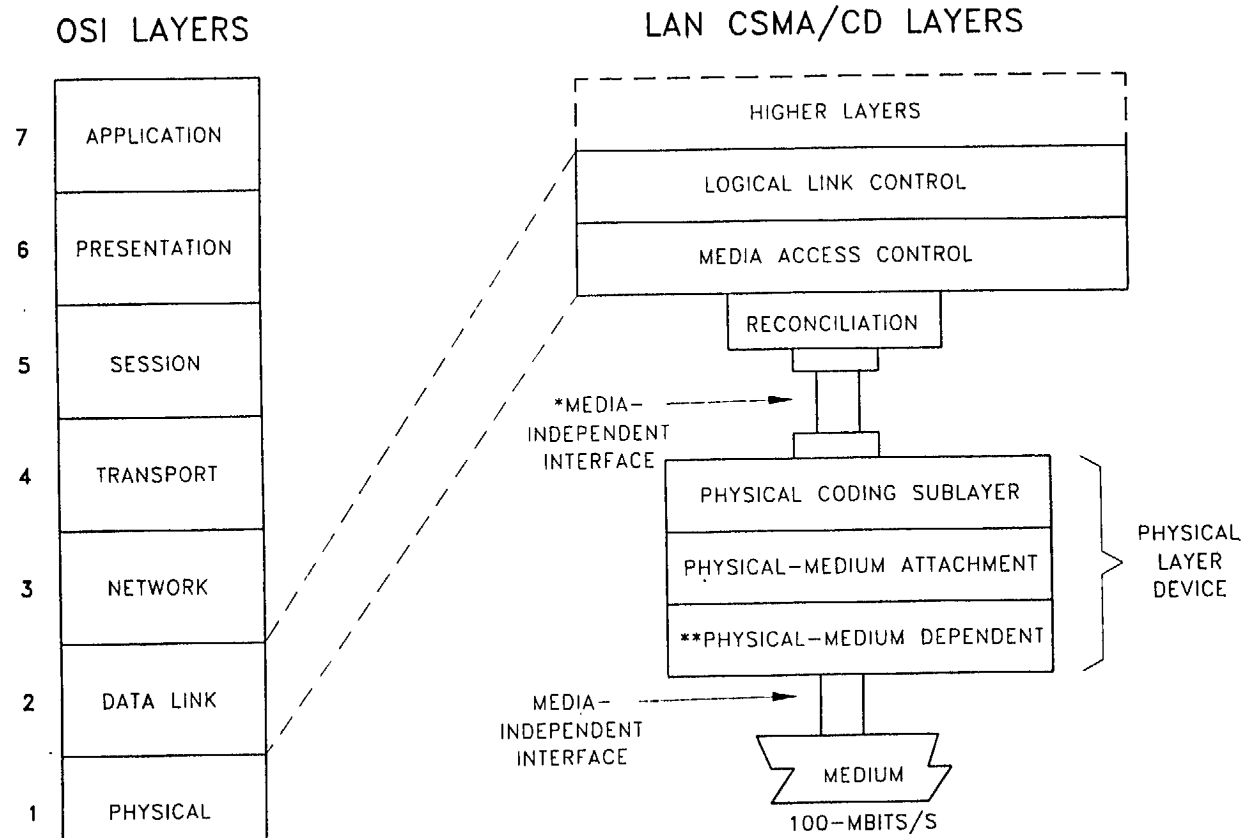
Fiber interconnects significantly extend operating distance compared with metallic interfaces. Low speed (10 Mbps) twisted pair copper typically can be extended to 500 meters; with 100 Mbps twisted pair copper limited to 100 meters. ETHERNET distance is typically 2500 meters maximum when fully compliant with the IEEE 802.3 standards. This is a timing restriction of the standard to assure its proper operation and not a restriction of fiber optics. ETHERNET addressing supports 1024 devices per network.

Table 4.1.1-2

Summary of Current LAN Standards

Protocol	Bit Rate	Common Name	Full-Duplex	**Block, Line Code**	**Standard Body**	**Cabling Type**
ETHERNET (IEEE 802.3)	10 Mbit/sec.	1 OBASE-T 10 BASE-FL	Yes	Manchester	IEEE Approved	2-pair Cat 3,5 UTP, Fiber
Demand Priority (IEEE 802.12)	100 Mbit/sec.	Demand Priority / 100 VGAnyLAN	NA	5B/6B	IEEE Approved	4-pair Cat 3,4, 5 UTP, STP
Fast ETHERNET (IEEE 802.3)	100 Mbit/sec.	100BASE-TX 100BASE-T4 100BASE-FX 1 00BASE-T-2	Yes No Yes Yes	4B/5B, MLT-3 8B/6T 4B/5B TPRI or QAM-Based	IEEE Approved IEEE Approved IEEE Approved IEEE Evaluation	2-pair Cat 5 UTP, STP 4--pair Cat 3,4, or 5 UTP, STP l-pair (2 strands) Fiber 2-pair Cat 3,4,5 UTP, STP
Isochronous ETHERNET (IEEE 802.9)	16 Mbit/sec. (10 Mbit/sec. + 6 Mbit/sec. ISO)	Isochronous ETHERNET	Yes	4B/5B	IEEE Evaluation	2-pair Cat 3,5 UTP
TOKEN RlNG (IEEE 802.4 and 802.5)	16 Mbps	TOKEN RlNG	Yes	4B/SB/Manchester	IEEE Approved	l/2 Pair UTP/STP

Protocol	Bit Rate	Common Name	Full-Duplex	Block. Line Code	Standard Body	Cabling Type
TP-PMD/CDDI (ANSI X3T9.5)	125 Mbit/sec.	TP-PMD / Fast TOKEN RING	NA	4B/5B, MLT-3	ANSI Approved	2-pair Cat 5 UTP, STP
ATM (ATM Forum)	25.6 Mbitlsec.	25 Mbitlsec. ATM	Yes	4B/5B	ATM Forum Approved	2-pair Cat 3,4,5 UTP, STP
	25.92 Mbit/sec.	25 Mbit/sec. CAP-4	Yes	2B/1 Symbol	ATM Forum Approved	2-pair Cat 3,4,5 UTP
	5 1.84 Mbit/sec	52 Mbitlsec CAP- 16	Yes	4B/l Symbol	ATM Forum Approved	2-pair Cat 3,4,5 UTP
	155.52 Mbit/sec.	155 Mbit/sec. ATM	Yes	NRZ	ATM Forum Approved	2-pair Cat 5 UTP, STP
	155.52 Mbit/sec.	155 Mbit/set. over Cat 3	Yes	CAP 64-based	ATM Forum Approved	2-pair Cat 3,4,5 UTP
FDDI (IEEE 802.5)	100 Mbps/200 Mbps (dual)	Fiber Data Distribution Interface	Yes	4B/5B	IEEE Approved	Fiber, Single Mode or Multimode
TP/PMO = Twisted Pair - Physical Medium Independent		UTP = Unshielded Twisted Pair		STP = Shielded Twisted Pair		CDDI = Copper Distributed Data Interface



*OPTIONAL FOR 10-MBITS/S DEVICES AND FOR 100-MBITS/S SUBSYSTEMS.
**SPECIFIED FOR 100BASE-Tx AND Fx ONLY; 100BASE-T4 DOESN'T USE THIS LAYER.

IEEE 802.3 STANDARD RELATIVE TO OSI 7 LAYER STANDARD

Figure 4.1.1-1

TOKEN RING with twisted pair are typically limited to 100 meters between stations. Extending TOKEN RING technology with fiber provide up to 100 Km (200 Km considering ring topology with the additional 100 Km being the fault recovery path) of total network length with up to 1000 interconnected terminals.

The modern LANs support Internet Protocol as well as Transport Control Protocol (thus TCP/IP). Thus all can be interconnected via bridges and routers.

ATM technology was primarily designed to work over fiber at OC-3 (155.4 Mbps) or higher SONET transport data rates. A recent modification of the standard supports 25.6 Mbps over UTP. The 25.6 Mbps ATM is called ATM-25 and was sponsored by IBM in an effort to bring ATM to the desktop. The problem with ATM-25 is that it does not compete with the 100 Mbps LAN technologies and is currently more expensive because there is not a significant demand. With fiber, ATM operating distance is not limited, except as dictated by optical transceivers utilized in equipment (i.e. optical signal link budgets which can be 30 to 80 Km for single mode fiber depending on laser technology used).

LAN switch technology has emerged to support higher throughput on LANs. A high speed switching bus allows interchange of LAN segment data at 600-2.5 Gbps or greater. Thus on ETHERNET or TOKEN RING, communications is virtually point-to-point. Switching technology significantly improves network performance as workstations and terminals are added.

4.1.1.1 Video Over LANs

Video is available in single frame (frame grabbed) and full motion. Full motion video is defined by Electronic Industries Association (EIA) 170 and National Television Standards Committee (NTSC) standards. Normal closed circuit television (CCTV) is 30 frames per second with 2:l interlace. Emerging high definition television standards may increase frame rate to 60 frames per second, non-interlaced. Typical CCTV cameras have 480H x 340V resolution or 163,200 resolution points. HDTV may increase to 1.3 million or greater resolution points. Full motion video has time critical requirements for line-by-line and frame-by-frame.

If video information is delayed, the image becomes distorted from a motion standpoint. Thus LANs are emerging which support, what is called, isochronous capability. Essentially, timing is “guaranteed” for video. IEEE Standard 802.9 defines an Isochronous ETHERNET 100 VG AnyLAN standard also supports isochronous transmissions. FDDI-II draft standards define an isochronous capability. ATM is isochronous. Thus, if real-time video is to be transmitted over a LAN, an isochronous LAN must be utilized to guarantee performance.

Lightly loaded LANs, especially 100 BASE-T ETHERNET and FDDI can support video transmission. There is adequate bandwidth (data rate) to support image transfer as well as contending data without impacting timing. However, as the LAN is loaded, it will reach a point where motion image data timing is severely impacted. In isochronous LANs, priority is given to time critical data to the detriment of lower priority data. Thus an ATM for instance, with video transmission integrated with normal data communications, may become impacted with video data consuming the bandwidth on a continual, high priority basis. Thus for video transmission over a network, the network technology must be either synchronous or isochronous and the link must be sized (adequate bandwidth) to handle video as well as data requirements. Otherwise on an isochronous network, priority video will consume the bandwidth on a continuous basis.

To minimize bandwidth, typically data compression is utilized. Typically 6.14 Mbps utilizing Motion Picture Expert Group (MPEG) II compression algorithm provides an adequate full motion video presentation. In fact the Digital Satellite Service (DSS) utilizes this data rate for high motion-full motion video. On a 10 Mbps ETHERNET with perhaps 8 to 10 terminals (which probably has an average data throughput of 4 Mbps) the full motion video timing may be impacted. On a 100 Mbps LAN, timing most probably would not be impacted for compressed video transfer over the. LAN unless a large number of terminals were utilized. Network access delays increase on ETHERNET as terminals are added, thus increasing probability that motion video timing will be impacted.

When full motion video is essentially continuous, it is a much better design to allocate synchronous communication links for communications. In fact no benefit is derived in allocating full motion video (digitized) to ATM which utilizes a SONET transport; direct interface with SONET for digital video eliminates the continuous, priority use of ATM bandwidth by video which defeats the purpose of ATM.

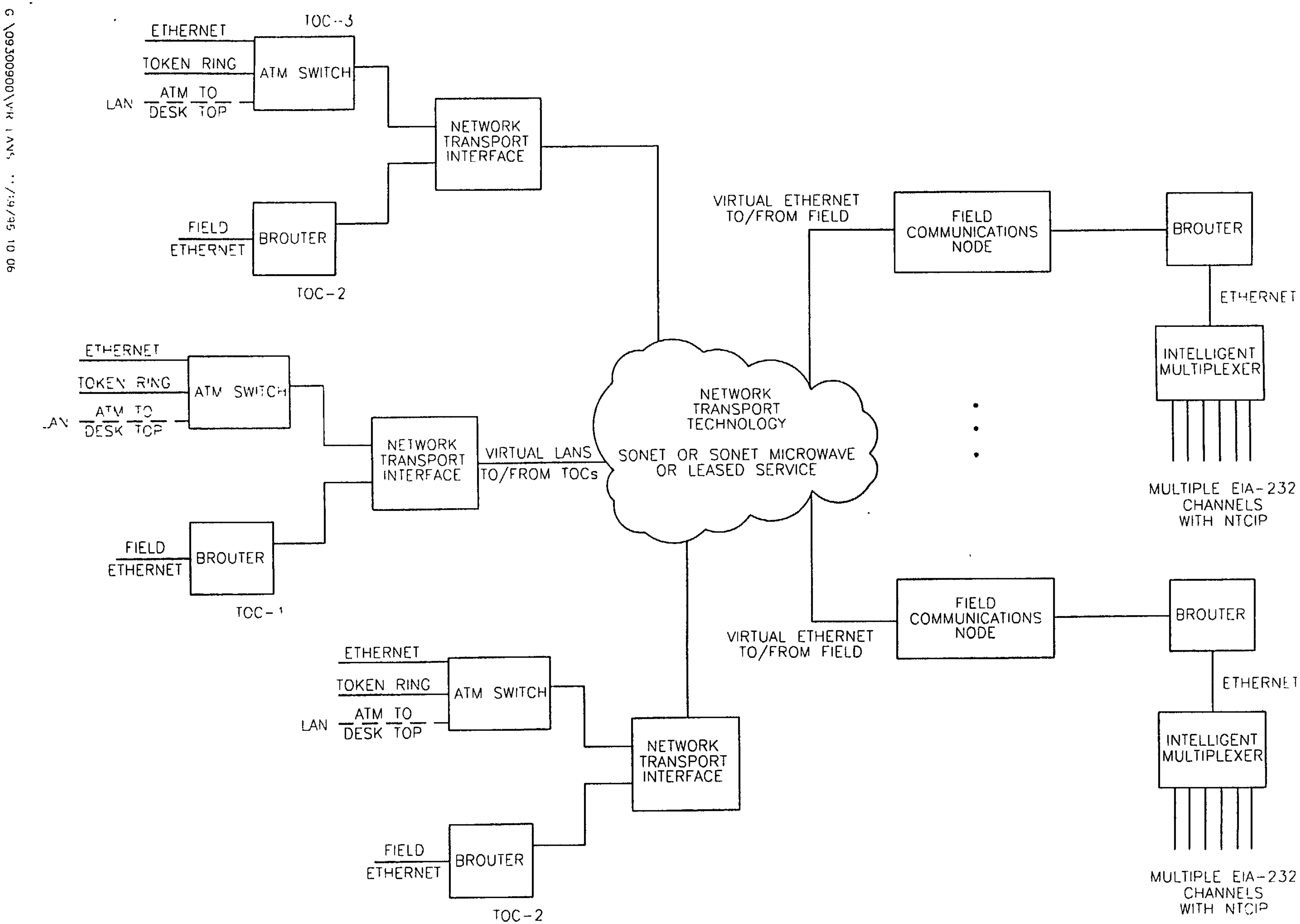
4 1.1 2 Future Projection of LAN Technology

LAN technology is projected to increase in data rates to higher SONET data rates. Today we are seeing OC-3 data rates of 155.52 Mbps. By mid-term we will have LANs operating at 622.08 Mbps (OC-12 rates) and by long-term LANs will be operating at OC-48 rates of 2.48832 Gbps. LANs will be isochronous. Network technology will continue to allow interconnection of ANY LAN to ANY LAN.

ATM will continue to grow in popularity into the mid-term period and prices will be significantly reduced. ATM will provide significant competition to Fast ETHERNET and 100 VG AnyLAN, eventually winning the technology competition. By the long-term period, ATM LAN(s) will dominate operating at OC-48 data rates on a local area basis. We will experience MAN and WAN ATM rates increasing to 19.91 Gbps (OC-384) and perhaps even to 39.81 Gbps (OC-768). SONET standards will be maintained to provide some degree of stability to rapidly changing technology.

4 1.1 3 Virtual and Relational Local Area Networks

The term “virtual” LAN has been utilized to describe a LAN extended from the local area network technology. **Figure 4.1.1.3-1** illustrates the basic concept. LANs are “virtually” integrated via the MAN/WAN, even though their independent time domain related to network standards (such as ETHERNET) resides within the local area environment. The virtual LAN operates, from a software standpoint, as if all attached equipment on the LAN were essentially local.



EXAMPLE OF VIRTUAL LANS THROUGH USE OF SWITCHES AND BROUTERS

Figure 4.1.1.3-1

The term “relational network” is essentially the same as a virtual LAN if technologies such as Address Resolution Protocol (ARP), Reverse Address Resolution Protocol (RARP), Internet Protocol (IP), Subnet Interworking Packet Exchange (SIPE), and Transport Control Protocol (TCP) are utilized. The intelligence within the bridge-routers, relational networks are self configuring allowing full freedom of user moves, adds and changes.

Relational LANs are automatically formed by the network intelligence associated with the protocol, not manually administered. This self-learning process is the result of inspecting the broadcast and multicast frames transmitted by each end station. The broadcast or multicast frame is then forwarded to local and remote LAN signals having end’stations matching the information “learned” from information embedded in the frame.

Perhaps the most significant difference in a virtual versus relational LAN is that relational LANs may be mixed while classically virtual LANs are the same standard. Certainly LANs of the same type may be interconnected with standard protocol supporting automatic network configuration understanding. Mixed LANs (such as 100BASE-T ETHERNET and FDDI) may be physically distributed, just as with virtual LANs and interconnected with self-configuring protocol. However, with different LAN standards, they become more “relational” than “virtual”.

In summary, the same LAN technology or different LAN technology may be interconnected utilizing bridge, router and switch technology supporting physical separation over a metropolitan area network. The benefits of this technology are:

- Significant simplification of system software
- Standard interfaces
- Ease of modular growth
- Improved communications reliability through use of proven network standards
- Ease of communicating with work groups

4.1.2 Metropolitan Area Communications Technology Overview

There are three (3) basic standards for Metropolitan Area Networks (MANs):

- Fiber Distributed Data Interface (FDDI)
    - ANSI X3T9.5
- Synchronous Optical Network (SONET)
    - Bellcore GR-253-CORE
    - ANSI T1.105-1991
    - ANSI T1.106-1988
- Asynchronous Transfer Mode (ATM)

- ATM Forum
- Bellcore GR-1113-CORE, GR-2842-CORE and GR-2845-CORE

FDDI represents an extension of TOKEN RING technology utilizing fiber. Operating data rate is 100 Mbps. A counter rotating optical ring or STAR network configurations may be utilized. Maximum link length is specified to be 100 Km. A counter rotating fiber may be utilized to support full-duplex operations; otherwise half-duplex operations are typically supported utilizing the token passing protocol. Standards allow up to 1000 attached stations. Distance between stations are a function of the type of fiber utilized and optical transceiver link budgets. FDDI adapter interfaces are available for computers and communications equipment. They are generally considerably more expensive than Fast ETHERNET or 100 VG AnyLAN products. Being an optical interface which includes a receiver and transmitter, failure of a unit or even turning off an interconnected FDDI terminal within the network will result in a network failure. For this reason a optical bypass switch is utilized which is activated when equipment is not powered or has failed.

