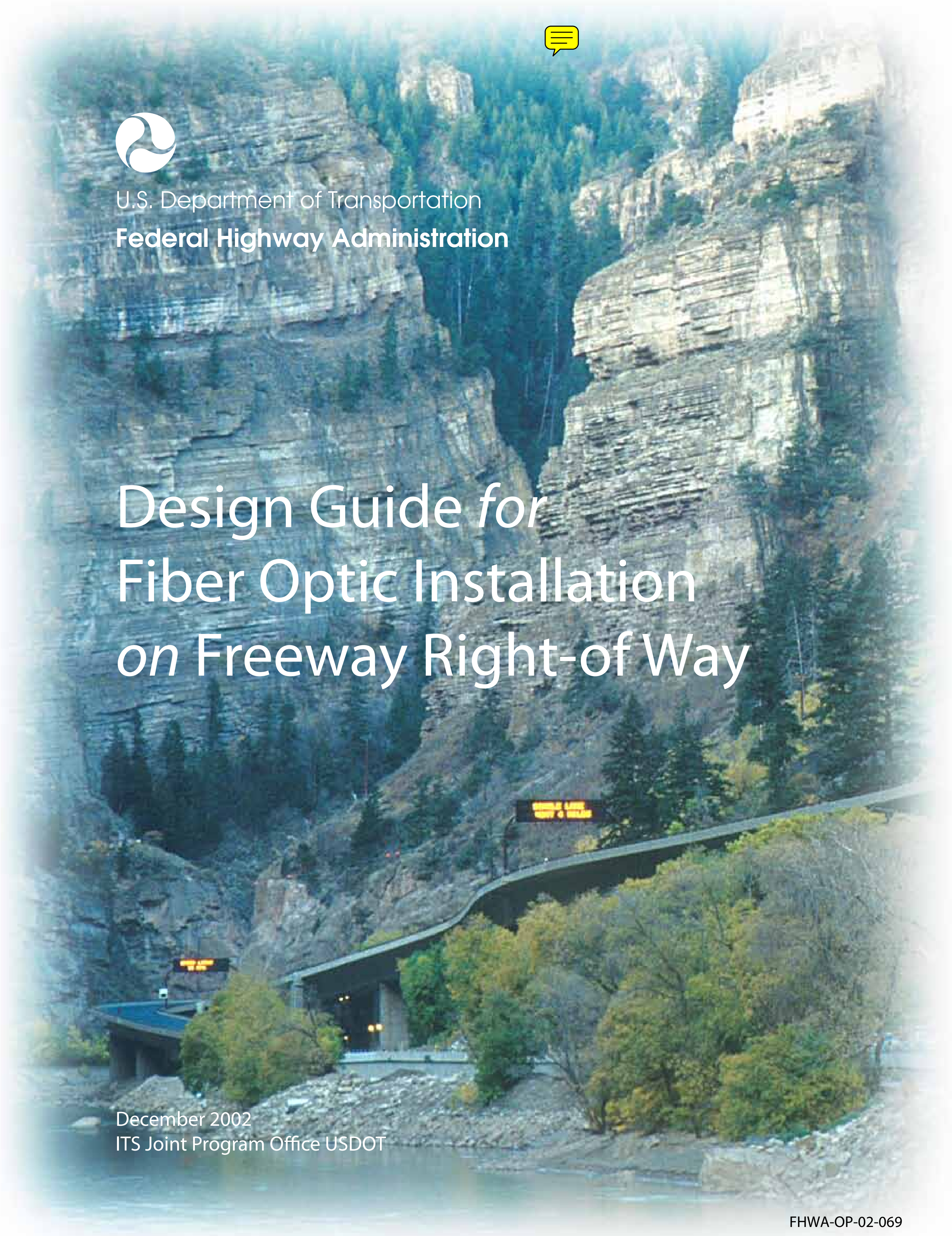

U.S. Department of Transportation

Federal Highway Administration

Design Guide *for* Fiber Optic Installation *on* Freeway Right-of Way

December 2002

ITS Joint Program Office USDOT

FHWA-OP-02-069

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Prepared for ITS Joint Program Office USDOT

Prepared by Aedilis Corporation

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Design Guide Purpose

Fiber optic technology provides exciting opportunities for the deployment of Intelligent Transportation Systems (ITS) through telecommunication networks and integrated communication systems, improving the operation of our freeways and enhancing the safety and mobility of the traveling public.

As the need and demand for electronic information increases, so will the installation of fiber optics across the United States. Our freeway right-of-way offers natural corridors for future telecommunication systems. By working together from project inception through completion, state Departments of Transportation (DOTs) and private telecommunication providers can share their resources for the ultimate benefit of both the consumer and the traveling public.

The *Design Guide for Fiber Optic Installation on Freeway Right-of-Way* provides practical guidance for state personnel to work efficiently and comfortably with telecommunication providers in order to support ITS deployment in a more cost effective manner. Although this *Design Guide* focuses on public/private partnerships, state DOTs independently engaged in implementing statewide Intelligent Transportation Systems will benefit from an understanding of the telecom design principles described herein.

The *Design Guide* describes the planning, design, and construction of a telecommunication network as an integrated process. As such, this necessitates a clear understanding of the whole as well as the parts. The unlimited number of combinations of these parts makes network placement in the freeway right-of-way a complex undertaking.

A multi-level decision-making process is required to successfully incorporate the numerous considerations and to satisfy the many requirements that will confront the state transportation agency. The information presented in the *Design Guide* is interrelated and interdependent, and can only be fully appreciated when read from cover to cover. The material is offered in an easy-to-read, richly illustrated format, and the reader's investment of a few hours will result in a valuable education. Enjoy!

A Word About Safety

At the very foundation of the *Design Guide for Fiber Optic Installation on Freeway Right-of-Way* are the core values of traveler safety and worker safety, as well as a commitment to prescribed freeway work zone traffic control procedures.