SONET is a network technology emerging from the telecommunications industry. It operates at increments of OC-1 data rate of 51.84 Mbps. **Table 4.1.2-1** summarizes modular SONET capability available today. OC-192 equipments are in early deployment status with OC-384 in very early deployment phase. The first OC-192 deployment occurred in 1995. OC-48 deployment has been continually growing since the early 1990s. OC-1 has not seen significant deployment in the public telephone networks; however, some small private networks are deploying OC-1, OC-3, OC-12 and OC-**48.**

Table 4.1.2-1
Modular SONET Capability Available Today

SONET Rate	Data Rate (Mbps)
OC-1	51.84
OC-3	155.52
OC-12	622.08
OC-24	1244.16
OC-48	2488.32
OC-96	4976.64
OC-192	9953.28
OC-384	19,906.56

Many of the SONET terminals support modular growth. Thus an OC-48 terminal shelf is designed to accommodate 4 each OC- 12 shelves and OC- 12 shelves are designed to accommodate 4 each OC-3 shelves. Below OC-3 SONET operates at the North American Electrical Hierarchy Standards of DS-0, DS-1 and DS-3. ANSITl .102-1989 and Tl .103-1987 defines these standards. The same ANSI standards define T- 1 and T-3. **Table 4.1.2-2** summarizes the North American Electrical Hierarchy Standards.

Table 4.1.2-2
North American Electrical Hierarchy Standards

DS-X	Data Rate
DS-0	69 Kbps
DS-1	1.544 mbps
DS-3	44.73 6 Mbps

The E- 1, also STS-1 data rate which includes SONET overhead is 51.84 Mbps.

There are numerous Bellcore Specifications defining specific SONET and associated interfaces. There are two (2) key configuration specifications for SONET:

- Bellcore GR- 1230-CORE, "SONET Bi-Directional Line Switched Ring Equipment Generic Criteria", and

- Bellcore GR- 1400-CORE, "SONET Dual-Fed, Path Switched Ring Equipment - Generic Requirements"

Line switched SONET has four (4) fibers in and four (4) fibers out. Path switched SONET has two (2) fibers in and two (2) fibers out. There is little performance difference except when there is a fiber break. In this case the information routing plan has to accommodate alternate path information routing which generally impacts maximum load plan. In line switched configuration, alternate paths are not utilized since two (2) additional fibers are available and bandwidth is not impacted. Also where time is critical, path switched systems must consider worse case path time delays (which are small - milliseconds - but still measurable).

There are two (2) fiber line switched SONET terminals on the market. However, in a failure mode, 50% of the bandwidth is lost (i.e. an OC-48 network essentially operates as an OC-24 in the failure mode). Thus, the benefits of line switched technology are lost with two (2) fibers.

Bellcore GR- 1377-CORE, "SONET OC-192 Transport System - Generic Criteria" defines the 10 Gbps SONET terminal, especially focusing on modulation, dispersion compensation, synchronization, jitter and other signal parameters.

Furthermore, within SONET there are a variety of network management options. Transition of SONET to OSI standards has generated Common Management Information Protocol (CMIP) as defined by Bellcore SR-STS-002751, "Interface for the CMISE/OSI Protocol Stack". CMIP operates with the Common Management Interface Service Element (CMISE) Open Systems Information (OSI). CMISE/CMIP is compatible with Guidelines for the Definitions of Managed Objects (GDMO) templet definitions given by ISO/IEC IS 10165-4. Managed objects are an outgrowth of SNMP, MIB object management standard. Thus CMISE/CMIP is a compatible network management standard with SNMP and both are supported by OpenViewTM network management software. Thus by using CMISE/CMIP SONET and other network elements utilizing SNMP can commonly be managed.

Signaling system server (Bellcore TR-NWT-000246) includes operations, maintenance, and administration parts. It is supported under ANSIT-l specifications.

Bellcore SR-NWT-002439, "Interface Functions and Information Model for Initial Support of SONET Operations Using OSI Tools" and Bellcore GR- 1042-CORE "Generic Requirements for Operations Interfaces Using OSI Tools: Information Model Overview, SONET Transport Information Model" and provided the framework for SONET with the OSI7 layer model.

The significant features of SONET are:

- Multimedia compatible
- Modular bandwidth
- OSI model compatible
- Fully supported international standards
- Widely utilized by public and private networks
- Many vendors competing for production
  - Lower market cost
- Design driven by Bellcore reliability and maintainability standards
  - High network availability
  - Low cost maintenance
  - Fully automated status monitoring and reporting minimizing staff needs
- Complies with OSI network management standards
- Available in outdoor and central office environment compatible configurations
- Compatible with ISDN and ATM technology standards
- Highly stable, open architecture standard
- Supports a variety of network architecture
  - Ring - Add/Drop
  - Linear Add/Drop
  - STAR
  - Medium Diversity (microwave and optical)

ATM emerged from early, Bellcore Broadband ISDN (BISDN) specifications. As originally conceived by Bellcore, ATM would provide an asynchronous mode adaptation to SONET with fully compatible interfaces at optical rates. Bellcore ATM specifications are summarized in **Table 4.1.2-3.** ATM Forum is the primary standards group now controlling the technology.

Virtual path cell switching and distribution capability is perhaps a major advantage of ATM when applied to SONET. SONET is a programmed path technology designed utilizing routing tables and add/drop design. ATM supports virtual path capability when utilized with SONET.

A second major advantage of ATM integrated with SONET is bandwidth optimization with asynchronous signal inputs. However, ATM has little advantage over SONET in distribution of full motion video transmission since video is a synchronous signal. Where video frames or short sequences of frames are to be transmitted utilizing Joint Photographic Expert Group (JPEG) standard, then ATM has an advantage of still optimizing bandwidth utilization. ATM just provides priority to the digital video signal which preempts other data. In fact, if enough video channels are added to an ATM network, lower priority data would be blocked.

Table 4.1.2-3
Bellcore ATM Specification Summary

Specification	Title
TR-73585	ATM Network Interface Specifications
GR-1113-CORE	ATM Adaptation Layer Protocols
GR-2837-CORE	ATM Virtual Path Multiplexer - Generic Requirements
GR-2845-CORE	ATM Network and Element Management Layers - Generic Requirements

ATM has a major advantage in “bursting” LAN data and is efficient in supporting virtual LANs over a metropolitan or wide area network. The reasons is that bandwidth utilization is optimized and more effective throughput is achieved as compared with use of normal brouters.

ISDN is a leased service of factional T- 1, T-3 and emerging OC-3 bandwidth. There are a number of services available on ISDN including Frame Relay and Switched Multi-Megabit Data Services (SMDS). The following specifications apply:

Frame Relay

- Bellcore GR- 1379-CORE, “Frame Relay Service, Generic Criteria on Operations Interfaces, Information Model and Usage”
- Bellcore TR-73578, “Frame Relay Service Interface and Performance Specifications”

ISDN

- Bellcore TR-73586, “ISDN Circuit Switched and Packet Switched Data Bearer Services, Performance Specification”

- Bellcore SR-NWT-002343, "ISDN Primary-Rate Interface Generic Guidelines for Customer Premise Equipment"

SMDS

- Bellcore GR- 1060-CORE "SMDS Generic Requirements for Exchange Access"
- Bellcore TA-TSV-001059, "Generic Requirements for SMDS Networking"
- Bellcore TA-TSV-001240, "Generic Requirements for Frame Relay Access to SMDS"
- Bellcore TR-TSV-001064, "SMDS Generic Criteria on Operations Interface"
- IEEE 802.6, "Information Technologies - Telecommunications and Information Exchange Between Systems - LAN and MANs, Specific Requirements, Distributed Queue Dual Bus Access Method and Physical Layer Specifications"

Essentially ISDN offers X.25, 56 Kbps services to OC-3 services as defined by Bellcore TA-TSO-001238, "Generic Requirements for SMDS on 155.52 Mbps Multi-Service, Broadband ISDN. It is available in packet switched or circuit switched configurations and is designed to accommodate digital data exchange. ISDN services are available on a metropolitan or wide area basis with cost of base service defined by bandwidth, service type and distance.

While there are various alternatives to leasing bandwidth, typically public network service suppliers must conform to FCC rules. Thus prices for services are regulated. They vary only by differences in operating cost. A formula developed in 1994 by Alcatel, Inc. based on a survey of service providers indicated that DS-1 leased service was provided with the formula:

DS-1 Leased Cost $/month = 23.3 (circuit length in miles) + 402

DS-3 Leased Cost $/month = 116.5 (circuit length in miles) + 605

Rates are generally controlled within Local Access and Transport Areas (LATAs). Between LATAs, long distance carriers are involved with rates. Legislation is pending in Congress that will open up competition both within LATAs and between LATAs. Cost of long distance infrastructure and infrastructure to each house and business office within a LATA is significant. Thus, even with more open competition, it will be some time in the future before competitive infrastructure can be installed.

With the capability of single mode fiber to support 50 to 100 Gbps of data on a single fiber pair or telephone service to 1.6 million homes on a single fiber pan (operating at DS-0), the wasted bandwidth of competitive fiber infrastructure to street comers will encourage partnerships (perhaps non-competitive such as cable TV and telephone service). Using digital satellite system digital motion picture encoding allows approximately 17 thousand homes to be serviced with fully interactive communications, including full motion video.

Where we are today with leased service is with a lot of old, twisted pair copper with very limited bandwidth. Thus for a public telephone company to provide wide band service, it consumes a considerable percent of their signal switching and distribution infrastructure (in bandwidth capacity). As public telephone companies display fiber and SONET technology, more bandwidth becomes available and thus lease rates should come down. Today, when a telephone company deploys a SONET OC-48 terminal system, they can service 32,256 customers with DS-O services (Plain Old Telephone Service [POTS]). If they sell DS-1 service, they can service 1,344 customers. If they sell DS-3 service, they can service only 48 customers. Thus, with electronics connected, selling wideband service is still questionably economical for a telephone company.

Within the MAN technology options which has open standards, **Table 4.1.2-4** summarizes the comparison. In general, SONET is the most cost/effective MAN technology to deploy with ATM being second. In general, wideband leased service is very expensive for MANS and even considering installation of a fiber infrastructure for MAN ITS applications, a break even return on investment is between 3 and 5 years.

Table 4.1.2-4
Summary Comparison of Standard MAN Technology

	SONET	ATM	FDDI	ISDN
Bandwidth	10	10	5	1
Cost	6	3	10	1
Modular Growth Capability	10	10	1	5
Digital Voice and Motion Video Compatible	10	10	1	8
Internet Compatibility between MAN Standards	10	10	5	10
Advanced Network Management for ITS	10	10	10	1
Low Bit Error Rate	10	9	10	5
Fault Tolerant	10	10	10	3
	76	72	52	34

It should be noted that there are wireless options to SONET, ATM and FDDI extensions other than fiber. Microwave technology is available to provide seamless interconnect between fiber and wireless network segments. Microwave may be utilized for network segments and to provide path medium diversity. With state-of-the-art in digital microwave; only an OC-3 data rate (15554 Mbps) may be supported. Parallel OC-3 channels terminating with an OC-12 terminal can be utilized to extend OC-12 SONET service. With microwave, bit error rate is typically decreased from 10^{-11} achieved with fiber to 10^{-6} with wireless based on normal microwave terminal deployment distance and standard fade margins. Higher reliability may be achieved at the expense of terminal separation distance with perhaps BERs of 10^{-8} achievable. Thus, utilizing wireless, overall link bit error rate is compromised to a small extent. However, digital microwave's performance is generally as good or better than that guaranteed for leased lines by public telephone network service suppliers. If designed properly microwave lengths can be very cost/effective.

4.1.3 Wide Area Communications Technology Overview

There are few Wide Area Network (WAN) standards other than adaptation of ISDN standards. The choices for WANs are:

- Dedicated Leased Service (ISDN) at Fractional T-l to T-3
- Dial-up service using Fractional T-l Brouter from and ETHERNET and synchronous modems (56 Kbps)
- Satellite Leased Service
  - Interface standards conforming to ISDN
- Dial-up or leased line service into an Internet, World Wide Web Hub utilizing V.32, V.34 or F-T1 modems

The standards referenced for North American Digital Hierarchy (ANSI Tl .102) apply to these interfaces. Satellites offer frame relay, multiplexed inputs for Fractional T-l (i.e. 56 Kbps) service. Most all of the WAN options involve a cost of access, use time and distance. Internet eliminates distance cost with cost.

Internet service options which are available are typically as follows:

- Dial-up V.34
  - $10/month 5 hours use time free and $2/hour use time after 5 hours
- Dial-up V.34
  - $20-30/month flat fee, no use time fee
- Dedicated Fractional T-l (56 Kbps) with automatic disconnect if no data
  - $45/month and no use time fee

- Dedicated Fractional T-l (56 Kbps) continually connected

  - $200-400/month and no use time fee

    ** Price depends on special services such as frame relay

Some of the common problems with Internet are:

- Security
- Communications service is not guaranteed
- Network performance is not guaranteed
- Significant data distribution delays may occur based on network circuit activity

Thus network reliability for critical data is an issue.

Leased ISDN service from public network suppliers does come with standards and service commitments controlled by FCC. Thus leased service provides improved reliability and performance compared with Internet; however, at a substantially greater price.

From a satellite standpoint, there are several options for service:

- Very Small Aperture Terminal (VSAT) - Service where a small Earth station terminal is utilized costing around $18,000 (installed)

- INMARSAT which supports use of a portable, 22 pound satellite terminal selling for around $15,000

The cost of service on VSAT or MMARSAT for 56 Kbps is around $3/minute. Thus satellite communications service, at this time, is reasonably expensive even though terminal prices have significantly decreased to affordable cost. There are some new satellites on the horizon such as:

Teledesic

- Craig McCaw and Bill Gates are key participants
- Will emphasize wider bandwidth service at lower cost
- 20-30 GHz frequency band, TDMA access

Spaceway

- Hughes Communications is sponsoring
- Same objective as Teledesic
- 20-30 GHz frequency band, TDMA access

MSAT

- McCaw, MTEL, Telsat-Canada are sponsors
- Stressing land mobile communications
- Communications spectrum of 1.6 GHz with 11-13 GHz feeder links and FDMA access

OrbComm

- OSC and Teleglobe are sponsors
- Focus is packet switching
- Communications spectrum 137.5-150.0 MHz and TDMA access

With new satellite services emerging, by the Year 2005, satellite use cost is anticipated to be $l/minute

Microwave may also be considered to be a WAN technology. Currently there are digital microwave equipment which supports DS-1/T-1 DS-3/T-3,OC-1 and OC-3 standards extension. Cost of microwave terminals vary with:

- Bandwidth
- Power
- Fault Tolerant Features
- Network Management Capability
- Terminal versus Repeater
- Add/Drop and Repeat versus Repeaters
- Height of tower required and availability of existing tower and equipment shelter

Disregarding mounting towers, the cost of generic microwave equipment is summarized in **Table 4.13-1**.

Table 4.13-1
Cost of Generic Microwave Equipment ($)

	DS-1		DS-3		OC-3
	MMF/HMF	LMMW	MMF/HMF	LMMW	MMF/HMF
Terminal Non-Fault Tolerant	15,000	12,000	30,000	25,0000	NA
Terminal Fault Tolerant	25,000	20,000	50,000	40,000	90,000
Terminal with SONET	NA	NA	NA	NA	90,000
Repeater	50,000	40,000	100,000	80,000	140,000

	DS-1		DS-3		OC-3
	MMF/HMF	LMMW	MMF/HMF	LMMW	MMF/HMF
Repeater with Add/Drop Terminal	50,000	40,000	100,000	80,000	160,000

MMF = Medium Microwave Frequency
HMF = High Microwave Frequency
LMMW = Low Millimeter Wave

As a general rule of thumb, a repeater is twice the cost of a terminal because:

- Two sets of transceiver electronics must be included
- Repeating electronic controls are necessary
- Two antennas are needed

Fault tolerant units include hot standby, spare electronic modules but generally do not include redundant antennas.

In general, the low millimeter wave (23 GHz) terminals, are less costly than the medium to high microwave frequency terminals (6-13 GHz). The SONET microwave terminals are being produced only in microwave frequencies at this time.

In general the 18-23 GHz microwave terminals are being utilized for short to medium (3-10 miles) range links with 6-13 GHz microwave being applied to long-range links of 20-30 miles. A typical microwave link includes a backbone operating a 6 GI-Iz with "spurs" operating at 10 GHz to 23 GHz. Microwave is line of sight. Comer reflectors may be utilized to bend microwave paths with some signal loss. Equally a repeater may be utilized with antennas placed in appropriate directions providing a fully extended link capability.

In the Washington-Oregon area where heavy rainfall may be considered, microwave above 186 GHz is not generally recommended. Lower frequencies have less attenuation and should be utilized.

Microwave (except some of the millimeter wave short haul) require FCC licenses. Generally licenses are available, especially to support rural area communications.

4 1.3 1. Metropolitan Area-to-Metrouolitan Area Communications (MA-MA/COMS)

Metropolitan Area-to-Metropolitan Area (MA-MA/COMS) includes the following ITS functional needs:

- Freeway Center-to-Freeway Center interoperability
- Freeway Center-to-Other Supporting Agency interoperability

- State Licensing
- State Environmental Protection

- Freeway Operations Center-to-Commercial Vehicle Operations Center (HAZMAT and others)
- Multimodal Transportation Coordination
- Freeway Operations Center-to-Regional Traveler Information

Typically dial-up public network service is utilized for Freeway Operations Center (FOC) to other remote agencies and for communications with CVO operations centers. Leased line (ISDN or other service) as well as dedicated (jurisdictional owned) communications network is utilized for FOC-to-FOC or FOC-to-Regional Traveler Information Center. Where a dedicated communications network, such as SONET, is installed along a freeway corridor, generally both FOCs become hubs on the SONET network.

Generally center-to-center information exchange is low data rate (T-l) unless:

A) Multimedia data exchange is contemplated where incident video is of interest to both FOCs.

B) Center-to-Center backup is contemplated where one FOC backs up another FOC. This requires the backup FOC to have full access to the failed Center's field communications. This generally cannot be economically accomplished without implementation of a dedicated communications network along the corridor. Leased bandwidth becomes prohibitive.

C) Virtual LANs are desired facilitating simplicity of interoperability and improved interoperability features. In this case typically 4 to 8 T-l circuits are required to provide adequate virtual LAN bandwidth to prevent bottlenecking" of the virtual LAN by the WAN extension. This becomes expensive for leased service.