Safety principles and requirements are well documented in American Association of State Highway and Transportation Officials (AASHTO) guides and policies and Occupational Safety and Health Administration (OSHA) regulations. The fundamental principals and applications of work zone traffic control are discussed in the Manual on Uniform Traffic Control Devices (MUTCD) Part VI, published by the Federal Highway Administration (FHWA). Some state DOTs have adopted even more specific safety requirements. For information on application of safety principles and requirements on the freeway right-of-way, refer to the Federal Highway Administration, the American Association of State Highway and Transportation Officials, the Occupational Safety and Health Administration, and the state Department of Transportation.

These safety and work zone traffic control issues within the freeway right-of-way are the responsibility of the Federal Highway Administration, the state Departments of Transportation, and the constructors. A successful partnership and a safe environment are created when coordination, communication, and cooperation are culturally ingrained into every project. The Federal Highway Administration is committed to this goal.

The National Perspective

Transportation is key to our nation's well-being, whether measured as economic growth, as international competitiveness, or as quality of life.

A Federal Highway Administration survey of surface transportation customers (*Moving Ahead: The American Public Speaks on Roadways and Transportation in Communities, February 2001*) shows increasing levels of satisfaction with the physical condition of our infrastructure. However, the same survey shows traffic congestion and highway safety are growing concerns for the traveling public. The survey also reveals that the public is reluctant to turn to capacity expansion as a first alternative to alleviate congestion because of the costs in taxes, environmental impacts, and space.

Survey respondents favored solutions that would minimize delays associated with roadwork and make our existing system function better – operational solutions, many of which are underpinned by Intelligent Transportation Systems (ITS) infrastructure. Through application of modern information technology and communications, ITS can improve the quality, safety, and effective capacity of our existing infrastructure. While good operation does not replace construction, it can certainly enhance it.

The ITS program in TEA-21 included a provision that all ITS projects funded out of the Highway Trust Fund had to conform with the National ITS Architecture and Standards. States and metropolitan areas have freedom to develop their own architectures that fit their unique needs, but with key elements compatible with the National Architecture.

Deploying ITS at the state and local levels requires a change in transportation culture and the development of new skills among the staff. It requires a shift in thinking, from primarily construction and rehabilitation of infrastructure, to active management of the transportation system to assure smooth operation and maximum safety. It requires a broadening of the traditional civil engineering skill base to include systems engineering, computer science, and electrical engineering.

If we are going to move to a full electronic national system of smart vehicles and smart roadways for safety, savings, and productivity, it will require the same type of programmatic commitment and institution building that was undertaken for the Interstate System in the '60s and '70s. It will require us to do more than try to fit ITS into existing funding mechanisms, federal regulations, and a transportation culture that has been created around a construction mission. It will require us to step back and think as boldly and as creatively as our predecessors did when they created the blueprint for the Interstate System.

Excerpted from the Statement of Christine Johnson
Director, ITS Joint Program Office USDOT
Program Manager, Operations Core Business Unit, FHWA

before the Committee on Environment
and Public Works Subcommittee on Transportation,
Infrastructure, and Nuclear Safety, US Senate
September 10, 2001

Chapter 1

Telecommunications and ITS: The Fiber Optic Backbone

In this Chapter:

- **Introduction**

The Eisenhower Interstate System as a communication and transportation network

- **National Strategy**

The role of state Departments of Transportation, the importance of telecommunications to Intelligent Transportation Systems (ITS), and ITS benefits

- **ITS Architecture**

A discussion of National and regional ITS architectures, subsystems and interconnects of information flows, telecommunication architectures, and ITS elements

- **Topology**

Definitions and usage for various types of network topologies and the importance of ITS architecture planning

- **How Does It Work? A Technical Primer**

Long haul and short haul fiber, access points, definitions and illustrations of various types of fiber and bandwidth comparisons

- **Putting The Pieces Together**

Typical state DOT topology, fiber optic link, and ITS device

- **Summary**

Introduction

One hundred years ago, an organized network of connected highways did not exist in any state in the country. When the first transcontinental crossing was undertaken in 1903, it was driven mostly in mud, dirt trails, and across deserts. By 1913, more and more people had begun to travel in cars, and the automobile industry became interested in constructing good roads. Through private industry efforts, the Lincoln Highway was promoted as a 3,300-mile road traversing the United States.

In 1919, the Army and the federal government sponsored the Transcontinental Motor Train to drive across the country and assess the feasibility of such a project. Lieutenant Colonel Dwight D. Eisenhower represented the Army as an observer, hoping for adventure. He would later say, "We were not sure it could be accomplished at all. There were moments when I thought neither the automobile, the bus, nor the truck had any future whatsoever." His experience in the convoy, combined with seeing the German autobahns during World War II, convinced him of the need for national transportation and communication networks.

"Our unity as a nation is sustained by free communication of thought and by easy transportation of people and goods.

The ceaseless flow of information throughout the republic is matched by individual and commercial movement over a vast system of interconnected highways crisscrossing the country and joining at our national borders with friendly neighbors to the north and south.

Together, the united forces of our communication and transportation systems are dynamic elements in the very name we bear — United States. Without them, we would be a mere alliance of many separate parts."

President Dwight D. Eisenhower
Message to Congress
supporting construction of Interstate System
February 22, 1955

The Federal-Aid Highway Act of 1956 funded construction of the National System of Interstate Highways, then called the greatest public works program in the history of the world. The interstate highway program of the mid-1950s was successful due to four key elements:

- a systems approach
- an overall design concept
- a federal commitment
- a financing mechanism

Figure 1.1
The Eisenhower Interstate System

Today, the original 41,000-mile network is known as the Eisenhower Interstate System and has grown to over 46,000 miles. Although it represents only 1% of the nation's highway system mileage, it carries 25% of all roadway traffic. When viewed as an integrated transportation and communication system, we begin to realize the full potential of this national network. The four key elements of success remain relevant.