4 1.3 2 Metropolitan Area-to-Rural Area Communications (MA-RA/COMS)

Communications between a metropolitan area and rural area typically involves standard freeway management communications with field sensors and electronic signs/signals and associated emergency services coordination. The major difference is that field device deployment density is generally much lower than associated with metropolitan area freeway segments. This is because traffic density is usually less and utilization as a percent of capacity is usually less. Capacity is usually only reached when an incident occurs or a natural hazard occurs (such as ice, fog, rock slide, snow avalanche, etc.). Areas where natural hazards may occur are usually predictable and based on terrain characteristics, altitude, and road construction characteristics. Thus, sensors and hazard warning devices are usually deployed in these areas. Sensors may be utilized to determine traffic flow rate and volume in potential hazards area and periodically along the corridor. However, use of incident detection sensors every 0.25 to 0.5 miles of corridor are not affordable within the rural area and not normally needed due to volume. Likely incident areas such as major highway and rail crossings may justify sensor deployment based on accident statistics.

In any case the rural communications environment is less dense in terms of communications devices per mile of freeway. The communications needs tend to be clustered in potential hazards areas. Communications timing needs tend to vary based on weather conditions which are highly seasonal.

Communications technology choices for metropolitan area FOC-to-rural field will be:

- Leased Service (lowest to highest cost ranking)
  - Paging
  - Public Telephone Network
  - Satellite
  - Cellular (on corridors supported)
- Jurisdictional Owned (lowest to highest cost ranking)
  - Meteor Burst
  - HF/VHF Radio Links
  - Power Line Modems (safety and technical risk issue)
  - Microwave
  - Fiber Optic Network
  - Dedicated Wireline

Ranking technology related to bandwidth provides:

- Optical Communications Link
- Microwave Link
- Public Telephone Network
- Satellite
- Dedicated Wireline
  - Cellular
  - VHF Digital Links
- Meteor Burst
- Data Link
- Paging

4.1.3.3 Rural-to-Rural Communications

Rural-to-rural communications generally involves sensor to a wide area communications node. This communications node may in fact exist in a small jurisdiction along the rural route. Thus it is similar to MA-RA/COMS technology.

Fiber optic communications links and microwave links are well suited to interconnect rural sensors to a rural communications node. Similarly, System Control and Data Acquisition (SCADA) wireless links are also candidate links.

4.1.3.4 Other Technologies Supporting Wide Area Communications and Not Complying with Network Standards

There are several technologies which support wide area communications that are not considered to be network technologies. These include:

- High Frequency (HF) and Very High Frequency (VHF) Radio Links
- Meteor Burst Communications Links
- Paging Systems
- Cellular Telephone Systems with Rural Support (either cells along major corridors or satellite support)

The following sections address this technology.

4.1.3.4.1 HF Digital Radio Links

HP digital radio links emerged in the 1950s for military applications. The U.S. Navy's Link II and NATO TADGA were examples. Developed by Collins Radios, these HF links operated with sideband diversity, supporting 1200 and 2400 bps communications. A Hamming Code was utilized to provide forward error detection and correction. These links have performed well to support real-time tactical data interchange from mobile computer to mobile computer. With adaptive link control and use of improved modulation, I-IF data rates have been extended to 4800 bps and atmospheric changes have been automatically compensated by frequency shifts.

HF frequency (0.5 to 30 MHz) has an extensive ground and sky wave. However, it is susceptible to multipath and fading conditions caused by ionospheric layer shifts. Sunspot activity creates noise within the HF band causing certain frequencies to be unusable at times. Due to the long wave length of HF, antennas are large. However, HF digital radio becomes an option for communications at low data rates to rural ITS Hubs from Metropolitan Freeway Centers.

HF radios and antennas are generally inexpensive as' indicated by the significant use by amateur radio enthusiasts (HAMs). However, HF digital modems are reasonably complex and expensive. A Field Hub with long periodic antenna, fault tolerant radio with atmospheric sounding and modem would cost approximately $20,000.

One issue with HF radios to achieve reliable operations is having adequate frequencies available for selection as atmospheric conditions change. FCC allocation of frequencies to support operation may be the single greatest deterrent to using HF. Without the ability to change frequencies, reliability will deteriorate.

HF does not have range limitations. The Naval Tactical Data Link 11 was designed to operate up to 500 miles. HF based on frequency selection, can support world wide communications with reasonably low wattage transmitters (20 to 50 watts).

Use of HF would require periodic frequency changes to avoid interference caused by ionospheric changes. Thus while feasible to utilize, it will be more costly and require larger antennas compared with VHF.

4.1.3.4.2 VHF Data Link

VHF is historically utilized for police and public works communications. Many states including Oregon and Washington have VHF networks established on a state-wide basis. Microwave links or leased public network links integrate field transceiver sites.

VHF is typically considered to be 30 MHz to 300 MHz with UHF operating from 300 MHz to 1 .O GHz. The low end of the VHF band (30-50 MHz) has some degree of ground wave which provides a non-line of sight capability. Above 50 MHz, VHF essentially becomes line of sight communications with some diffraction extensions. Lower end frequency VHF signals generally can penetrate foliage and thus can communicate in rural areas with vehicles.

VHF digital radios have been developed which support communications between police dispatching centers and digital terminals within police vehicles. Typically these terminals operate at 1200 to 2400 bps; however, newer radios with 25 KHz to 30 KHz bandwidth have the potential to operate at 9.6 Kbps to 19.2 Kbps. However, to accommodate fading and other performance interfering parameters, 9600 bps is considered to be a realistic upper limit.

It is feasible to establish a VI-IF link between a Freeway Operations Center and a rural Field Hub. VHF radios, wireless modem, and fixed site antenna could be installed for under $5,000. Operating in conjunctions with a state-wide network, eliminating need for repeaters, would make VHF a possible link from metropolitan to rural area as previously discussed.

4.1.3.4.3 Meteor Burst Communications Link

The first commercial operational meteor burst communications was fielded in 1957 and referred to as "JANET" (see proceedings of the Institute of Radio Engineers, 12-57). Meteor burst communications is based on:

- High probability of an ionized meteor trail being present
- Proper angles are established between the meteor trail, transmitter site and receiving site

Typically meteor burst communications systems operate in the 30 MHz to 50 MHz range with the possibility of operating up to 100 MHz. The SNOTEL project was deployed in the mid-1970s utilizing meteor burst. SNOTEL consists of two master stations located at Boise, Idaho and Ogden, Utah and 540 remote data terminals distributed over 11 western states. SNOTEL brings back to a central site in Portland the following information which is utilized by the USDA, Soil Conservation Service:

- Snowpack monitoring
- River level and rainfall monitoring
- River quality monitoring
- Lighthouse monitoring
- Air and water pollution monitoring

Field sites utilize three (3) element Yagi antennas and solar power to recharge batteries for remote electronics. Antennas typically have 12 dBi gain. Operations of SNOTEL indicate 600 K bursts/hour on an average with each burst providing approximately 1 second of communications. Average wait time for communications link at 90% probability is 1.0 minutes.

Typical data rates range from 1200 baud to 9600 baud depending on modulation. Typical link connect time is one second. Thus with 660 connects per hour the bit rate is:

(660 x 1 x 9600) + 3600 = 1760 bps average, continuous throughput.

What can be said about Meteor Burst Communications is:

- It works
- It is the lowest cost wide area coverage
- It does not support high data rates over a long period (typically 1200-1700 bps)
- Real-time links are not possible.
- It is usable if wait time for data can be several minutes and if connect time messages are reasonably short
- When connects are made the link quality is as good as point-to-point with associated wireless bit error rates.

Meteor Burst Communications is certainly a candidate for collecting remote weather and hazards sensor information and perhaps communicating with remote variable message signs, HARs and kiosk terminals. A field station with communications terminal, antenna, battery and power supply is $5200 (reference MCC/quantity = 100).

Federal Standards 1055 entitled "Telecommunications for Meteor Burst Communications" is in the approval process. It covers communications procedures and network protocol. If approved, meteor burst could be considered as an open network standard.

4.1.3.4.4 Paging

Paging systems continue to be deployed on a competitive basis. Interactive paging systems are supporting duplex communications. Paging systems can support transmission of a 500 byte message to a remote terminal at 6.4 Kbps-to-g.6 Kbps with response of 15 bytes at 300 to 600 bps. Some interface standards exist such as the Post Office Code System Advisory Group (using two-level FSK which limits data rate). Motorola offers a FLEX protocol which is synchronous and supports higher data rates. The European standard is called ERMES (European Radio Message System) which is similar to FLEX.

Today it is possible to establish a reliable "receive only" data link using a paging system with the terminal selling for around $400 (reference Motorola Tango Pager) and service costing $20/month. The interactive paging capability requires microcellular receivers to be deployed to accommodate the low wattage transmission of the paging device. The response links are rapidly being deployed in metropolitan areas; however, it will be years before rural corridors have interactive paging support.

A paging network standard will emerge which will make pagers usable for periodic transfer of data to remote sites terminals/controllers with limited receipt of operational status data from the remote terminals/controllers.

Paging technology is in a major technology transition state. Palm-sized computers and pocket organizers with integrated paging are reportedly in development by Sharp, Casio and Pion and will include wireless messaging, voice mail and E-mail. Motorola has a prototype, l/8 VGA display integrated with an interactive pager. Motorola advanced paging products are planned to be deployed in the 1997- 1998 time frame per Electronic Design News (EDN) (12-21-95) in an article entitled "Not Your Ordinary Beepers: New pagers Add Two-Way and Voice Features" (by Gary Legg).

Coca-Cola is now deploying vending machines which have embedded paging technology to send request for restocking when a minimum level is reached. The referenced EDN article states that companies are developing interactive paging systems integrated with-the vehicle's GPS guidance systems which will automatically send a message to an emergency monitoring service supporting "Mayday". The issue with interactive paging is the deployment of microcellular receiver terminals to receive the low power paging units transmitted signal. Urban deployment is in its initial stages and rural deployment is in the future and only along major traveled routes.

In summary, interactive paging is an emerging technology which has a future in ITS applications. The outgoing page (to the mobile unit) covers a wide area because of transmission power. However, low power, portable pager units have limited power and limited communications range. They typically require more cells than compared with cellular telephones. This cost of the supporting infrastructure is reasonably high, limiting deployment only to areas where use fees provide a return-on-investment for paging companies.

4.1.3.4.5 Cellular Telephone

Table **4.1.3.4.5-1** summarizes cellular technology. Currently the Advanced Mobile Phone Service (AMPS) is presently deployed in the United States. It has been modified to transmit digital information in packet form on a "not to interfere" basis with voice. This service is called Cellular Digital Packet Data (CDPD) service. It can support 9.6 Kbps of data service.

Emerging in the U.S. are five (5) competing standards for the Personal Communications Service/Personal Communications Network (PCS/PCN) and all associated digital cellular communications. These competing standards are:

IS-54 Time Division Multiple Access Digital Service

IS-95	Qualcom Code Division Multiple Access (CDMA) Digital Service (Spread Spectrum)
IS-136	Enhanced Time Division Multiple Access Digital Service
GSM	Global System for Mobile Communications (a European Standard being deployed in the USA)
R-CDMA	Wide band CDMA

In reality IS-136 will become the major competing standard with IS-95. We will see GSM grow but be overcome by the winner of the TDMA-CDMA competitive deployment. The digital services can support up to 19.2 Kbps of packet service. Because of the wider bandwidth, we may see R-CDMA deployed for purely digital networks.

CDPD is currently deployed for "Mayday" and is utilized with "SMART Call Boxes" to support non-time-critical controllers interface to a Traffic Operations Center (TOC). Digital cellular will only enhance this operation.

Table 4.1.3.4.5-1
Summary of Cellular Technology

	Analog Cellular		Digital Cellular					Analog Cordless	Digital Cordless / PCN / PCS				
	AMPS	ETACS	IS-54	GSM	Q-CDMA (IS-95)	PDC	R-CDMA	CT	CT2	UPCS	DECT	PHP	DCS-1800
Frequency Rx Band MHz Tx	869-894 824-849	916-949 871-904	869-984 824-849	935-960 890-915	869-894 824-849	940-956 810-826 (& 1477-1501 1429-1453	---	Varies by Country	869/868	---	1880-1990	1895-1907	1805-1880 1710-1785
Radio access method	FDMA	FDMA	TDMA/ FDMA	TDMA/ FDMA	CDMA/FDMA	TDMA/FDMA	CDMA	FDMA	TDMA/ FDMA	TDMA/ FDM	TDMA/ FDMA	TDMA/ FDM	TDMA/ FDMA
RF channel	30 kHz	25 kHz	30 kHz	200 kHz	1.25 MHz	25 kHz	40 MHz	20 kHz	100 kHz	700 kHz	1.728 MHz	300 kHz	200 kHz
Modulation	FM	FM	B/4 DQPSK	GMSK	BPSK/ OQPSK	B/4 DQPSK	---	FM	GFSK	--	GFSK	B/4 DQPSK	GMSK 0.3
Channel rate	---	---	48 kbits/s	270.8 kbits/s	10 or 32 kbits/s	42 kbits/s	20 or 40 kbits/s	---	72 kbits/s	514 kbits/s	1.1Mbits/s	384 kbits/s	270.8 kbits/s
Number of RF channels	832	1,000	832	124	10	1,600	---	10,12,15,or 20	40	---	10	300	7 50
Voice Channel per RF channel	1	1	3	8	20-60 per sector	3	126	1	1	10	12	4	16

	Analog Cellular		Digital Cellular					Analog Cordless	Digital Cordless / PCN I PCS				
	AMPS	ETACS	IS-54	GSM	Q-CDMA (IS 95)	PDC	R-CDMA	CT	CT2	UD-PCS	DECT	PHP	DCS-I 800
Duplexvoice channel size	60 kHz	SO kHz	20 kHz	50 kHz	--	20 kHz	--	40 kHz	100 kHz	70 kHz	144 kHz	--	so kHz
Voice bit rate	---	---	8 kbits/s	I3 kbits/s	8-32 kbits/s	8 kbits/s	16 kbits/s	–	32kbitsls	32 kbits/s	32 kbitsls	--	13 kbitsls
Phone transmit pwr max/avgmW	600/600	--	3,000/200	1,000/125	200/6	—	10011	510	10/5	100110	250/10	250110	250/10
Max cell	>32 km	>32 km	>32 km	32 km	2.5 km	>32 km	450 m	100 m	100 m	500 m	500 m	500m	--

Notes: AMPS = Advanced Mobile Phone Service; CT = Cordless Telephone; DECT = Digital European Cordless Phone; ETACS = Enhanced total Access Corns System; GSM = Global System for Mobile Corns; PCS = Personal Communications Service; PDC = Personal Digital Cellular; PHP = Personal Hand Phone

For cellular to operate in the rural area, cells must be deployed along major corridors. Many of the major corridors such as I-5 and I-84, have rural cellular terminals deployed. Table 4.1.3.4.5-2 summarizes choices of digital data service with CDPD being the first to be deployed along I-84.

Where corridors have cellular coverage, then cellular is a primary candidate for rural interactive communications with vehicles. When ITS Hubs are within communications distance with a cellular field terminal (transceiver) then cellular becomes a viable means of communications with the Hub at 19.2 Kbps.

Cost of cellular service varies from location to location. Typical costs are $30/month per cellular phone plus $0.20 to $0.30 per minute depending on the time and day of the week. Some cellular companies do not charge for night and weekend use. Some cellular companies cut flat rate contracts with jurisdictions at $0.10 to $0.20 per minute of use any time. Oregon state negotiated rates with AT&T Wireless service is $0.l4/minute (anytime). In any case there is a significant use fee that can impact jurisdiction's operating budgets. For instance, if a cellular circuit is utilized continually and a flat rate of $0.14/minute is in place, jurisdiction's operating cost for this link is $73,584 within a local area. Rural areas would include perhaps increased cost for long distance communications.

Private Data Service (PDS) is available in urban areas. **Table 4.1.3.4.5-3** summarizes the service and cost of the two (2) major suppliers of PDS service.

Interfaces with cellular phones is fairly standard. Laptop PCs are available with cellular modem interfaces. While these interfaces are not fully open at link and network level, they are typically supported by EIA 232 standard at the physical layer and some elements of the link layer. When utilized with software supporting wireless modems, a degree of openness through use of commercial standards is achieved.

4.1.3.4.6 Medium Considerations

Mediums represent the "pathway" through which communications signals travel. Mediums include:

- Air (wireless such as radio frequency or light wave including and laser)
- Copper Twisted Pair
- Copper Coax
- Copper Electrical Conductor
- Fiber Optic Cable
  - Single Mode
  - Multimode
- Water (acoustic and green laser)

Table 4.1.3.4.5-2
Private Data Network/Personal Communications Service Overview

Technology	Description	Coverage	Speed	Pros	Cons
Narrowband and broadband PCS	Sends data to radio base station, which forwards it to public network; details will vary with implementation	Nationwide and regional	Unknown; networks under construction	Should be inexpensive; high capacity for broadband; network lets sender know if message is received	Won't be available until late 1996
Circuit-switched cellular	Sends data stream to cellular base station, which forwards it onto public network	Nationwide and regional	2.4- 14.4 kbit/s; depends on modem	Nationwide availability; quick setup for large base of cellular voice users	High cost; reliability
CDPD	Sends packetized data over idle capacity on cellular voice network; cellular base station forwards data onto public network	Regional; nationwide planned late 1994	19.2 kbit/s	Speed; reliability; TCP/IP built into protocol	High equipment cost; slow rollout
Packet radio	Sends packetized data to radio base station, which transmits it over private network	Nationwide	2.4- 19.2 kbit/s	Cost/effective for short text messages	Speed; not good for large files
Trunk radio/SMR	Sends analog data stream to radio base station;'enhanced version uses digital technology to integrate data and voice	Regional	4.8 kbit/s	Integrates voice and text in one device	Term in al gear expensive

Ref.: pata Communications

Table 4.1.3.4.5-3
Planning Cost for Private Data Service (Packet Radio)

Service Provider	Availability	Throughput	Pricing Structure
Ardis Lincolnshire IL	400 U.S. cities	4.8 kbit/s in most areas 19.2 kbit/s in some cities; actual throughput: 2.4-8 kbit/s	6 cents per 240-character message plus 3 cents per character Plan 1: $39000 messages (36 cents for each additional message) Plan 2: $69/250 messages (28 cents for each additional message) Plan 3: $99/425 messages (23 cents for each additional message) Plan 4: $139/650 messages (21 cents for each additional message) Plan 5: $299/l,500 messages (20 cents for each additional message)
Ram Mobile Data, Inc. Woodbridge NJ	266 U.S. cities	8 kbit/s; actual throughput: 2.4-8 kbitls	4 cents for 2-55 bytes; up to 12.5 cents for 488-5 12 bytes Plan 1: $25/100 kbytes (35 cents for each additional kbyte) Plan 2: $66/200 kbytes (33 cents for each additional kbyte) Plan 3: $85/275 kbytes (28 cents for each additional kbyte) Plan 4: $135/500 kby-tes (27 cents for each additional kbyte)
Ref.: Data Communications			

The water medium is only applicable to waterway types of sensors and associated communications which typically require bottom mooring. Buoys may be utilized for supporting over-the-water (versus under the water acoustic) radio frequency communications.

Classically, copper twisted pair has been utilized for LAN, MAN and WAN digital communications. Copper twisted pair has both frequency attenuation and signal amplitude attenuation versus distance. Thus, amplification is periodically required and signal bandwidth requirements must be matched to the bandwidth-distance parameter of the cable. Lower gauge cable (such as AWG 19) has less signal amplitude attenuation loss than higher gauge cable (such as AWG 24). Thus for longer cable runs requiring less frequent line amplification, AWG 19 cable is utilized. Shorter runs typically utilize AWG **22** or AWG **24. Table 4.1.3.4.6-1** summarizes typical twisted pair cable links. (Category references are per ANSI/EIA/TIA 568.) With line amplification, links can be extended. **Table 4.1.3.4.6-2** summarizes modem performance over twisted pair copper medium (without line amplification).

Coax is typically utilized for wide bandwidth, short distance communications. Coax can support GigaHertz bandwidth for short distance and several hundred MegaHertz bandwidth for several thousand feet. High frequency fall off of signals with distance dictates the use of frequency attenuation equalizers prior to amplification. Otherwise lower frequency signals will be amplified more significantly than higher frequency signals, resulting in either saturation of amplifiers with low frequency signals and unacceptable signal-to-noise for high frequency signals. Due to the cost of coax, the difficulty to install and the link reliability with in-line electronics, coax links are rapidly being replaced by fiber optic cable.

Electric power lines are being utilized as a medium for data communications. Power lines, because of their large AWG size, offer a lower signal loss compared with AWG 19 or AWG 22 communications cable. Not being of twisted construction, power lines may be more susceptible to externally induced, electromagnetic interferences at frequencies higher than 60 Hz. Power lines are generally designed to minimize 60 Hz induced interference through physical separation. Companies, such as Echelon, Inc., have designed data modems which operate over power lines. A complete line of modems are available including some supporting fault tolerant operations. These modems have been deployed in support of remote power distribution station monitoring and control. Conventional modem data rates are available. Repeaters are available to extend operating distances.

The use of power lines for communications involve consideration of:

- Low cost medium, generally available in urban and rural areas.
- Installation and test human safety is an issue
- Being metallic, power lines are susceptible to lightning and thus power surges which destroy modems protective circuitry from the line power
- At every transformer, a bypass/repeater must be included

Table 4.1.3.4.6-1
Summary of Twisted Pair Copper Communications Links

Circuit	Rates	Number Pairs Full Duplex	BER	Repeaterless Distance	Comment
Repeatered T-I Carrier	• DS-1 • 1.544 Mbps	2	--	2000 meters	• Requires expensive design, line conditioning, repeater installation (links over 6,000 ft.)
High Bit Rate Digital Subscriber Line (HDSL)	• 1.544 Mbps Full Duplex	2	10-7	3700 meters depending on gauge and quality of loop plant	• Inexpensive to install and operate • Intended for low cost T- 1 loops
Symmetric Digital Subscriber Line (ADSL)	• Up to 6.5 Mbps (downstream) • Up to 640 Kbps (upstream)	1	10-7	Up to 3700 meters over 24 AWG TWP	• Designed for "video on demand" • Easy to install and operate
ISDN Basic Rate (BRI)	• 160 Kbps • (2B + D) B = DS-0,64 Kbps D = Data, 16 Kbps	1	10-7	Up to 5.500 meters for 19,22, and 24 AWG TWP	• Intended for Telephony Company • Switched digital services
Bell 202/400 Type Modem	• 1200/2400 bps	2	10-7	Upto 16 Km for AWG- 19 or 22	• Intended for low speed point-to-point or multidropped digital networks
Plain Old Telephone System (POTS) Basic Rate	• DS-0,64 Kbps	2	10-7	1400 meters typical without amplification from a Multiservice Data Terminal (MSDT)	• Intended for voice distribution from MSDT to Home
10BASE-T	• 1- Mbps	2	10-7	2500 meters using Cat. 3 or 5 cable	• LAN Applications
100BASE-TX	• 100 Mbps	2	10-7	205 meters over Cat. 5 shielded or unshielded cable	• LAN Applications

Circuit	Rates	Number Pairs Full Duplex	BER	Repeaterless Distance	Comment
100BASE-T-4	. 100 Mbps	4	10^{-7}	205 meters over Cat. 5 shielded or unshielded cable	. LAN Applications
100 VG AnyLAN	. 100 Mbps	4	10^{-7}	2500 meters over Cat. 5 shielded or unshielded cable	. LAN Applications

Table 4.1.3.4.6-2
Performance of Modern Communications Interfaces
to Twisted Pair Copper

Interface	Max. Data Rate (baud)	Range without Modem (meters)	Max. Data Rate with Modem (baud)	Range with Modem at Max. Rate (meters)	Range with Modem at 9.6K (Baud) (meters)
EIA-232	19.2K	15.2	11.5K	1610	4830
EIA-232N.23	19.2K	15.2	2400	16100	NA
EIA-422	10M	107	1M	610	4830
EIA-485	1M	152	1M	610	4830
v.35	2M	15.2	128K	1610	1610
EIA-530	256K	15.2	128K	1610	1610
Current Loop	19.2K	15.2	19.2K	1070	1524

The concept of operation is reasonably straight forward. The modem is isolated from the power line which eliminates the modem becoming part of the power circuitry. The isolator (usually a capacitor) will allow high frequency signals to be injected onto the power line. These signals operate at frequencies above 60 Hz and are thus not interfered with by the power line. Receiving modems can detect the higher frequency signals, converting them to digital information with conventional EIA 232 or EIA 485 outputs.

Fiber optic medium consists of single mode and multimode fiber cable. **Table 4.1.3.4.6-3** summarizes the basic characteristics of current production fiber. There are two (2) types of single mode fiber:

- Depressed Clad
- Matched Clad

Lucent Technology, Inc. (formerly AT&T) owns the patent rights on depressed clad cable. Matched clad cable has a slightly smaller mode field diameter but also exhibits slightly better performance. To provide competitive opportunities, generally both depressed and matched clad construction is allowed. However, once a fiber is selected, it is recommended to stay with the same fiber type. There is a greater attenuation loss in splicing a matched clad fiber to a depressed clad fiber compared with splicing fiber of the same type.

Table 4.1.3.4.6-3
Fiber Optic Cable

	Single Mode (Matched Clad)	Multimode
Core Diameter	8.3 um	62.5 um
Mode Field Diameter	9.3+/- 0.5 um	NA
Cladding Diameter	125+/- 2 um	125+/- 2 um
Attenuation at 1550 nm Best Grade Worse Grade	 0.25 dB/Km 0.4 dBKm	 NA NA
Attenuation at 13 10 nm Best Grade Worse Grade	 0.35 dB/Km 0.5 dB/Km	 1.2 dB/Km 2.0 dB/Km
Attenuation at 850 nm Best Grade Worse Grade	 NA NA	 3.7 dB/Km 5.0 dB/Km
Bandwidth 1550 nm 131omTl 850nm	 Unlimited with Current Electronics Unlimited with Current Electronics NA	 NA 500 MHz-Km 160 MHz-Km

There are a number of fiber diameters available for multimode including 50 um and 62.5 urn. The 50 urn is an old NATO standard and is found in older single mode systems. The modem standard is 62.5 um fiber. Less than 2% of the multimode fiber currently being produced is 50 urn, driving cost up for special production runs.

Both single mode and multimode fiber have two operating frequencies. The higher frequency exhibits less attenuation. Single mode fiber has no bandwidth limitations within data rates commonly deployed. Multimode fiber has bandwidth impacted by distance.

Fiber cable is typically available in increments of 6 or 12 fibers. Typical fiber counts are 12, 24, 36, 48 96, 144, to 216. Fiber cable is available in:

- Tightly Buffered (typically for indoor use)
- Loose Tube
- No metal (dielectric cable)
- Armored Protection
  - Light
  - Heavy

- Figure 8, Steel Messenger
- Figure 8 (or equivalent) dielectric messenger

Cable diameter varies from 10 mm to 23 mm depending on fiber count and construction. A 36 fiber cable is typically 12 mm in diameter and weighs 0.12 Kg/m (dielectric construction) with a 216 fiber cable having a 18.9 mm diameter and weighing 0.29 Kg/m. Minimum bend radius of the 36 fiber cable is 12 cm and for the 216 fiber cable is 19 cm. Bellcore GR-20-CORE covers the fiber cable specifications with EIA/TIA 455 defining test requirements.

Cable cost comparisons are indicated in **Table 4.1.3.4.6-4.**

Table 4.1.3.4.6-4
Cost Comparison of Fiber
(12-95 Information Provided by Seicor Corp.)

Fiber Count	Single Mode		Multimode	
	Dielectric cost $/Ft.	Dielectric Self Supporting cost $/Ft.	Dielectric cost $/Ft.	Dielectric Self Supporting cost $/Ft.
12	0.65	0.95	1.69	2.23
24	1.04	1.36	3.05	3.59
48	1.85	2.29	5.72	6.27
72	2.68	3.16	8.45	8.99
96	3.56	4.12	11.21	11.81

Metallic armor is more expensive; however, most ITS projects are utilizing dielectric cable due to:

- Its protection against lightning and associated, potential damage to electronics.
- Safety (Human and Equipment)
- Ease to work with compared with armor and associated reduction in installation time
- Lighter weight
- Can coexist with power cables under 600 volts.

What is readily seen from the cost comparison table is that:

- Single mode fiber is significantly less expensive than multimode.

- Single mode fiber is competitively priced with copper twisted pair and provides significantly more bandwidth, significantly more safety and significantly more reliability (2.5 times).

Today, with the significantly production and deployment of single mode fiber versus multimode fiber, it makes little economic sense to deploy multimode fiber. The cost differential in single mode fiber modems versus multimode fiber modems is about $400 per unit. With two optical modems required to communicate, an $800 cost differential exists between multimode and single mode optical modems.

The break even distance for a 12 fiber cable is 769. feet ($.65/ft versus $1.69/R = $l.04/ft.; $800 / $1.04/ft. = 769 feet). The break even distance for a 29 fiber cable is 398 feet ($800 / $2.0 l/ft. = 398 feet). Thus only within a building structure or on a small campus is multimode fiber justified.

Air is the last medium. Radio frequency, infrared or laser (light wave) communications is necessary. In general, the higher the frequency the greater the attenuation of the signal. For RF signals the attenuation loss can be approximated by:

$$\text{Loss (dB)} = 36.6 + 20\log f + 20\log d$$

where: f = Frequency in MHz
d = Distance in miles between transmitter and receiver

Attenuation loss essentially increases by 6 dB with the doubling of distance. For example, RF path loss for a 100 MHz signal at 20 miles is 102.6 dB, at 1 GHz is 122.6 dB and at 10 GHz is 142.6 dB. A 1 watt transmitter produces 30 dBm (disregarding antenna coupling loss and antenna gauge). A 10 watt transmitter produces 40 dBm and a 20 watt transmitter produces 43 dBm of signal output. Typical antenna gains are 5 dB to 30 dB depending on design. Directional antennas are typically higher gain than Omni antennas. Considering an RF link with a 20 dB antenna, a 10 watt transmitter would have an effective radiated power of 60 dBm and at 20 miles the signal to the receiver would be -22.6 dBm for 100 Mhz, -42.6 dBm for 1 GHz and -62.6 dBm for the 10 GHz signal. With typical receivers having minimum detectable signals (considering receiver noise figure) of -90 dBm and a fade margin of 25 dB-30 dB desired to maintain a reliable link, all links would be adequately supported with a 10 watt transmitter. However, a 1 watt transmitter becomes marginal at 10 GHz frequency, except for short distance communications.

The above example assumes no loss from foliage. Typically all frequencies above 30 Mhz require line-of-sight communications, with the exception that a small ground wave exists up to 50 Mhz as previously mentioned.

For comparison, single mode cable would have a signal loss of 11.26 dB at 1300 nm. A twisted pair cable would have an equivalent signal attenuation of 64.4 dB. It can readily be seen that less signal power is required to communicate over single mode fiber than any medium.

Table 4.1.3.4.6-5 compares some communications mediums (Ref. IEEE Spectrum **6-94). Table 4.1.3.4.6-6** provides a comparative ranking of mediums. Clearly, single mode fiber is the best medium available followed by air (RF or light communications). Clearly water is the least desirable medium followed by coax. This is not to say that specific factors such as budget, zoning regulations, disruption of commercial service or other factors do not preempt the factors utilized in the comparative tradeoff of mediums. Single mode fiber is the best overall medium. Cost of multimode fiber and bandwidth limitations make it a lower choice than compared with microwave for rural ITS applications.

4.2 Leased Service Overview

4.2.1 Frame Relay

Frame relay is a technology emerging from the older X.25 packet network services offered by telephone companies. It emerged with Integrated Services Digital Network (ISDN) standards. Frame relay is designed and optimized for data networking, especially through the public telephone networks ISDN infrastructure. It uses variable length frames instead of fixed length cells (as are utilized by ATM). Thus frame relay has a lower overhead compared with ATM cells and with the correct mixture of data traffic, can provide more efficient data transfer.

Frame relay is optimally designed to transport data at data rates up to T- 1 or E- 1. ATM on the other hand, is designed to transmit multimedia (voice, video and data). Thus frame relay is not a replacement for ATM; it competes only with the pure data communications applications of ATM.

Frame relay utilizes statistical multiplexing of frames. If a data connection is temporarily not used, its capacity is instantaneously reallocated to other frame relay circuits requiring the bandwidth.

Customer premise equipment includes a device called “Frame Relay Access Device” or FRAD. The FRAD provides attachment of customer premise equipment to the public frame relay network. Access may be at fractional T- 1 to T-l. The FRAD port is a physical connection that provides a gateway to the frame relay service. A single physical port connection may support one or more virtual circuit connections to other locations. Virtual circuits are the logical connections utilized in a frame relay network. They are typically assigned a throughput rate, known as the Committed Information Rate (CIR). The network typically will not lose data unless the user exceeds the CIR (over subscription).

Permanent Virtual Circuits (PVCs) are defined at the time the service is installed. The distant ends of the network must be known so that logical connections may be established between interface points. The logical connections remain established permanently, even if the local access line is a dial-up connection.

Switched Virtual Circuits (SVCs) are logical connections which are established on demand. SVCs are just emerging in Telcos with the use of modem switching technology.

Table 4.1.3.4.6-5
Communications Medium Comparisons

Characteristics	Twisted Pair	Radio	Microwave	Power Line	Coaxial	Infrared	Fiber Optic
Typical range, meters	1-1000	50-10,000	1,000-10,000	10-5,000	10-10,000	0.5-30	10-60,000
Typical data rate, kb/s	0.3-56	1.2-9.6	9.6-155,000	0.06- 10,000	300-10,000	0.05-20	1-1,000,000,000
Relative modem cost, US $	$300	$600-$3,000	$10,000-$90,000	$200	$30-$50	$20-$75	$300-$1,000
Typical installation cost	High	Low-Medium	Medium	Low	High	Low	High

Ref.: IEEE Spectrum, June 1994

Table 4.1.3.4.6-6
Medium Comparative Ranking

	Medium						
Characteristic	Twisted Pair Copper	Coax	Power Line	Single Mode Fiber	Multi-mode Fiber	Air	Water
Bandwidth	3	5	3	8	6	10	1
Bandwidth/Distance	3	5	3	10	6	8	1
Cost of Medium	5	1	9*	5	2	10	10
Cost to Implement Communications over Medium	10	7	9	7	9	5	3
Reliability of Medium to Support Corns	7	4	7	10	10	5	5
Human Safety (Ops. & Maint.)	8	8	1	10	10	8**	5
Ranking	36	30	32	50	43	46	25

Notes: Max Score = 60
* = Assumes mostly installed by Power Utility
** = Safety is RF energy or optical laser energy

Three (3) main physical access options are supported for most ISDN frame relay services:

- Dedicated Local Loops
- Shared Local Loops
- Dial-Up

Dedicated local loops are typically available in two (2) configurations:

- 56/64 Kbps
- 1.53612.048 Mbps

Shared WAN access of ISDN allows the non-frame relay applications to share the same physical local T-l/E-l loop, minimizing network access cost at each user location.

Frame relay service has less end-to-end delay compared to the older X.25 packet network technology. ANSI T1.618 - 1991 "Core Aspects of Frame Relay Protocol for Use with Frame Relay Bearer Service) does not support isochronous operations and is thus not compatible with motion video or voice.

Bottom line, frame relay reduces the interfaces complexity at a site. The "network" is provided as a service with each physical interconnect essentially a virtual circuit. Thus a single high-speed line at a site supports many virtual connections to the sites having physical interfaces to the service.

Frame relay does not support increased reliability of communications since equipment is shared and a single point failure can exist with a single physical interface to the service. Depending on the equipment and internal design of the network service, multiple routing paths can increase service reliability.

Typical frame relay physical interface equipment based on a 500 site network is $6600 (Ref.: Data Communications, 9-95). Per Strategic Network Consulting (Ref.: Telecommunications "Evaluating Frame Relay versus Data Link Switching") frame relay monthly cost is $330/month per interconnect. For a 100 physical interconnect network the receiving cost would be $396,000 per year.

4.2.2 Switched Multimegabit Data Service (SMDS)

SMDS is a high speed, connectionless, public packet switching service that extends local area network like performances beyond the users premises and across a metropolitan and/or wide area. SMDS complies with ISO 8473 and IEEE 802.6 standards.

SMDS Interface Protocol (SIP) operates across Subscriber Network Interface (SNI) and is based on the Distributed Queue Dual Bus (DQDB) MAN Medium Access Control (MAC) protocol per IEEE 802.6, Section 18-3. This protocol supports the capability for many systems or nodes to be interconnected in a shared medium configuration which operates as two (2) unidirectional buses. SMDS provides for the exchange of variable-length SMDS packets up to a maximum of 9188 octets of user information per packet. Security and privacy for subscribers are offered by means of an access path that is dedicated to an individual user. SMDS furthermore validates the SMDS source address associated with every SMDS data packet and that the SMDS is legitimately assigned to the SNI from which the data packets originated.

SMDS sustained information rates are:

4 Mbps
10 Mbps
16 Mbps
25 Mbps
34 Mbps

based on class of service from 1 being the lowest (i.e. 4 mbps) to 5 being the highest. From 11 to 16 SMDS data units (packets) may be transmitted concurrently.