State transportation agencies have traditionally been organized with a focus on managing construction projects. Now that the Eisenhower Interstate System is complete and very few additional lane miles are being added to the highway system, the transportation community must begin to focus much more effort on effectively operating the infrastructure to get the most capacity out of what we have. This is a fundamental change for many transportation agencies and one which requires a new mind set — managing and operating the existing transportation system so that its performance meets or exceeds customer expectations.

National Strategy

In 1991, recognizing the critical need to address our aging transportation network and its pressing challenges, Congress created an Intelligent Transportation Systems (ITS) program. The program has four key functions:

1. Promote the implementation of a technically integrated and jurisdictionally coordinated transportation system across the country;
2. Support ongoing applied research and technology transfer;
3. Ensure that newly developed ITS technologies and services are safe and cost-effective; and
4. Create a new industry by involving and emphasizing the private sector in all aspects of the program.

Many local and state governments are turning to ITS to improve traffic mobility, provide better services to and communications with their customers, and make travel safer. ITS encompasses a broad range of innovative technologies, systems, and information management strategies, which when linked together can greatly improve the safety and efficiency of travel and mobility in urban and rural areas, on transit systems, and on freeways.

Key Concept:

Telecommunications moves data between the major elements of an ITS

Telecommunications is a crucial factor in enabling an Intelligent Transportation System to function. Telecommunications ties the physical components together and moves data between the major elements of an ITS. In turn, the ITS can create optimal value by providing information and commanding resources to improve system-wide efficiency. Not surprisingly, telecommunication infrastructure can be the single most expensive component of an ITS, in terms of both implementation, and operations and maintenance.

In the mid-1990s, the deployment of ITS technologies began to proliferate. This created a need for a significant telecommunication infrastructure to support the use of cameras and other devices within the freeway system. At the same time, a major expansion was underway in the telecom industry.

These two factors produced a common interest among state transportation agencies, hereinafter referred to as Departments of Transportation (DOTs), and the telecom industry. The result was the evolution of a public/private partnership that allowed telecommunication companies to install their fiber optic cable on freeway right-of-way (ROW) in return for ITS infrastructure for the state DOT. These projects, known as Shared Resource Projects, became increasingly accepted as more states decided, with FHWA approval, to allow the longitudinal installation of fiber optic cable on their right-of-way.

The rationale for the sanctioning of this installation on heretofore forbidden real estate was based on the inevitable installation of telecommunications on the right-of-way to support state DOT ITS requirements. Ordinarily, this would be done at substantial cost to the state and the taxpayers. Shared Resource Projects permit states to gain access to needed telecommunications and create significant value for the public. The telecom industry gains access to freeway ROW connecting major population centers, which creates an ideal environment for long haul communications.

ITS Benefits

In the spring of 1996, the ITS Joint Program Office (JPO) established a set of ITS Program goal areas. The goal areas include:

- improving traveler safety
- improving traveler mobility
- improving system efficiency
- increasing the productivity of transportation providers
- conserving energy while protecting the environment

Within this context, many known ITS benefits support implementing an Intelligent Infrastructure and Intelligent Vehicle program. These benefits are outlined in Table 1.1.

Table 1.1: Benefits of an ITS program

Intelligent Infrastructure

Metropolitan	Rural	ITS for Commercial Vehicle Operations
Improve Safety of the Traveling Public	Improve Safety of the Traveling Public	Safety Assurance
Arterial Management Systems	Crash Prevention & Security	Credentials Administration
Freeway Management Systems	Emergency Services	Electronic Screening
Transit Management Systems	Travel & Tourism	Carrier Operations
Incident Management Systems	Traffic Management	
Emergency Management	Transit & Mobility	
Electronic Toll Collection	Operations & Maintenance	
Electronic Fare Collection	Road Weather Management	
Highway-Rail Intersection		
Regional Multimodal Traveler Information		

Intelligent Vehicles

All Platforms	Platform Specific
Collision Avoidance and Warning	Personal Vehicles
Other Driver Assistance	Commercial Vehicles
	Transit Vehicles
	Emergency and Special Use Vehicles

ITS Architecture

Intelligent Transportation Systems are interrelated systems that work together to deliver transportation services. Integration of these systems requires an architecture to illustrate and gain consensus on the approach to be taken by a group of stakeholders regarding their particular systems. An ITS Architecture defines the subsystems and the interconnections and information exchanges between these systems. There are two different types of ITS Architectures.

The National ITS Architecture is a general framework for planning, defining, and integrating ITS. It was developed to support ITS implementations over a 20-year time period in urban, interurban, and rural environments across the country. The National ITS Architecture is available as a resource or tool for use by any region and is maintained by the USDOT independently of any specific system design or region in the nation.

A regional ITS architecture is a specific regional framework for ensuring institutional agreement and technical integration for the implementation of ITS projects in a particular region.

"The vision for the nation's future surface transportation system is based, in short, on creating an integrated national network of transportation information. Both the quality and quantity of data transmission will increase. And as a result of network integration, not only will we see greater efficiencies in America's transportation system; we will see a fundamental shift in how America does business."

Larry Yermack
Chairman, ITS America
United States Congressional Hearings devoted to
Intelligent Transportation Systems, September 10, 2001

National ITS Architecture

There are numerous advantages to using the National ITS Architecture as the basis for creating a regional ITS architecture. Primary among these is a significant savings of time and cost because the National ITS Architecture represents a complete framework of ITS services, has already undergone considerable stakeholder review, and has a variety of tools to assist the user in creating a regional ITS architecture.