The benefit of SMDS is higher performance compared with frame relay and use of a network protocol . standard in accordance with 802.XX standards. SMDS service is more expensive and more limited than frame relay in its availability.

4.3 Trends In Communication

4.3.1 General Trends

Electronic technology, as history has proven, rapidly changes. ITS systems planners cannot be "technology chasers". The key to a successful system is not change for new technology's sake but to change because new technology clearly solves a need unfulfilled by current technology. If one is concerned about technical obsolescence, it can almost be insured that from the initial process of designing a new ITS system until the time that it becomes operational., electronic technology will have changed.

What is important related to technology is to identify the standards within which technology will change. SONET technology emerged from Broadband Integrated Services Digital Network (B-ISDN) standards and thus interfaces which were defined under old B-ISDN standards are still compatible with SONET technology which did not exist at the time B-ISDN were created. Similarly, ETHERNET technology still grows under the IEEE 802.3 standards. This is not to say that new standards for new technology will not emerge; what is being said is that if a solidly supported standard is selected, the probability is that technology will grow within the standard with both extension of the standards and maintenance of common points of interoperability.

What we are seeing in the 1995-1996 era is:

A) A rapid transition from copper to fiber optic at all communications levels from LANs, MANS and WANs to computer buses and even to the chip level. We are reaching the peak limits of data transfers over metallic connections and then can only be expanded by optical communications.

B) We are seeing optical processing technology in its infancy. Lagging behind the deployment of optical communications at the computer bus and chip level will be actual optical processing modules. A major part of the future computer may in fact include optical processors.

C) We are seeing significant improvements in the ability to communicate faster and more reliable over marginal physical mediums. Transmission of data over power lines at 10 Kbps over several 10's of kilometers has been proven. Modems which can literally transmit megabits per second over barb wire are available utilizing advanced signal processing technology.

D) Conventional computer technology is currently advertising 200 MHz processor chips. Computers will continue to improve in integrated functionality and processing speed. This will increase the demand for higher performance communications networks. It will further increase deployment of multimedia integrated systems.

E) Wireless technology is in an advanced evolutionary state. With FCC opening up new commercial frequencies, we are in a rapid deployment phase of wireless cellular voice and digital communications technology. The revolution will more be in the wireless coverage and associated services than in the development of new wireless technology. We are currently pushing limits of bandwidth utilization efficiency with current modulation technologies. Either FCC allocated bandwidth must increase or new modulation technologies must evolve to achieve greater wireless communications data rates.

F) Copper twisted pair is not totally obsolete. Currently technology development is underway to increase data rates on old copper twisted pair networks. High-bit-rate Digital Subscriber line (HDSL) Technology and Asymmetric Digital Subscriber Line (ADSL) are examples of this technology. HDSL is providing up to 2.049 Mbps over twisted pair for campus type distances and up to 6 Mbps utilizing ADSL technology.

G) A rapid transition is currently occurring with video from analog to digital. Domestic user deployment has started with Digital Satellite Service and use of the MPEG-II compression/decompression algorithms. CCTV cameras will be all digital starting in late 1997 with transition continuing from analog to digital into the early 21 st Century. Then all video transmission and receiving equipment will be digital. Analog video will totally disappear by 2010. High definition TV standard will emerge by 1999 with an option of standard versus high resolution for data transmission and display. MPEG-II covers high definition transmission.

H) Private Data Network suppliers will continue to grow. There will be a "shake-out" in the early 2 1 st Century with perhaps four (4) major survivors. Data rates will continue to increase as modem technology improves. Perhaps 38.8 Kbps to 50 Kbps may be possible over private data networks by 2010.

I) New optical fiber and optical transceiver technology will emerge in the early 2 1 st Century supporting higher data rates over a single fiber for longer distances. Wave division multiplexing will improve making multiple networks possible operating over a single fiber. This technology will help offset the growing need for bandwidth.

Not only is wireless communications technology in a rapid deployment which supports both voice and digital, but also fiber cable is in a rapid deployment state. Just about every major city in the U.S. has fiber going in the ground (or aerially) which is replacing both twisted pair and coax copper. We are seeing a wide bandwidth communications medium being installed "to the curb". This will change the way individuals communicate, watch television, shop, pay bills, etc. We have discussed the information age since the early 1980's and we are now really in the information age.

Today we are seeing the first deployment of MPEG-II compressed video technology in the Digital Services Satellite (DSS). The DSS terminal is available today for $500 to $600, receiving and converting full motion, compressed video to conventional analog form for display. Compressed digital video technology will rapidly be deployed with eventual embedding into television monitors or perhaps the TV monitor just becoming the monitor utilized for the home computer. In any case, video distribution will be digital and cheap. Emphasis will be on asynchronous communications networks, whether optical or wireless, which are capable of supporting multimedia. New ground-based lightweight personal data assistant (PDA) terminals will emerge competing for the DSS network user market. This technology was tested during the 1996 Summer Olympics in Atlanta and proved to be successful. This technology offers wide bandwidth to the curb with interactive capability -- a capability compatible with ITS requirements.

Internet will continue to grow with more gateways and more bandwidth. Multimedia Internet will start evolving in mid-term period and will be completely available in the long-term period as fiber optic cable completely replaces the old copper communications infrastructure with limited bandwidth. Cost of Internet will most likely increase as government subsidies are removed. Users will have to pay for unrestricted communications distance (World Wide).

4.3.2 Communications Technology Projections for Mid-Term Period (2003-2007)

Mid-term communications technologies are as follows:

- SONET Technology

  Firmly established and deployed on a worldwide basis. OC-384 terminal equipment (19.64 Gbps) in production with operational deployed networks. Price reduction (1996 baseline) which places OC-384 terminals only about 30% higher than current OC-48 terminals. This will be accomplished by use of large scale integration and lower optical transceiver cost.

- ATM Technology

  ATM technology has become affordable, competing with ETHERNET of today. Computers are "plug and go" whether LAN, MAN, or WAN. OC-3 and OC-12 ATM channels will become an integral part of SONET terminal equipment. Thus both synchronous and asynchronous data transfer will be accommodated with common terminal equipment. ATM ports to the desktop will be optical operating at OC-3 data rates. Copper twisted pair interface options will be offered at older 25 Mbps and 44.78 Mbps data rates.

- LAN Technology

ATM LANs will be common, replacing ETHERNETs as the leading LAN technology.

- Leased Network Service

Many competing networks will emerge selling bandwidth to subscribers. The proliferation of competing network services will drive cost down. Profit margins will be small and many of the network service providers will approach Chapter 11. Poor maintenance service will be a characteristic of these for fee networks in an effort to service.

- Merging of Service to the Home

Communications service to the home will emerge to one supplier who will provide telephone, Internet interface, cable television, security service, etc. over a common, fault tolerant network. Competition for these services will keep cost down. All service will be digital and at a wide bandwidth supporting digital TV (possibly 9.24 Mbps or 6 DS-1s with 4 devoted to TV. Service will be offered to homes in terms of parallel TV channels at 6.16 Mbps per TV channel. High definition TV option will be offered with 18.48 Mbps service.

- MPEG-II, Version X Video Compression

Based on momentum of DSS, MPEG-II video compression/decompression algorithm will emerge as the National standard. Chip sets will be available at very low cost to virtually eliminate analog video for new systems. CCTV cameras will output compressed video. Video switching and distribution will be via standard communications network technology. There will not be a separate video switch and communications switch.

- Wireless Communications - Cellular

The U.S. will have standardized on a digital cellular standard. CDMA will win over TDMA because of its enhanced capability. Rapid deployment of CDMA cellular networks will start moving wireless service into rural areas. Initial deployment will focus on high profit, metropolitan areas. Increased competition for cellular service will drive down service costs. Some companies will seek rural business to subsidize metropolitan business. Due to capital investment required for rural areas, only the more profitable wireless companies (and better capitalized) will seek rural expansion. By the mid-term, we will start to see a “shake out” of the cellular companies who purchased frequencies/coverage areas in the 1995 time period.

Heavily traveled rural corridors will be first to see full coverage digital cellular. Other corridors will follow, but at a slower pace. CDPD upgrade from AMPS will continue to be utilized until a suitable National standard emerges.

With extension of digital cellular to rural areas, there will be a need for right-of-way. Progressive states will trade right-of-way for fiber cable in the rural area. This cable will commercially be utilized to integrate cellular nodes and to deploy multimedia service to small rural communities.

- Digital Microwave

Recognizing the need for more bandwidth, FCC will most probably modify microwave regulations allowing more bandwidth. Power limitations in the 18 GHz and above will be adjusted to allow more effective area of higher microwave frequencies with wider bandwidths. Microwave operating at OC-6 will be deployed and OC-12 will be emerging. These will be fully compatible with SONET/ATM offering seamless extension.

- Satellite - Wireless

Wider bandwidth satellite channels and satellites in low earth orbit will be available at more affordable cost. Competition in satellite provided services will cause a decrease in channel cost. Low earth orbit satellites will drive the emergence of a new class of portable digital terminals with improved capability at a low cost.

- Meteor Burst - Wireless

A renewed interest in meteor burst communications supporting rural communications will emerge. This increased interest will support research into improved meteor burst modems and higher data rates. Meteor burst will continue to be less costly than cellular and satellite services for private networks.

- Controller Technology

With emphasis on open architecture in the mid-1990s plus efforts to develop an open architecture 2070/20xxxx controller using standard data bus and circuit card modules, we will emerge in the mid-time period with a fully open architecture controller. We will have migrated from special 170/179 and NEMA interfaces into truly open interfaces at levels below (sensors/signal heads) and above the controller (network interface). The NTCIP protocol will emerge as a standard before the turn of the Century but modified to accommodate modem network interface. Plug compatibility with an ATM/SONET network will be available at an affordable cost. Optional wireless interfaces will be available. The open architecture controller will be capable of performing most all field device control functions. SNMP protocol or a more modem version such as CMIP will be included in the new product.

- Automated Highway Systems (AI-IS)

Technology related to AHS will continue in a research and development status. It is predicted that we will not see any “driverless” control of vehicles during this period. In fact, it is predicted that emphasis will be replaced from external control of vehicles to providing more safety devices in vehicles and maintaining the “driver in control”. We have seen the trend in air traffic control with technology emphasis placing the “surrounding traffic picture” in the cockpit of the aircraft, making the pilot responsible for collision avoidance. We will see in vehicles coming out of car manufacturers a modem, multimodal information system with automatic vehicle location (GPS) within vehicles and with integrated sensors that makes the driver aware of his external surroundings (other vehicles, road hazards, upcoming road crossings, etc.) and of unsafe conditions. Cellular digital will continue to be the mayday link of choice and infrastructure to vehicle links for corridor status and hazards will continue to be FM Digital Subband(RDS) and cellular digital. Those that cannot afford modem in-vehicle systems will utilize Radio Data Service (RDS) with an after market in-vehicle information display. Emphasis will continue to be on users paying cost with jurisdictions paying only for critical services.

We will begin to see information links between vehicles to exchange safety related data. These links will be low power and perhaps.CDMA/spread spectrum or infrared. Radar or LADAR will be active devices supporting vehicle safety.

Commercial vehicles will also have similar equipment as private vehicles. More emphasis will be placed on commercial vehicle safety automatic monitoring and reporting due to influence of insurance companies. Automatic CVO clearance stations will also include automatic vehicle safety checks. CVO tags as we know them today (HELP and Advantage 75) will be utilized only on older vehicles. New vehicles will have an integrated communications link with the vehicular information system. Commercial vehicles will take advantage of the expanded cellular coverage into rural areas and mobile satellite terminals perhaps will start a decline. Unless satellite cost is competitive with cellular, cellular will obsolete mobile satellite when rural cellular coverage is achieved.

- Internet

Fiber to the “curb” (home and office) will have continued during this period providing easy real-time, interactive multimedia access. In the same manner that homes of the SO’s and 90’s had integrated security and intercom systems, homes and offices of this era will have integrated information systems for internal and external communications and control of functions such as security, air conditioning, energy management, child monitoring, cooking, recording-entertainment, etc. Emergence of a household Internet address will be initiated. Electronic mail will be common place with mail (as we currently know it) becoming obsolete. Internet will converge with integrated communications to the home, and will become a common information service. Internet of tomorrow will be the local, long distance, cable TV and Internet services of today bundled into one service. Bandwidth will be expanded and delays minimized. Internet will become the primary access medium for traveler information with users having instant access to any Interstate corridor and major urban corridor conditions. Interactive route planning software will emerge for home and office PCs with Internet providing the real-time database.

4.3.3 Communications Technology Projections for Long-Term Period (2008-2017)

Vision of 2008 to 20 17 communication technology certainly is fuzzy. It is predicted that by the long-term period, fiber optic communications will have virtually replaced copper twisted pair and coax communications. Old copper infrastructures will have become unreliable requiring replacement. Fiber optic cable will be the replacement. Homes and commercial buildings will replace copper communications lines with fiber optic. Buildings will include microcells which connect low power portable telephones into the fiber network. The trend will be in the wireless technology to utilize more dense cells and lower power transmitters. Perhaps we will see even adaptive portable cellular telephones where only the amount of RF power needed to provide connectivity will be utilized. The objective will be to reduce RF interference as proliferation of wireless continues.

By this time period we may see public/private partnerships to install backbone communications fiber along major corridors with embedded wireless microcells. Perhaps this partnership will allow use of the microcells to periodically communicate corridor status and to receive mayday messages. In any case the primary purpose of the microcells will be to support personal communications. Jurisdictions would be highly restricted in use.

By this time period, FCC will have seen a need for higher wireless cellular data rates. Thus some cellular bands will be “opened” (wider bandwidth) supporting data services greater than 19.2 Kbps. Perhaps cellular digital rates of 200 to 500 Kbps may be in operation based on wider bandwidths and improvements in modulation technology.

Techniques to deploy fiber optic cable will have been perfected to significantly reduce installation cost. Fiber cable with integrated flexible conduit will be available. Construction machines will be available which will automatically trench, bury and cover with concrete a fiber cable. Cost of fiber installation will be significantly reduced, again making it highly attractive for urban extension.

Digital microwave will continue to have improved capability. Perhaps we will have OC-48 digital microwave by this time period.

We will have progressed through a generation of vehicles with the predominant number of private and commercial vehicles having an integrated vehicle information system and digital cellular link. A second RF toll tag replacement link will also be embedded. This will be a microcellular link utilizing spread spectrum. Toll tags as we know them today, will be obsolete.

For rural corridors not receiving expansion of cellular and fiber, perhaps a low cost pseudo communications satellite technology will be developed utilizing tethered balloons (similar to those currently utilized in Arizona for border security). These balloons will become solar powered platforms for longer range cellular communications and perhaps "God's eye" view of the corridor perhaps utilizing advanced radar imaging technology for day/night, all weather surveillance.

All communications will be digital and advanced compression technology will continue to shrink bandwidth requirements for video and voice.

It is still doubtful if fully automated highway technology will be deployed. Emphasis will continue to be improved awareness by the driver with collision avoidance stressing capability embedded within vehicles and perhaps communications between vehicles.

North American Digital standards will be maintained (as currently defined by ANSI) but will be significantly expanded in the optical communications area. There will be little difference in LAN/MAN/WAN technology. Interworking networks will be common place.

Houses will have gone through a 20 year (minimum) period and will be candidates for modernization. Thus both old and new homes will transition to fiber interconnected integrated home information systems. As in the mid-period, Internet will become the common information service to the home for voice, data and video. Your current telephone number will essentially be a "web" address. Wide bandwidth of fiber to the home will support multiple service channels including voice, movies and data. ITS systems will find it easy to distribute corridor status data to a large majority of the population at very low cost. Cellular will emerge as a wireless extension.

What this period will mean for ITS is easier access to travelers and broader coverage. "Add On" communications devices (such as toll tags, RDS adapters, etc.) will disappear and integrated communications functionality will have emerged. Communications and computers will have merged where communications is a common extension of a computer's information data bus. The numerous requirements for bridges and routers will have decreased as common standards are widely deployed.

This will be an era of "communicating anything, anywhere" at affordable cost.

4.3.4 Should ITS Wait for the Future

ITS should not wait for the future. By deploying systems complying with North American Digital/Optical Hierarchy Standards, communications compatibility is assured. The rapid and extensive deployment of SONET networks assures that this ANSI/Bellcore/ITO standard will continue to be around well into the next century.

Public/private partnerships are available today to reduce communications cost. The key to success is how these partnerships are advertised to assure best participation. It is important that the public sector stays in control of their future. This means that the public sector should negotiate a separate fiber cable owned by the public jurisdiction and thus controlled by the public partner. Right-of-way is a valuable asset if properly marketed.

4.4 Considerations in Public/Private Partnerships

4.4.1 General

There is a growing need in the public sector for communication. Larger municipalities are paying from $100,000 to near $1 million per month for leased service. Dade County, Florida for instance pays $100,000 per month for lease communications services to a portion of their traffic signal controllers. Dade County Information and Telecommunications Services Division was paying an equal amount for networking judicial, law enforcement and financial services of the County. This equaled to $2.4 million per year. For this service fee, 750 miles of interconnected fiber could be installed per year. Generally a private jurisdictional network can be installed with a break even cost of under 3 years, and never exceeding five (5) years. Dade County had the vision to:

A) Recognize the continued outflow of tax payers dollars and potential cost savings to the tax payers.

B) Recognize the need for common integrated services within the County.

C) Recognize the value of right-of-way.

Thus, Dade County traded right-of-way for fiber and has its own modem optical network which integrates all.major County computer operations.

ITS involves core elements of Traffic Signal Control, Freeway Management, Public Transit Management, Emergency Services, Toll/Turnpike Management and Traveler Information. Other area functions include Port Authority, judicial, utility, public works and financial. Many functions require interoperability. Public Transit Operations require interoperability with Traffic, Freeway, Emergency Service, Port Authority, Traveler Information/Services and Financial. Thus it make logical sense to:

- Combine public data communications requirements
- Develop an integrated network plan
- Find a private partner desiring right-of-way
- Trade right-of-way for fiber
- Procure high reliability, low maintenance SONET equipment to implement a public network
- Start saving tax payers money

Cost of electronic terminal equipment can be shared among the public agencies utilizing the network. Benefits include:

- Cost savings
- Jurisdiction is in control of its communications future
- Build-out and modification is initially under jurisdictional control
- Integration with the public telephone network is simple, supporting access to cellular

Owning bandwidth in someone else's electronics does not place one in control of his communications future. Owning a fiber cable with dark fiber does.

Generally FHWA's funds can be utilized for operational communications but not for administrative communications. Thus where administrative services are involved the portion of the bandwidth that they use should be funded by the administrative agency.