An architecture defines a framework within which a system can be built. It defines the elements of the system and the information that is exchanged between them. An architecture is important because it allows integration options to be considered prior to investment in the design and development of the elements of the system. An architecture is functionally oriented and not technology specific, which allows the architecture to remain effective over time. It defines "what" must be done, not "how" it will be done. The functions performed by the system remain the same while technology evolves. The primary components of an ITS Architecture are the Subsystems and the Interconnects of the information flow.

Subsystems. Subsystems are individual pieces of the *overall* Intelligent Transportation System that perform particular functions such as managing traffic, providing traveler information, or responding to emergencies. Subsystems can be associated with particular organizations such as Departments of Transportation, information service providers, or public safety agencies. They are sources and/or users of information provided by other subsystems within or on the boundary of the ITS Architecture. Subsystems include centers (for traffic, transit, and emergency management, among others), roadside components, vehicle equipment, and traveler devices that participate in ITS.

Interconnects. Interconnects of the information flow define the information exchanged between subsystems such as traffic information, incident information, or surveillance and sensor control data. The flows depict ITS integration by illustrating the information links between subsystems. In ITS, this integration is not only technical but institutional as well. The system interfaces that are defined require cooperation and shared responsibilities on the part of the owners and operators of each participating system.

The National ITS Architecture is shown in Figure 1.2 on page 10.

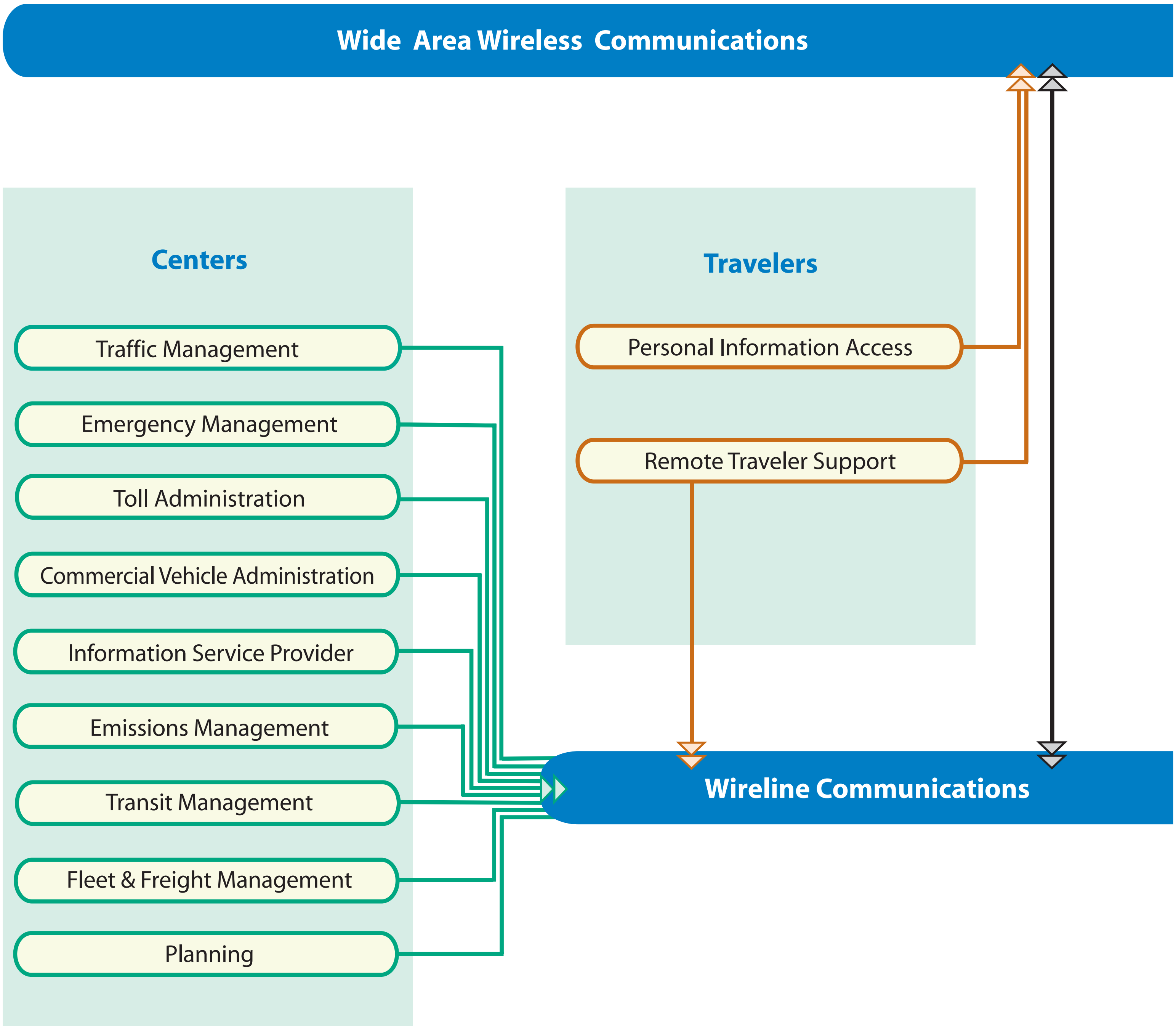
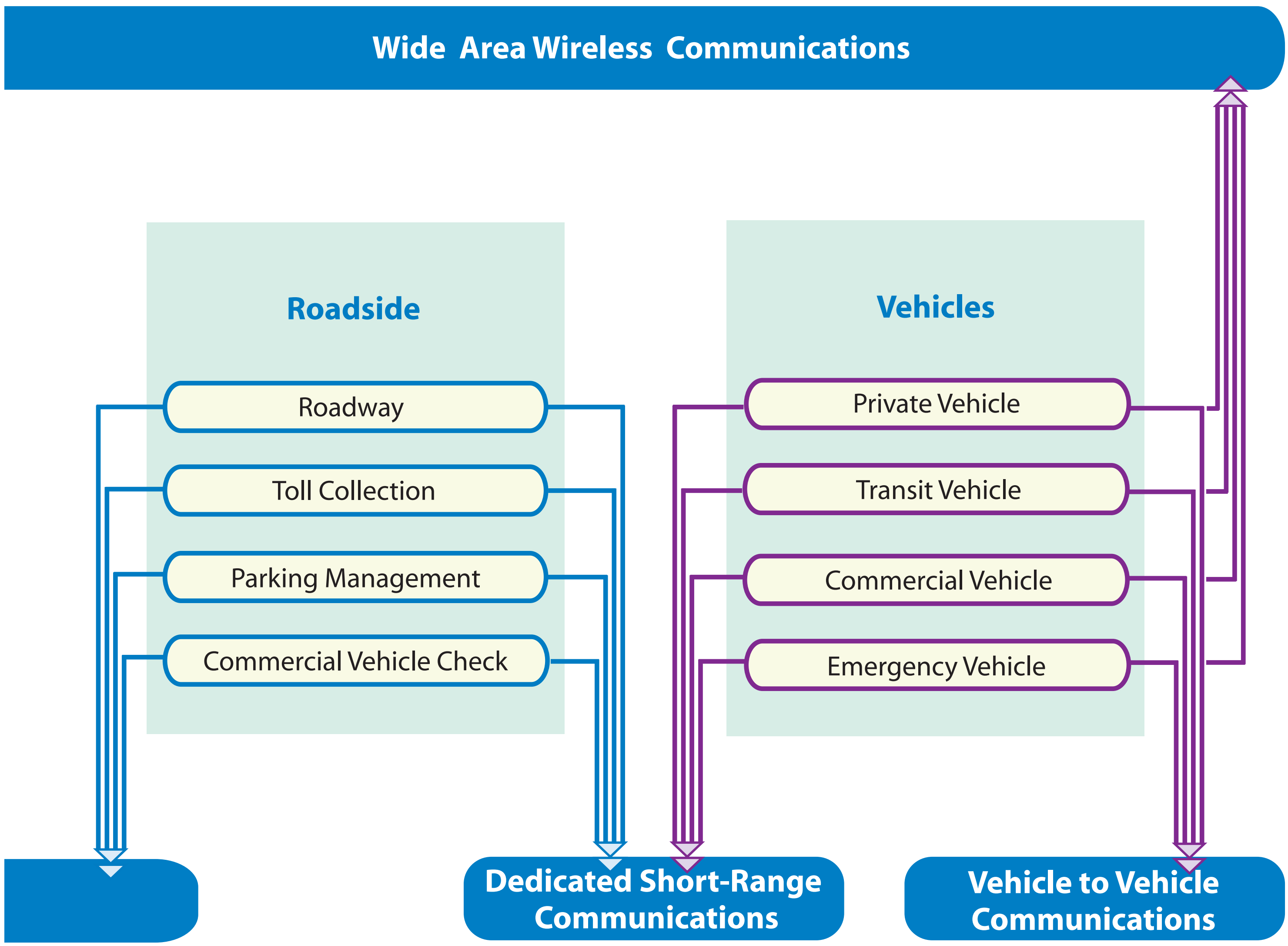


Figure 1.2 - National ITS Architecture Subsystems and Interconnects


Wide Area Wireless Communications
Roadside
Roadway
Toll Collection
Parking Management
Commercial Vehicle Check
Vehicles
Private Vehicle
Transit Vehicle
Commercial Vehicle
Emergency Vehicle
Dedicated Short-Range Communications
Vehicle to Vehicle Communications

Regional ITS Architecture

A regional ITS architecture can provide significant value in helping to define telecommunication requirements. By identifying types, volumes, sources, and users of transportation information, the regional ITS architecture helps in understanding connectivity and bandwidth requirements, as well as the nature (periodic, continuous, random) of the communication flow.

The most important contribution of a regional ITS architecture in defining telecommunication requirements is that when taken to its most detailed level, it identifies the information to be communicated between external elements and the ITS systems/subsystems, and between the ITS subsystems. Thus, it provides the foundation for determining the telecommunications capacity and access points required in the eventual network.

Telecommunications Architecture

Most activities involve the transmission of information to support a particular function. Each activity will produce unique types of information, both vital and non-vital. In defining the supporting communication subsystems, it is important to know the formats of information (voice, data, or video); how often and how fast information must be sent (capacity or bandwidth); and the origin and destination of data traffic (topology).

Given that a regional ITS architecture has been developed, the fundamental requirements of the telecommunications network will have been defined as well. A telecommunications architecture describes the points of need for telecommunications service and the nature of what is needed at each point. In telecommunication terms, this would be the bandwidth and type of service required to communicate the content and category of information. As with an ITS architecture, the telecommunications architecture is not a design for a particular system; it does not identify the specific devices or the technologies used, although it may identify appropriate standards. The telecommunications architecture goes one step further than the regional ITS architecture by defining the geographic distribution of all of the devices and systems. A telecommunications architecture represents information requirements combined from several planning efforts.

An Intelligent Transportation System contains different devices at different points of need. These devices have three characteristics: their requirement for telecommunications may vary from little to substantial; their location may vary from close by to a remote distance from facilities; and they may be easily accessible to very difficult to access.

Thus, some key questions must be answered about the elements of the system. For example:

- Where will the cameras, signs, detectors, and other devices be placed?
- Where will the digital information be sent for analysis and redistribution?
- Is the information required at the operations center, maintenance facility, or emergency services facility?

The answers to these questions, in conjunction with the information data flow of the regional architecture, will allow the definition of telecommunication requirements.

These requirements form the basis of determining where and how much fiber will be required to serve ITS needs. This information is crucial in determining the viability and desirability of a Shared Resource Project for the state DOT.