4.4.2. How Private Partnerships are Derived

Usually jurisdictions advertise available right-of-ways and solicit interested parties to make a proposal for use with proposed compensation to the jurisdiction. The solicitation states that award "will be made based on the greatest benefit to the jurisdiction". Some bidders may offer bandwidth, some may offer dark fiber, some may offer a dedicated fiber cable and some may offer a dedicated innerduct of the conduit. Value to the jurisdiction is ranked as follows:

- Cable and Conduit #l value
- Cable only #2 value
- Dark Fiber only #3 value
- Bandwidth (lighted) #4 value

SONET terminals generally equate to the value of 4000 feet of fiber cable buried in conduit. Thus buried fiber optic cable in conduit is a much more valued offer than lighted fiber. With lighted fiber, the owner of the fiber and terminal equipment control use, build-out, and availability.

Fiber in trade dictates that no build-out can be accomplished without participation by the owner of the fiber. The reason is that the fiber is accessible only within his splice closure.

Providing the jurisdiction with a cable means that the jurisdiction owns splice closures and is in full control of build-out. Providing the jurisdiction with conduit means that the jurisdiction has the ability to expand.

A critical factor in partnering is that the jurisdiction must define their breakout requirements and utility boxes must be installed at required locations of breakout with slack cable. Otherwise, even if the private partner provides the jurisdiction with their own cable, there will not be a means of installing a splice closure for breakout.

The jurisdiction should be aware that the private partner has a biased motive and this is to acquire future business from the jurisdiction. The private company has a profit motive with profits enhanced by a sole source posturing. The jurisdiction must prevent sole source posturing to obtain the most cost/effective communications solution. For this reasons they should obtain professional consultation to assist in evaluating and negotiating the best trade offer of right-of-way for communications infrastructure.

While fiber has been the predominant right-of-way of interest, cellular companies are rapidly emerging with the auctioning of frequencies by the FCC. Right-of-way to install "cells" will become an issue in the late 1990's. Thus there is an opportunity for jurisdictions to seek compensation from cellular companies such as fee-free use for a number of terminal devices. This may include cellular SMART call boxes with a digital interface for controllers which do not require continuous, real-time interconnectivity (such as weather station controllers, variable message sign controllers, etc.).

It should be remembered that right-of-way must be of commercial benefit to a potential, private partner. Thus it is in the best interest of the jurisdiction to:

- Advertise early to "auction" right-of-way for communication infrastructure.
  - Otherwise the private partner will fulfill needs with other right-of-ways such as railroad, power transmission line, oil/gas pipeline, etc. There is a critical time window for business need based on private business plan.
  - Where there are right-of-way alternatives, the private company will evaluate all of his alternatives.
  - Sometimes alternate right-of-way better suits a potential private partner's needs and the jurisdiction may:
    - Cut his best deal with the alternate right-of-way
    - Can adapt the alternate right-of-way to meet jurisdictional needs

    Thus breaking out of an alternate right-of-way to the jurisdictional's primary corridor of interest is still more cost effective than cutting a poor deal with the private partner. All alternatives should be considered.

4.4.3 Power, Pipeline and Rail Partners

Railroads, power utility companies and pipeline companies are rapidly deploying fiber optic communications down their right-of-ways. Electric Power Research Institute (Palo Alto, CA) indicates that power companies are deploying SONET communications systems at a rate perhaps greater than ITS. Thus there are partnerships which can be developed.

4.4.4 Other Issues with Partnerships

It is important that the jurisdiction assures that quality installation is utilized. The jurisdiction should include in its partnership agreement standards of practice that are required. This includes defining the quality of fiber cable (such as referencing Bellcore GR-20-CORE), and the type of conduit, installation (such as fusion splicing), splice closure, etc. Otherwise an unreliable, poor quality installation will be achieved.

Dade County, Florida is an example of a public/private partnership which did not define quality of materials and installation. Fiber cable was installed by a company in the cheapest manner possible. Survivability and reliability was not an objective but rather than low cost/quick service. Cable installation breeches normal industrial standards. Thus, not all of the time that both partners have the same quality, reliability and maintainability objectives. These must be definitive and part of the understanding in the partnership agreement.

5.0 TRADE-OFF ANALYSIS AND RECOMMENDATIONS

For comparative planning purposes the I-84 corridor will be assumed to represent 2.64 million feet and the SR 14 and I-82 segments representing 1 .584 million feet. Installing a fiber optic cable down these routes would essentially provide unlimited bandwidth for the deployment of low or high data rate ITS controllers including video. The fiber could support deployment of video on the establishment of high performance virtual, interoperable local area networks between TOCs. Kiosk terminals and emergency telephones could be deployed at virtually any location. The corridor fiber medium would essentially offer support for any required communications both current and future. Obviously the fiber optic cable would have adequate single mode fiber to support interconnects of along-the-corridor ITS devices to the communications nodes. Because fiber along the corridor offers the optimum in communication from a performance standpoint, it then can be utilized as the comparative baseline for comparing other communications options.

The cost of a fiber communications backbone is a function of installation technique. The lowest cost installation technique is aerial. Assuming that utility poles are in place, fiber can be installed aerially for $4.00 per foot. Trench and bury becomes the next less expensive installation technique. Trench and bury cost approximately $6/foot. A planning cost of $5/foot will be utilized supporting a 50/50% installation mixture. Installation in conduit is the most expensive and would cost an average of $12/foot.

By using single mode fiber, communications network hubs can be 30 miles apart providing a 15 mile (24.14 Km) fiber run. Assuming a 0.4 dB/Km single mode fiber attenuation, the maximum fiber path loss would be 9.7 dB. Considering splice loss and connector coupling loss this is well within the capability of low cost optical modems which typically provide 15-17 dB link attenuation budgets.

Because of its open architecture, stable standards, multimedia capability, reliability, maintainability and modularly expandable bandwidth, SONET technology is the most prudent choice. Most of the ITS freeway systems including California (CALTRANS) and Washington State DOT, have chosen SONET for freeway communication. For the I-84 corridor it is estimated that 20 SONET communications nodes would be required and 10 would be required along the remaining corridors. (Note: Several additional nodes were added as a contingency for installation location flexibility.) OC- 12 SONET terminals, which support 622.08 Mbps of bandwidth (or 12 DS-3s or 336 DS-Is or 8064 DS-OS) would cost approximately $130,000 including node building. This includes $40K for equipment, $40K for installation and test and $50K for a node building. With installation of SONET nodes the only additional cost will be ITS controller communications which would be approximately $3000 per controller device (assuming new digital cameras with integrated codec are utilized for CCTV). The cost of controller integration to a communications backbone is common for all applications, whether wireless or leased service and is not peculiar to an optical backbone.

Disregarding ITS controller interconnect cost and adding four (4) SONET terminals (one per TOC at $80K each) provides a baseline comparative cost for the highest performance communications solution. This is summarized in **Table 5.0-l.**

Table 5.0-l
SONET Backbone Cost Estimate

Corridor	Feet of Fiber (million ft.)	Number of COMS Nodes	Number of TOC Terminals	Fiber Cost @ $/5/ft.	cost of COMS Terminals and Nodes	Total Cost of Corridor(s)
I-84	2.640	20	2	$13.2m	$2.76m	$15.96m
SR 14/I-82	1.584	10	2	$7.92m	$1.46m	$9.3 8m
Total All Corridors	4.224	30	4	$21.12m	$4.22m	$25.34m
Note: m = million = 10^6						

Table 5.0-l indicates that the fiber backbone and terminals in TOCs planing cost would be $25.4 million.

Based on the requirements of **Table 3;1.1-1,** 118 ITS field devices are associated with I-84 and 46 are associated with the SR 14/I-82 corridors. Kiosk terminals recommended (see Table 3.1.2- 1) are 11 along I-84. **Table** 5.0-2 presents a total communications cost for the corridors assuming deployment of an additional 20 CCTV cameras for I-84 and 10 CCTV cameras for SR 14/I-82 corridors. Cost of CCTV camera communications will include cost of codec transmitters and receivers at $6000 each in addition to the optical modem cost.

Thus, as shown in **Table 5.0-2,** the total cost of a modem communications system with all communications interconnects and deployment of 30 CCTV cameras in addition to identified ITS sensors, electronic signs and kiosk is $26.32 million ($16.65 million for I-84 and $9.67 million for SR 14/I-82). Since I-84 is a main commercial corridor, partnership for right-of-way for fiber may be possible to reduce cost. **Table** 5.03 presents the cost of just implementing defined ITS field devices plus the 11 kiosk terminals identified (i.e., no CCTV).

Table 5.0-4 provides a summary of cost as ITS capability is added.

Table 5.0-2
Total Communications Cost with
Fiber Backbone to Service Requirements

Corridor	Cost of Backbone	Controller Interconnects	CCTV	Cost for Interconnect ($3k each)	Cost of Video Codec	Total Cost
I-84	$15.96m	129*	20	$447k	$240k	$16.65m
SR 14/I-82	$9.38m	46	10	$168k	$120k	$9.67m
Total	$25.34m	164	30	$582k	$360k	$26.32m

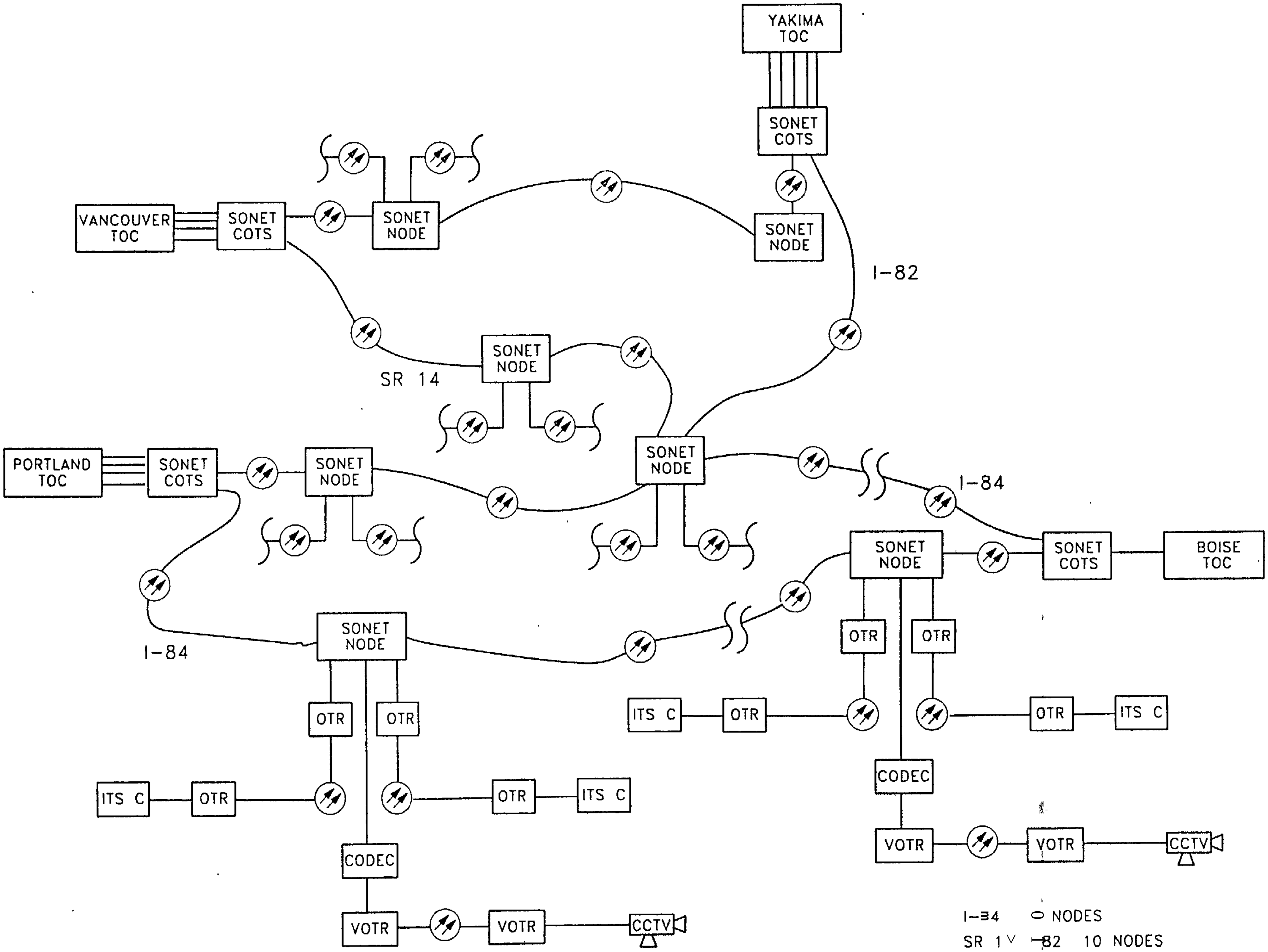
Note: m = million
k = thousand
* = include in kiosk terminals

The communications baseline planning estimate shown in **Table 5.0-3** represents a 20.2% loading of the network for field devices. Assuming a brouted ETHERNET with essentially no bandwidth limitations is virtually established between TOCs. The network would be loaded less than 25% providing adequate growth. **Figure 5.0-l** summarizes this architecture.

Table 5.0-3
Basic ITS Deployment Cost

Corridor	cost of Backbone	ITS Controller Interconnects	Kiosk Terminals	ITS Controller Interconnect Cost	cost of Kiosk Interconnect	Total Cost
I-84	$15.96m	118	11	$354k	$33k	$16.35m
SR 14/I-82	$9.38m	46	0	$138k	$0	$9.52m
Total	$25.34m	164	11	$492k	$33k	$25.87m

Note: m = million
k = thousand



SONET ARCHITECTURE

Figure 5.0-1

Table 5.0-4
Comparative Cost for Optical Backbone

Corridor	Basic ITS Device Deployment	Cost with Kiosk	Cost with CCTV
I-84	$16.31m	$16.35m	$16.65m
SR 14/I-82	$9.52m	$9.52m	$9.67m
Total	$25.83m	$25.87m	$26.32m

In summary, for approximately $26 million all communications requirements identified can be accommodated including adequate bandwidth expansion most likely for the next 10 years (assuming only ITS functions utilize the network). This will be the comparative baseline for alternative communications supporting identified ITS services to be deployed.

5.1 Private Communications Related to ITS

There is adequate cellular and satellite service along the corridor to support:

- Commercial vehicle communications with their dispatching centers
- Evolving "Mayday" reporting via cellular links.

Thus communications to support CVO functions and in-vehicle "Mayday" functions will not be considered as a public communications cost.

5.2 Alternative Communications Approach

5.2.1 Meteor Burst Communications Cost

Meteor burst communications can accommodate the requirements summarized in **Table 5.2.1-1**.

Table 5.2.1-1
Summary of Requirements Compatible with
Meteor Burst Solution

ITS Controller Supported	Number I-84	Number SR 14/I-82	Meteor Burst can Accommodate	Requirements Met
Road Weather Stations	34	8	Yes	42
Variable Message Signs	28	13	Yes	41
Weigh-in-Motion	14	2	No	0
Bridge Vehicle Overweight	6	6	No	0
Tunnel Vehicle Overheight	0	2	No	0
Rockfall Detection System	0	2	Yes*	2
Count Station	30	10	Yes	40
Down Hill Information System	1	0	No	1
Parking Information System	2	0	Yes	2
Research Sites	3	3	Yes	6
Kiosk	11	0	Yes	11
Total	129	46	—	145 (83%)
Note: *has small delay before activating VMS				

Meteor burst will not support real-time critical functions such as driver warning for overweight or overheight. This function can logically be accomplished by local area communications with event occurrence information provided by the meteor burst link to the TOC. This is further true of the weigh-in-motion sensor where electronic signage and enforcement should be accomplished locally via local area communications with event occurrence reported to the TOC.

To simplify estimates of cost, it will be assumed that all requirements are met with meteor burst technology. Cost data was obtained from meteor Communications Corp. (MCC). No effort is made to size the solar panel to accommodate ITS device needs. In areas where power is available, solar panels will not be required. **Table 5.2.1-2** summarizes the planning cost of a meteor burst communications network. This network is illustrated in **Figure 5.2.1-1.** Based on deployment of 175 remote terminals and a two (2) frequency base station, planning cost for communications is estimated to be approximately $2 million.

Table 5.2.1-2
Meteor Burst Communications Solution Cost

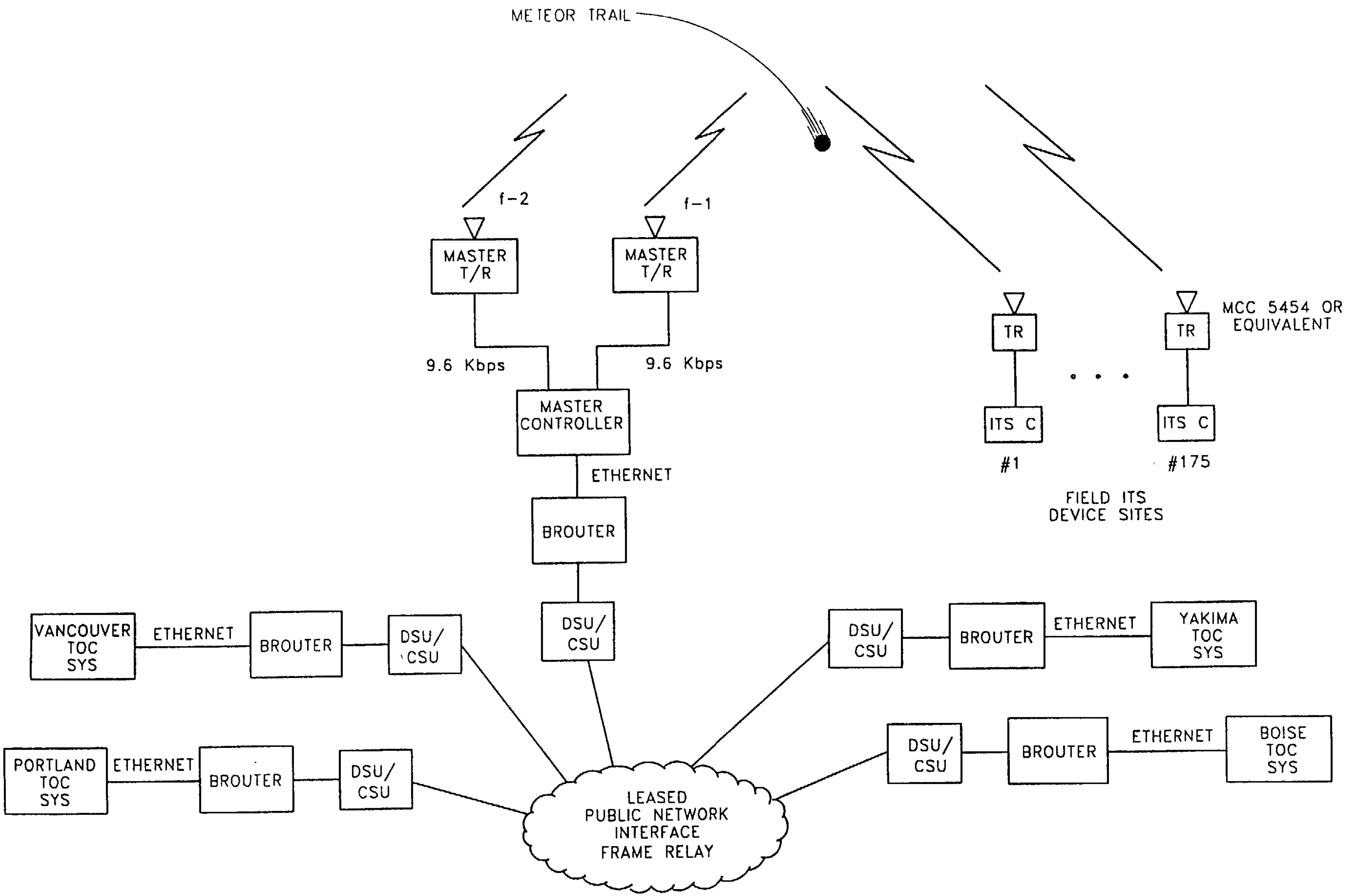
Corridor	Number of Remote Terminals	cost @ $8K/Inst.	Base Station	Base Station to TOC Link	Total Cost
I-84	129	$1.032m	$0.2m	$0.024m/yr. (lease)	$1.232m
SR 14/I-82	46	$0.368m	—	$0.024m/yr	$0.368m
Total	175	$1.40m	$0.2m	$0.048m/yr.	$1.6m
([$0.048x 10] + $1.6 = $2.1m/10 year lease)					

5.2.2 Wireless Interconnect from Roadside to Microwave Backbone

A superior approach compared to meteor burst is to utilize the existing microwave system in Oregon and VHF digital radio interconnects to the roadside ITS controllers. **Figure 5.2.2-l** illustrates this communications option. **Table 5.2.2-l** summarizes its cost. Towers were considered relative to I-82 extension. Planning cost of this communications alternative is $1.82 million. This approach has significant advantages over the meteor burst solution:

- Significantly more bandwidth
  - Each microwave site can provide independent EIA 232 channel interconnects to the TOC
- Near real-time (real-time except for polling protocol)
- Much more response
- Reduces need for leased service

While the cost is similar, performance is greatly enhanced utilizing the microwave backbone.