Photo 1.1
Traffic operations center

ITS Elements

The following list provides a general overview of ITS elements that may have a function in a state DOT's telecommunications ITS architecture.

Freeway Surveillance

- Loop Detectors
- Other Traffic Detectors
- Data Station
- Closed Circuit Television (CCTV) Cameras
- Emissions & Environmental Sensors
- Weather Sensors
- Truck Inspection

Freeway Communication

- Fiber Optic Cable
- Fiber Optic Hub

Freeway Management at Roadside

- High Occupancy Vehicle (HOV) Lane Control & Monitoring Equipment
- Ramp Meter System
- Ramp Gates
- Ice Monitoring Equipment
- De-icing Equipment
- Bridge Scour Monitoring Equipment

Traveler Information at Roadside/Site

- Full Matrix Variable Message Sign (VMS) & Controllers
- Fixed Highway Advisory Radio (HAR) & Controllers
- Call boxes
- Kiosks
- Truck Electrification

Incident Management Equipment

- Portable VMS
- Portable HAR

Emergency Services Equipment

- Cellular radio, communication services per vehicle

Transportation Management Center

- Computers and Hardware
- Facilities and Communications

Traveler Information Center

- Computers and Hardware
- Facilities and Communications

Emergency Response Center

- Computers and Hardware
- Facilities and Communications

Electronic Toll Collection System

- Automated Vehicle Identification (AVI)
- AVI Plaza Computer Equipment
- Dedicated AVI
- Express AVI

Topology

The origin and destination of data traffic is called the topology. A topology map of devices needing telecommunications support is often developed as part of preparing a telecommunications architecture. A build-out plan showing likely additions to the field equipment is the result of a significant planning effort.

As is typical of many engineering problems, there are a number of ways to design a telecommunications network to meet the requirements. Alternative network configurations should be evaluated for both cost and technical performance.

Fiber optic networks use several common topologies and frequently employ hybrids of those topologies to allow for flexibility and cost savings. Each topology has advantages and disadvantages, and hybrids are often developed to take advantage of unique network requirements and existing circumstances. Common topologies are illustrated in Figure 1.3 and defined as follows:

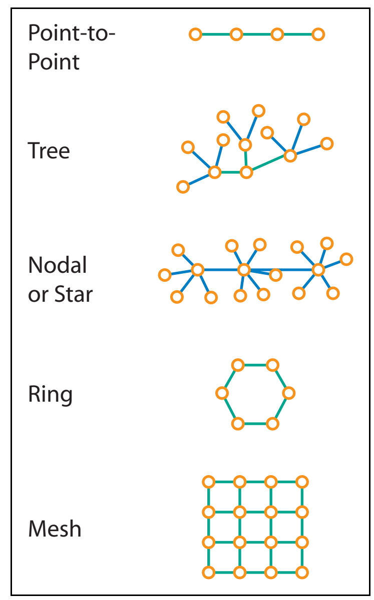


Figure 1.3 - Network topology examples

The **point-to-point** topology is typical for long distance runs between metropolitan centers.

In a multidrop network architecture, such as the **tree** or **nodal (star)** topologies, many slower devices are fed from a single, higher-speed line. The transition point between a high speed line and a slower device is called a "drop". In such an architecture, a single cut in the fiber optic backbone will take all upstream drops offline. Similarly, a malfunction in one drop may cause it to transmit constantly, which can effectively block communications with other drops on the line.

For metropolitan or urban areas, the **ring** topology is often used. Similar to the ring freeway system, this architecture allows for alternate routing, which provides the best reliability. If there is a failure at one point, the "traffic" can be sent in the opposite direction at the speed of light to arrive at its proper destination. Often the tree and ring topologies are combined to maximize system reliability and accommodate the dispersed nature of ITS devices.

In **mesh** topology, each point is directly connected to every other point on the network. Costs and complexities increase significantly where more than four points are connected. A mesh topology offers network redundancy and resiliency, but comes at a high cost and is difficult to configure and reconfigure.

Evaluating alternative topologies requires specific expertise rarely found in the traditional transportation consulting community. Yet it is essential that this expertise be sought out and employed to develop the communication design.

Experience has shown that the cost of different configurations can vary greatly, in terms of both initial installation and future operation. While initial installation costs may not be the guiding factor if the state DOT is considering a public/private partnership, operating costs will be a major factor. It is unlikely that a public/private partnership will provide all of the fiber installation required for a complete network, therefore the state DOT may choose to complete the network by building the remaining portions independently.

It is recommended that the DOT complete a telecommunications ITS architecture planning process prior to making solicitations of the private sector for any business venture. Only then is the DOT fully prepared to determine the essence and value of the network, whether built by the private sector or on its own.

How Does It Work? A Technical Primer

Long Haul

Long haul fiber optic networks operate by sending beams of light down glass fibers. These systems have a limited broadcast length, and a variety of things can further reduce this length, such as splices and bends. When the signal weakens to a certain level, it must be regenerated or rebroadcast. Typically, this occurs at a regeneration facility or through an optical amplifier on a long haul backbone.

Short Haul

Short haul fiber optic networks, commonly found in urban areas, have different requirements. Data is transmitted to the fiber via modems or direct broadcast. In-line modems boost the signal and transmit data along a dedicated fiber to a multiplexer. Multiplexers gather data from several fibers and broadcast it on a single fiber. Multiplexers will generally be located at ITS hubs where they will consolidate data from several sources for transmission to centers or facilities.

Access Points

Access points, or vaults, are designed into fiber optic networks where there are existing or planned ITS devices, communication hubs, or other network facilities. Over the life of the system, access points are used to allow for easy changes to the network. They may be constructed some distance from the planned architecture location due to construction or environmental constraints.

Access points normally consist of a vault for slack cable storage and necessary splice equipment. The fibers needed at the access point are separated from the other strands and run through a splice case. A fiber cable extension is run from the splice case, and must be of a sufficient length to attach to a patch bay that can be lifted from the vault to a fiber maintenance van or tent. Location of vaults and splicing procedures are discussed in Chapter 4: *Telecommunication Networks and Construction Methods* and Chapter 5*: Network Placement.*

Fiber Optic Technology

Two basic types of fiber optic technology are currently available: multimode and singlemode. Selection of the most appropriate type will depend on the length and desired speed of transmission. A Light Emitting Diode (LED) or a laser serves as the light source used to convert an electrical information-carrying signal into a corresponding optical signal. It is the light transmission through the optical fibers that enables communication, including voice, video, and data.

Multimode Fiber. Multimode fiber is an optical waveguide that allows more than one mode, or light path, to be guided along the fiber. The light rays travel on different paths in the core and arrive at the end at slightly different times, which limits system bandwidth. Graded index multimode fiber is the preferred medium for use with short links such as Local Area Networks and Wide Area Networks (under 2km) and is usually less expensive than single-mode fiber.

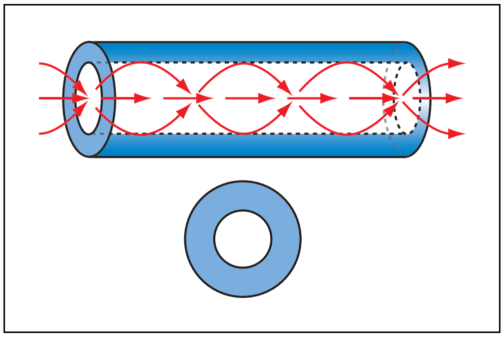


Figure 1.4 - Multimode fiber

An LED source is often used with multimode fiber. A Light Emitting Diode (LED) is a semi-conductor device that converts an electron flow into photons. It works like a shotgun: one modulation creates multiple photons with each carrying the same information. LEDs are good for short distances and low-speed applications.

Singlemode Fiber. Singlemode fiber is a step index fiber waveguide that allows only one mode (light path) to be guided along the fiber. It is used for spans where minimal power loss over distance and limited use of repeaters are desirable. This fiber type is used as a backbone and for video, voice, and data transmission. Non-Zero Dispersion

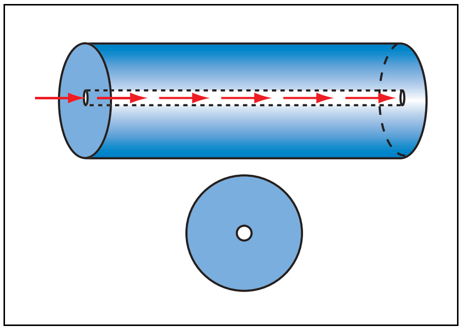
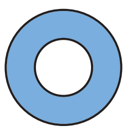
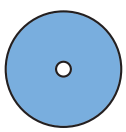
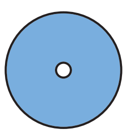


Figure 1.5 - Singlemode fiber

Shifted (NZDS) fiber is a singlemode fiber designed for long haul applications and used with Regeneration Facilities and Optical Amplifier applications.

Typically, a laser source is used with singlemode fibers. Lasers are very fast and very directional. They are used for both power and speed (modulation), but are more expensive than LEDs. The laser is a coherent light source — one in which the amplitude of all light waves is exactly equivalent, and rise and fall together — with a narrow spectral width.

Table 1.2: Comparison of fiber types used by Departments of Transportation

	Type	Broadcast Distance	Application
	Multimode Fibers	2 km (1-2 miles)	CCTV Variable Message Signs Access Controls
	Standard Singlemode Fibers Uses laser light sources	up to 48 km (up to 30 miles)	Metropolitan Rings Video Signals Voice Signals Data Signals
	NZDS Singlemode Fibers Can transmit 160 lasers over each fiber	100 km (62 miles)	Long distances Multiplexed circuits Dense wavelength division multiplexing

Digital Hierarchy Multimode Fiber

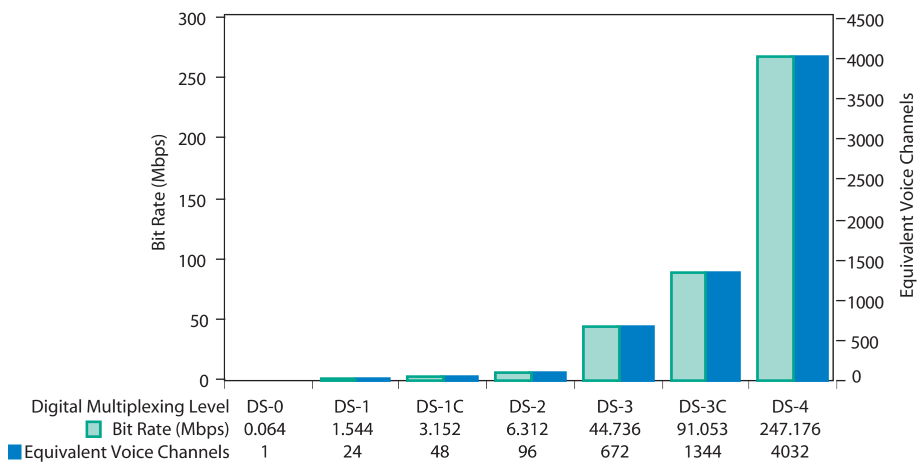


Figure 1.6 - Graphical depiction of multimode fiber bandwidth

Digital Multiplexing Level	Equivalent Voice Channels	Bit Rate (Mbps)
DS-0	1	0.064
DS-1 (T-1)	24	1.544
DS-1C	48	3.152
DS-2	96	6.312
DS-3 (T-3)	672	44.736
DS-3C	1,344	91.053
DS-4	4,032	274.176