NOTE:

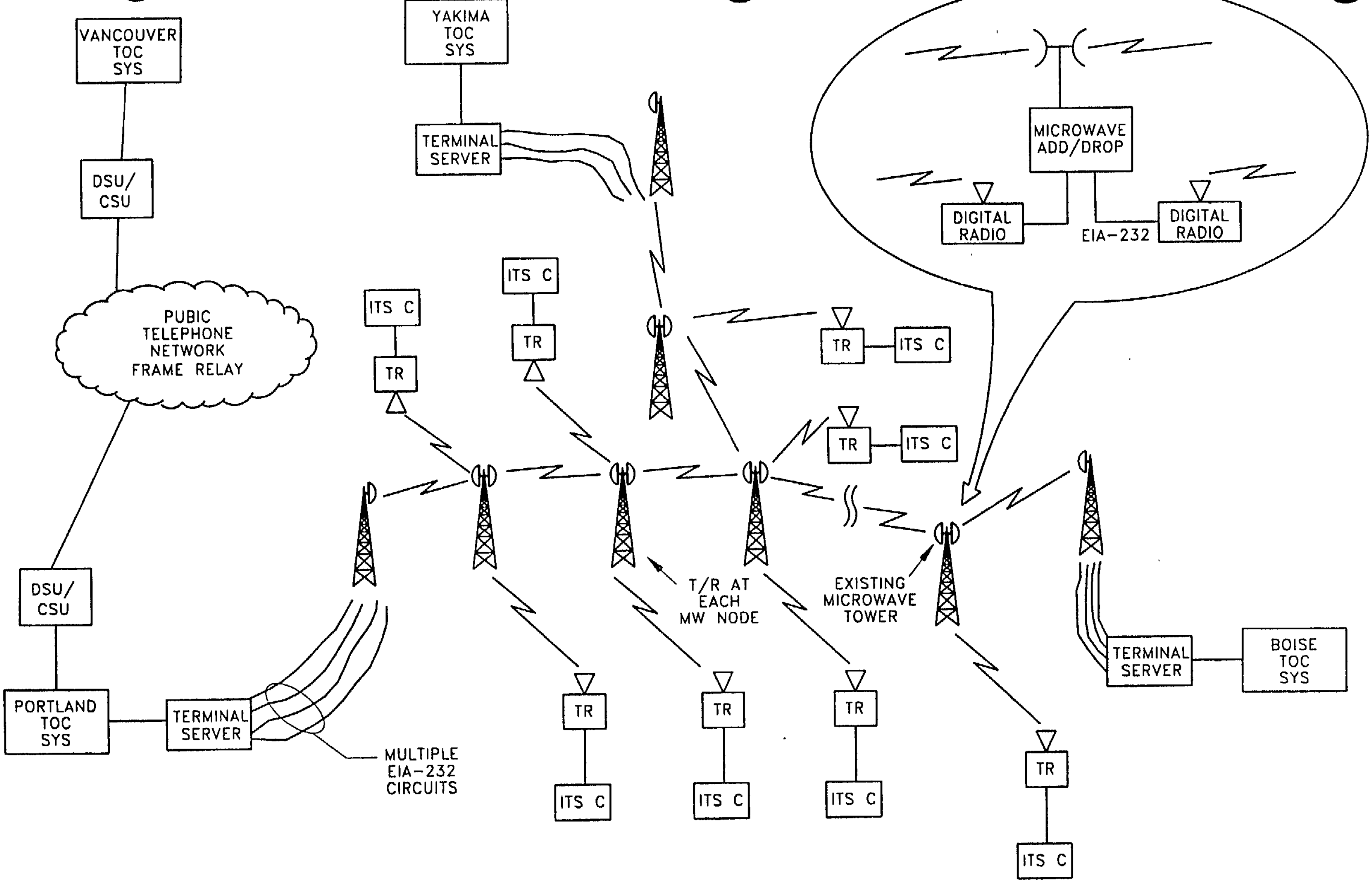
T/R TRANSCEIVER

ITS C = ITS DEVICE CONTROLLER

DSU/CSU = DATEC SERVICE UNIT/ CUSTOMER SERVICE UNIT (MODEM)

METEOR BURST COMMUNICATIONS SOLUTION

Figure 5.2.1-1



MICROWAVE BACKBONE WITH DIGITAL WIRELESS TO THE ROADSIDE

Figure 5.2.2-1

Table 5.2.2-l
Planning Cost for Microwave Backbone (Existing) with Wireless Links to tlie Roadside

Corridor	Number of Remote Terminals	Number of Nodes	Cost of Field Interconnect	TOC Interconnect	Leased Service	Total
I-84	129	16	$l.l6m	$0.05m	—	$1.21m
SR 14/l-82	46	6	$0.42m	$0.10m	$0.086m	$0.61m
Total	175	22	$1.58m	$0.l5m	$0.09m	$1.82m

5.2.3 SONET Microwave

A SONET microwave backbone could replace the existing analog microwave backbone. The advantage of an upgraded SONET microwave system are:

- Seamless integration with SONET terminals in TOCs
- Multimedia could be supported
- Bandwidth would be expanded by a factor of 60 (relative to 9.6 Kbps channels)
- Fully open architecture would be achieved

The system would look similar to **Figure 5.2.2-l** with the exception that a fiber interconnect would be made between the terminating towers and the TOCs. The cost of modernizing the microwave network from a planning standpoint is $3.3 million. This includes 3.5 miles of aerial fiber interconnect to TOCs. It also assumes that the towers, antennas and microwave equipment shelters are usable. This would be a true add/drop network that would "plug and play" at any node with a SONET fiber optic extension as required. The bandwidth, while not as wide as the baseline SONET optical solution still is significantly larger than the current microwave network. This network would support 3 DS-3s or 84 DS-1s or 2016 DS-OS with subrate multiplexing of DS-OS of 4 9.6 Kbps/DS-0. Corridor CCTV surveillance could be supported by use of short haul microwave as fiber extensions or a combination of both. With 30 CCTVs deployed, all low speed ITS circuits allocated and virtual ETHERNETS between TOCs, the network could still support 384 DS-OS channels or 16 DS-1 s. This is based on 3.08 Mbps video compression (12: 1 compression which provided good quality motion video). **Table 5.2.3-1** presents the planning cost to upgrade to SONET Microwave.

Table 5.2.3-l
Planning Costs to Upgrade to SONET Microwave

Corridor	Number of Existing MW Sites	Number of New Sites	cost to Upgrade	cost of New Sites	cost to Interface	Cost of Field Interconnects	Total Cost
I-84	11	—	$0.99m	—	$0.l56m	$l.16m	$2.31m
SR 14/I-82	—	2	—	$0.40m	$0.l56m	$0.42m	$0.98m
Total	11	2	$0.99m	$0.40m	$0.3 12m	$1.58m	$3.28m
*Note: See Table 4.2.2- 1: same extensions utilized to the roadside							

5.2.4 Use of CDPD or Available Digital Wireless Service

Survey indicates that CDPD will be available in the area by the time that EDP projects are funded. Thus CDPD becomes an option for communications. Enhanced Specialized Mobile Radio service (ESMR) is reportedly available in Colorado, California, Washington State and the Pacific Northwest. ESMR operates at 4.8 Kbps. Its availability along the route is unknown. No private data service was identified. Table 5.2.4-l presents typical average cost of wireless service. Based on the scenario shown in **Table** 5.2.4-2 costs will be developed as presented in **Table 5.2.4-3. Table** 5.2.4-3 indicates that the cost of cellular digital service would far exceed the cost of installing fiber over a 1 O-year period. It should further be noted that no video is included in the planning cost nor TOC-to-TOC interoperability.

5.2.5 Leased Telephone Network Service

One option to meet communications requirements is to utilize leased communications service such as frame relay. The State of Oregon currently utilizes frame relay service. The negotiated rates are not know; therefore, publicly available rate information will be utilized for planning costs. **Table 5.2.5-l** summarizes the cost and **Figure 5.2.5-l** illustrates the system approach. It is unclear if leased communications would be available in any rural area requiring a leased service interconnect. This does not include any CCTV video. Leased ISDN T-l lines would be required to accommodate any video. **Table** 5.2.5-2 summarizes video cost estimate using leased service. Basically, quality full motion video over leased service is unaffordable. The estimated 10 year cost of leased service (less CCTV) is $9.5 million.

The service provided by frame relay does not limit performance and near real-time (but not time critical) communications can be supported. It is superior, from a performance standpoint with meteor burst.

Table 5.2.4-1
Prices of Wireless Data Services

Technology	Data Rate Supported (Kbps)	Price	Estimated Cost to Transmit a Small File (80 bytes)	Estimated cost to Transmit a Medium File (500 bytes)	Estimated Cost to Transmit a Large File (10 kbytes)	Estimated CPE Cost (doesn't include laptop or PDA)
CDPD	19.2 (14.4 effective)	12 to 58 cents per kilobyte; monthly minimums range from $15 to $140 and include a specified amount of data	1-9 cents	7-29 cents	$1.40-$5.80	CDPD modem, $300 to $1,500
Circuit-Switched Cellular	19.2 (10-13 effective)	20 to 40 cents a minute, using the same rates as voice cellular	20-40 cents	20-40 cents	20-40 cents	Cellular modem, $300-$350; cable, $60-$70; data-capable cellular phone, $150
Enhanced Paging	9.6	Flat rate with unlimited or limited messages; monthly prices range from $4.95 for 1 kbyte to $39.95 for 4 kbytes	39-79 cents	N/A	N/A	Alphanumeric pager or PCMCIA card, $200-$400 (some companies include pager with service)
ESMR	4.8	10 cents per 140-character message; service costs $5 per month	10 cents	N/A	N/A	Portable phone with data screen, $500-$1,000
Private Packet Radio	4.8- 19.2	25 to 27 cents per kilobyte; monthly service plans range from $25 to $300 and include 100 to 360 kbytes of data	2 cents	12- 14 cents	$1.25-$1.35	Wireless radio modem or PCMCIA card, $500

Technology	Data Rate Supported (Kbps)	Price	Estimated Cost to Transmit a Small File (80 bytes)	Estimated cost to Transmit a Medium File (500 bytes)	Estimated Cost to Transmit a Large File (10 kbytes)	Estimated CPE Cost (doesn't include laptop or PDA)
Spread Spectrum	9.6-240	Flat monthly rate for unlimited usage; rates vary by provider and application	N/A	N/A	N/A	Wireless modem, $300-$600; cable, $20

CDPD = Cellular Digital Packet Data
CPE = Customer Premises Equipment
EMSR = Enhanced Specialized Mobile Radio
N/A = Not Applicable
PDA = Persona1 Digital Assistant
PCMCIA = Persona1 Computer Memory Card International Association

Ref.: Data Communications

Table 5.2.4-2
Digital Wireless Cost Scenario

	Poll Cycle	Data Transmitted (AV) (bytes)	Cost/ Transmission ($)	Total Cost/Day ($)	Number	Total Cost/ Day $x k
Road Weather Stations	5 min.	80	0.1	28.8	42	1.21
Variable Message Signs	5 min.	80	0.1	28.8	41	1.18
Weigh-in-Motion	30 sec.	80	0.1	288.0	16	4.61
Bridge Vehicle Overweight	30 sec.	80	0.1	288.0	12	3.46
Tunnel Vehicle Overheight	30 sec.	80	0.1	288.0	2	0.58
Rockfall Detection System	30 sec.	80	0.1	288.0	2	0.58
Count Station	5 min	80	0.1	28.8	40	1.15
Down Hill Information System	30 sec.	80	0.1	288.8	1	0.29
Parking Information System	5 min.	80	0.1	28.8	2	0.06
Research Sites	5 min.	80	0.1	83.52	6	0.50
Kiosk	20 min.	500	0.29	20.88	11	0.23
Total		500	0.29	$1660.4	175	$13.83k

Table 5.2.4-3
Total Cost for 10 Years
(No Maintenance cost Included)

Corridor	Field Interfaces Supported	TOC Interfaces	Cost of Interfaces ($x k)	Operational Cost/Day ($x k)	Operational Cost 10 Years ($x m)	Total 10 Year Cost ($x m)
I-84	129	4	89.4	8.9	32.48	32.49
SR 14/I-82	46	4	33.6	4.9	17.88	17.89
Total	175	8	$123.0k	$13.8k/day	$50.36m/10Yr.	$50.38m/10Yr.
Note: k = thousand m = million						

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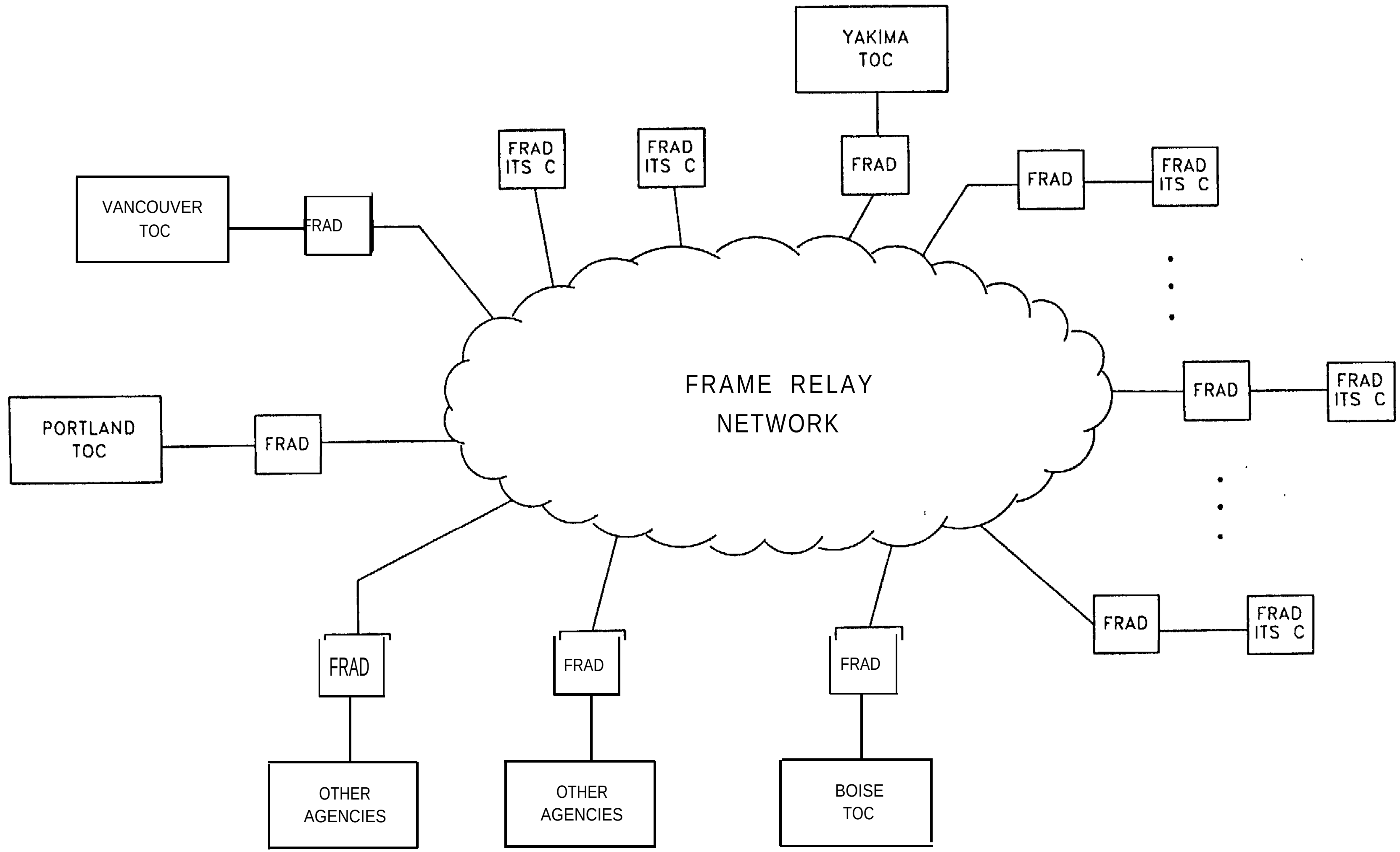


NOTE:
FRAD = FRAME RELAY ACCESS DEVICE
TOC = TRAFFIC OPERATIONS CENTER
ITS C = ITS CONTROLLER
CCTV NOT SHOWN

EXAMPLE OF FRAME RELAY COMMUNICATIONS

Figure 5.2.5-1

Table 5.2.5-l
Planning Cost for Leased Telephone Network Services

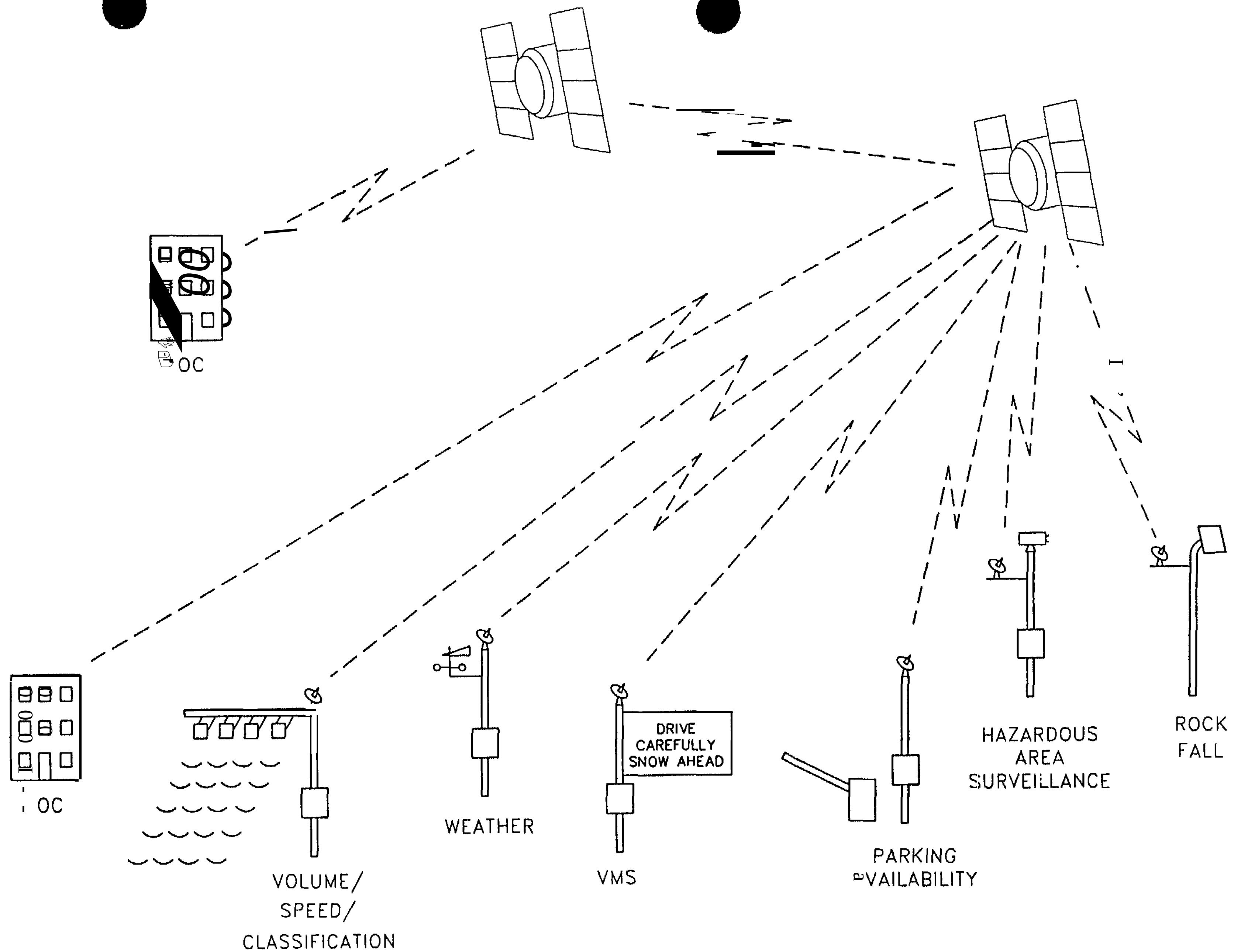
Corridor	Field Interfaces	TOC Interfaces	Fixed cost ($x m)	Recurring Cost/Month ($x m)	Recurring Cost 10 Years ($x m)	Total 10 Year Cost ($x m)
1-84	129	4	0.80	0.05	6.0	6.8
SR 14/I-82	46	4	0.30	0.02	2.4	2.7
Total	175	8	1.10	0.07	8.4	9.5

Table 5.2.5-2
Planning Cost for CCTV Video Leased Service

Corridor	CCTV	T-l Circuits	Circuit cost ($2k/mo)	Codec ($6k/ea)	Cost 10 Years
I-84	20	40	$80k	$240k	$9.84m
SR 14/I-82	10	20	$40k	$120k	$4.92m
Total	30	60	$120k/mo	$360k	$14.76m/l0 yrs

52.6 Satellite Communications

Satellite coverage of the corridors has been validated through interviews with truckers who utilize satellite communications service. Very Small Aperture Terminal (VSAT) or INMARSAT (or equivalent) satellite service are candidates for rural communications as shown in **Figure 5.2.6-l.** CALTRANS District 7 utilizes VSAT to back up fiber optic communications. This use of VSAT is not new to ITS. Cost of installed VSAT terminals are approximately $15,000 assuming availability of power. It is feasible to utilize a battery/solar panel powered terminal where commercial power is not available.



SATELLITE COMMUNICATIONS SOLUTION EXAMPLE

Figure 5.2.6-1

Cost of communications service via the satellite provider varies from $2/minute from low bandwidth interconnect to $15/minute for T-l bandwidths. **Table 5.2.6-l** summarizes acquisition cost of satellite ground stations. **Table** 5.2.6-2 summarizes operating costs of a satellite network. **Table** 5.2.6-3 presents the total acquisition and operating cost of a satellite network.

The total 10 year cost (not including maintenance) is estimated to be $63.6 million while satellite use time may be reduced with the evaluation of Low Earth Orbit (LEO) satellites, use cost still is estimated to be a minimum of $l/minute While this could reduce operating cost to perhaps $40 million (assuming a 3 to 4 year delay in availability and evolution to the $l/minute satellite use fee, this still represents a $4.69m solution. Certainly a cost reduction in ground station will be achievable with the emergence of LEO and associated competition. However, even considering VSAT versus LEO ground station technology, the cost of satellite solution is still driven by channel cost. The $40 million solution does not include consideration of video channels which would further increase cost.

Table 5.2.6-l
Fixed Cost of Satellite Ground Terminals

Corridor	Number of VSAT Terminals	Acquisition Cost at $1 5k/ter	TOC Terminal cost	Total Cost
I-84	129	$1.94m	$0.03m	$1.97m
SR 14/I-82	46	$0.69m	$O.O3m	$0.72m
Total		$2.63m	$O.O6m	$2.69m

Table 5.2.6-2
Operating Cost of a Satellite Network

	Poll Cycle	Data Transmitted (bytes)	Minute/Year Use @ 19.2Kbps	Number of Devices	Minutes of Use x 1000/yr.	$1,000/yr @ $2/min	$1,000,000 10 yrs
Road Weather Stations	5 min.	80	7504	42	147.2	$294.4	$2.94
Variable Message Signs	5 min.	80	3504	41	143.7	$287.4	$2.87
Weigh-in-Motion	30 sec.	80	35,040	16	56.06	$1,121.2	$11.21
Bridge Vehicle Overweight	30 sec.	80	35,040	12	420.5	$841.0	$8.41
Tunnel Vehicle Overheight	30 sec.	80	35,040	2	70.1	$140.2	$1.40
Rockfall Detection System	30 sec.	80	35,040	2	70.1	$140.2	$1.40
Count Station	5 min.	80	35,040	40	1,401.6	$2,803.2	$28.03
Down Hill Information System	30 sec.	80	35,040	1	35.0	$70.0	$0.70
Parking Information System	5 min.	80	3504	2	7.0	$14.0	$0.14
Research Sites	5 min.	500	21,900	6	131.4	$262.8	$2.63
Kiosk	20 min.	500	5475	11	60.2	$120.4	$1.20
Total			248,127 min./yr	175	3,047.4 min/yr	$6094.8/yr	$60.93 /yr

Table 5.2.6-3
Comparative Cost of a Satellite Communications Network

Acquisition Cost	10 Year Operating Cost	Total 10 Year Cost
$2.69M	$60.93M	$63.62M

5.2.7 Dial-Up Service

A possible communications option is dial-up telephone operating with a standard V.34 modem. This is an approach utilized by Colorado DOT (CDOT) for controlling rural ITS VMS and weather sensors on major corridors supporting ski resorts. The "capped" cost of supporting six (6) ITS field controllers utilizing long distance dial-up in Colorado was $50/day/controller A fee of $0.50 per call was also part of the contract.

Utilizing the Colorado scenario, the recurring cost for 75 field locations would be $1.37 million/year or $13.7 million over a 10 year period. Another $75,000 for instant interconnect cost is applicable as well as $30.0/month/ites for basic interconnect service ($270k/10 years). Thus dial-up service is estimated to cost $14.05 million for 10 years or $1.17 million/year.

Due to the significant cost of dial-up service to rural ITS devices CDOT is in the process of modifying communications to rural controllers.

5.2.8 Cost Comparison Summary

Table 5.2.8-1 summarizes the planning cost of candidate communications approaches which are considered to meet identified ITS services. Leased wireless is the most expensive (based on evaluation scenario). Meteor burst is the least expensive but has response time limitations as well as inability to support video. Utilizing the existing microwave network with VHF digital wireless interconnects to the roadside can support all time critical functions and "frame grabbed" video transmission from the field to TOC(s). This is a very economical solution. By upgrading the existing microwave network to SONET microwave (assuming towers are usable) provides adequate bandwidth to meet all identified ITS service communications requirements, existing ODOT microwave communications plus full motion video. This approach provides the most flexibility.

Table 5.2.8-l
Cost Comparison of Candidate Communications
Approached to Meet Recommended ITS Service Needs Over 10 Years of Operation

Communications Approach	Ranking by Cost	I-84	SR 14/I-82	Total	Motion Video Capability	Limitations
Optical Backbone w/SONET	6	$15.96m	$9.38m	$26.32m	Yes	None
Meteor Burst	1	$1.47m	$0.61m	**$2.08m**	No	Does not support time critical requirements; 9.6 kbps max. data rate
Microwave Backbone w/Roadside Digital Wireless Interconnects	2	$1.210m	$0.600m	$1.82 m	No	9.6 kbps max. data rate
SONE T Microwave Backbone w/Roadside Digital Wireless Interconnect	3	$2.30m	$0.980m	$3.28m	Yes	OC-3 bandwidth
Digital Cellular Service	7	$32.49m	$17.89m	$50.38m	No	19.2 kbps max.
ISDN/Fram eRelay Leased Service (Video)	4	$6.80m ($9.84m)	$2.70m ($4.92m)	$9.50m ($14.76m)	Yes	F-T 1/T- 1; may not be available at required interconnect point
VSAT/SATCOM	8	$40.91m	$22.71m	$63.62m	Yes	**F-T1**
Dial-Up/V.34 Modem	5	$9.05 m	$5.00m	$14.05m	No	33.4 kbps

,ease telecommunications services such as frame relay will mee servic e requirements, however, is uneconomical compared with other options. Service drops along the rural corridor may not be available or the service supplier may change cost of twisted pair or fiber installation to the rural interconnect point. Thus there are costs as well as availabilit risks in the leased service approach.

Similarly, dial-up service to rural areas has a significant recurring cost and issues with availability and cost of interconnects in rural areas.

The optimum choice from a performance, growth capability and ITS device interface flexibility is a dedicated optical backbone implemented with SONET. Thus any costs above that of a dedicated SONET network are not considered competitive.

5.3 Cost and Performance Trade-Off of Communications Candidates to Support Implementation of ITS Services

5.3.1 Trade-Off of TOC-to-Field Communications Approaches

Table 5.3.1-1 provides a trade-off analysis of communications alternatives. **Table 5.3.1-2** summarizes the pros and cons of each alternative.

SONET microwave is indicated as the best overall choice. This is based on usability of existing towers. The reasons for this choice are primarily cost, performance and standards.

The optical backbone with SONET installed is ranked as the second place candidate. Without question this is the best choice from a performance, reliability, maintainability, standpoint and the ability to plug just about any new ITS controller into the network in the future. Unfortunately the solution is much more expensive than alternate solutions and requires a much longer period to implement.

Partnering with a private communications service provider providing right-of-way for-fiber is a possible way of reducing cost.

Use of the existing microwave backbone or leasing communications services are two (2) additional options. Using the existing microwave network provides the advantages of:

Table 5.3.1-1
Trade-Off of Communications Alternatives

No.	Evaluation Factor	Optical Backbone w/SONET	SONET Microwave Backbone w/Wireless to Roadside	Existing Microwave w/Wireless to Roadside	Meteor Burst	VSAT/ SATCOM	Cellular/ Digital	Dial-Up	ISDN/ Frame Relay
1	Cost High = 0 Low = 10	6	8	9	10	3	4	5	7
2	Cost of Expansion Bandwidth High = 0 Low = 10	6	8	9	10	3	4	5	7
3	Installation Location Flexibility High = 10 Low=0	10	10	10	10	10	8	5	5
4	Flexibility of Interface Adaptation Highly Adaptable = 10 No Options = 0	10	10	1	1	5	1	1	5
5	Communications Reliability High = 10 Low=0	10	8	8	4	9	7	9	9
6	Cost High = 0 Low = 10	8	5	8	5	5	8	9	9
7	Network Management Capability High = 10 Low-0	10	10	3	0	2	0	0	2
8	Can Support Full Motion Video Yes= 10 No=0	10	10	0	0	5	0	0	10*
9	Open Standard Yes = 10 No=0	10	10	10	10	10	10	10	10
10	Time to Install Short = 10 Long = 0	1	7	10	10	9	8	5	4
	Total	81	86	68	60	61	50	49	68
	Ranking	2	1	3	5	4	6	7	3

Table 5.3.1-2
Pros and Cons of Communications Options

	Pros	Cons
Optical Backbone w/SONET	▪ International Standard ▪ High Data Rates Achievable (2.5 Gbps) ▪ High Reliability ▪ Modular Expandability ▪ Flexible Interfaces ▪ Supports Full Motion Video ▪ Supports Multimedia ▪ Low Maintenance Cost	▪ Cost to install ▪ Time to install
SONET Microwave w/Wireless to the Roadside	▪ International Standard ▪ High Data Rates (155.52 mbps) ▪ Flexible Interfaces ▪ Modular Expandability ▪ Low Initial Cost (compared w/other options) and Low Operating Cost ▪ Supports Multimedia	▪ Installation coordination w/existing towers ▪ Possible conflict in Oregon due to legislative bill restricting competition with private communications companies
Existing Microwave Backbone w/Wireless to Roadside	▪ Low Initial and Low Operating ▪ Cost compared w/other options ▪ Quick Deployment ▪ Simple Installation	▪ Limited bandwidth available ▪ Will not support motion video ▪ Possible conflict in Oregon due to legislative bill restricting competition with private communications companies
Meteor Burst	▪ Quick Deployment ▪ Low Cost ▪ Easy Expandability	▪ Will not support real-time critical functions ▪ Limited bandwidth ▪ No support for video
VSAT/SATCOM	▪ Quick Deployment ▪ Network Options Available ▪ Easy Expandability	▪ Extensive operating cost for real-time systems ▪ Limited, affordable bandwidth ▪ Real-time video bandwidth is very expensive
Cellular/Digital	▪ Quick Deployment ▪ Low Cost Terminal Equipment	▪ Limited bandwidth' ▪ Will not support full motion video ▪ High operating cost ▪ Specific installation site coverage not guaranteed

	Pros	Cons
Dial-Up	▪ Reasonably Quick Deployment ▪ Low Cost Interface	▪ High operating cost ▪ Limited bandwidth ▪ Will not support full motion video ▪ Interconnect availability may be a problem
ISDN/Frame Relay	▪ Good Communications Service ▪ Reasonably Quick Service Access if Physical Infrastructure is Near Installation ▪ Supports Networking	▪ Continued cost of lease service ▪ Frame relay will not support motion video; must use T- 1 (s) ▪ Interconnect availability along rural corridor

- Low cost deployment
- Quick deployment
- Proven communications channels over the corridor

Using frame relay lease service is more expensive compared with using the existing microwave backbone by a 7: 1 margin. Lease service interconnects may not be available where needed; the wireless solution can support reasonably quick installation of communications services.

5.3.2 Traffic Operations Center-to-Traffic Operations Center Communications

There are three (3) candidates for TOC-to-TOC communications:

- Dedicated SONET interconnect
- SONET microwave interconnect
- Leased service (frame relay) interconnect

Unless the SONET optical fiber solution is selected, providing fiber to interconnect the distributed TOCs will be prohibitive. Similarly, unless SONET microwave is selected to interface the field environment with TOC's SONET microwave option would be too expensive to support TOC-to-TOC interoperability. Leased option for TOC-to-TOC interoperability will be approximately $0.2 million for 10 years. In most cases the lease service option will be the lowest cost communications approach. Similarly, coordination with other agencies most likely will be accomplished by lease services.

6.0 SUMMARY

Table 6.0-l summarizes the recommended communications. SONET microwave is the most cost/effective TOC-to-field communications. Cellular telephone and satellite coverage of the corridor are important to support Mayday and AVL/AVM from vehicles and traveler information distribution to vehicles. FM subband digital communications is effective in providing corridor status information to vehicles. Leased ISDN/frame relay service is the most cost/effective communications option for TOC-to-TOC interoperability and to support coordination between state agencies.

Table 6.0-l
Communications Summary

ITS Requirements	Lease Cost	Best Performance	Best Cost/Performance	Recommendation Comments
TOC-to-TOC	Lease dISDN/ Frame Relay	SONET	SONE TMicrowave	If SONE Tor SONE Tmicrowave are deployed in the rural area use the technology for center-to-center interoperability
TOC-to-Field	Meteor Burst	SONET	SONE TMicrowave	Use .SONE T microwave if supportable by existing microwave towers; otherwise use existing microwave
Vehicle-to-Infrastructure Mayday	Cellular Telephone	Satellite	Cellular Telephon e	Private Option/Decision
Vehicle-to-Infrastructure AVL/AVM	Cellular Telephone	Satellite	Cellular Telephon e	Private Option/Decision
Infrastructure-to-Vehicle Traveler Information/ Hazards Warning/ Differential GPS	FM Digital Sideband	Cellular	FM Digital Sideban d	Support FM digital subban dITS information distribution; cellular company supports traveler info by cellular service
TOC-to-Other Agencies	Lease dISDN/ Frame Relay	Lease dISDN/ Frame Relay	Lease dISDN/ Fram e Relay	Lease dISDN/Frame Relay