Table 1.3: Comparison of multimode fiber equivalent voice channels and bit rates

Digital Hierarchy Singlemode Fiber

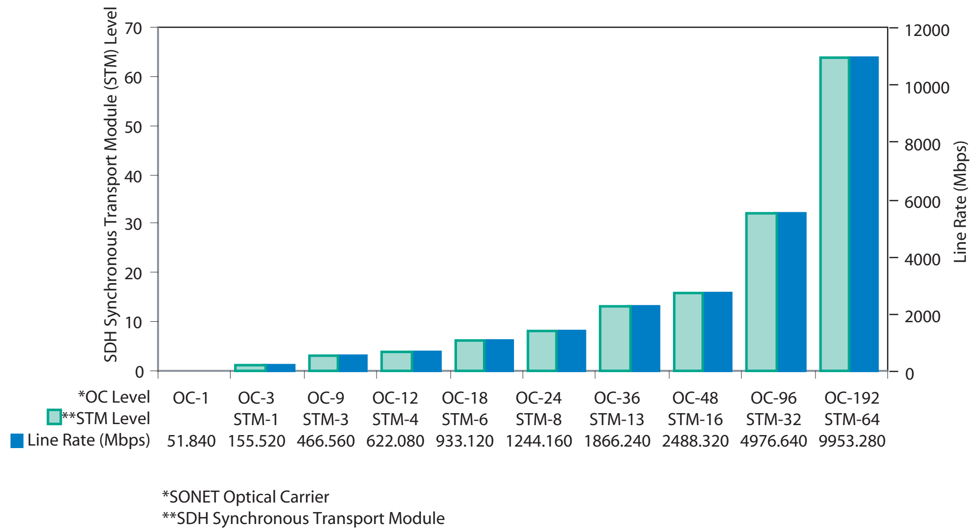


Figure 1.7 - Graphical depiction of singlemode fiber bandwidth

SONET Optical Carrier (OC) Level	SDH Synchronous Transport Module (STM) Level	Line rate (Mbps)
OC-1		51.840
OC-3	STM-1	155.520
OC-9	STM-3	466.560
OC-12	STM-4	622.080
OC-18	STM-6	933.120
OC-24	STM-8	1244.160
OC-36	STM-13	1866.240
OC-48	STM-16	2488.320
OC-96	STM-32	4976.640
OC-192	STM-64	9953.280

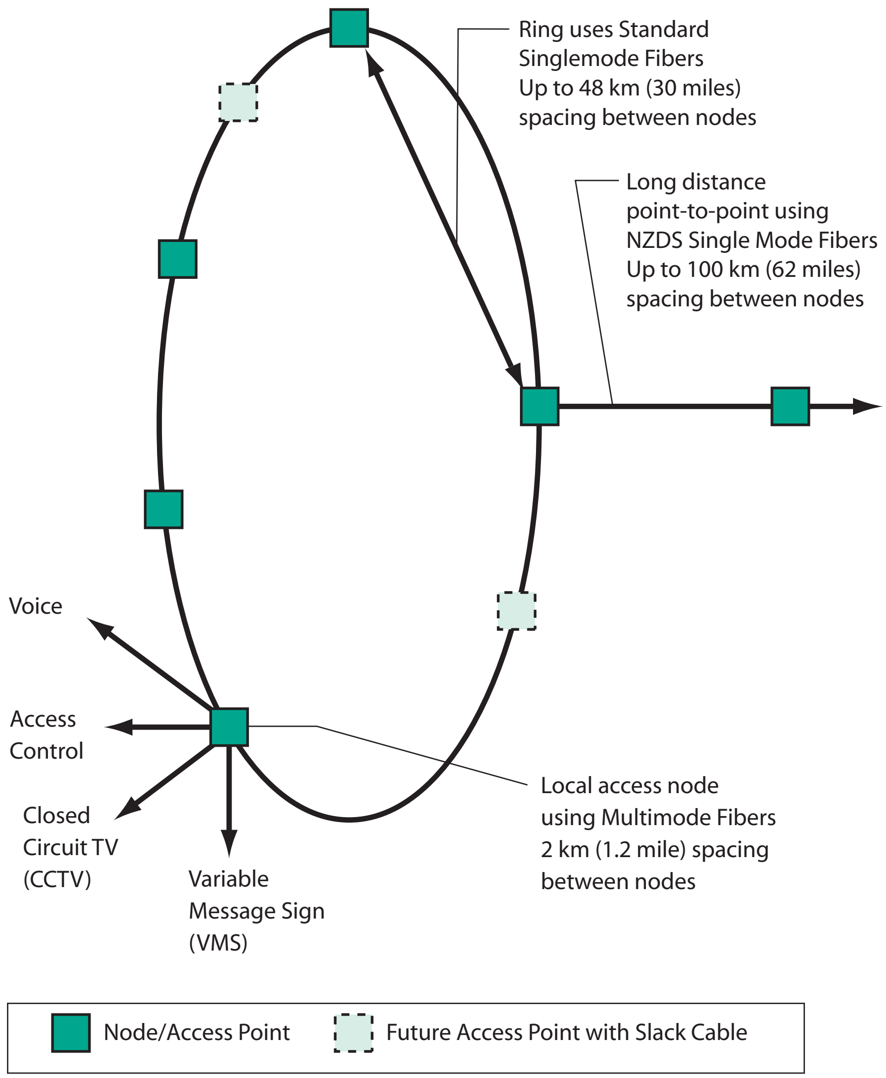
Table 1.4: Comparison of singlemode fiber Synchronous Digital Hierarchy STM Levels and line rates

Putting The Pieces Together

Typical DOT Topology

The figure below shows a ring and star topology for pigtail circuits or other mediums such as twisted pairs. For local drops, an access point is needed to enter into the ring, and a star topology is used from that ring access point to connect ITS devices using multimode fibers.

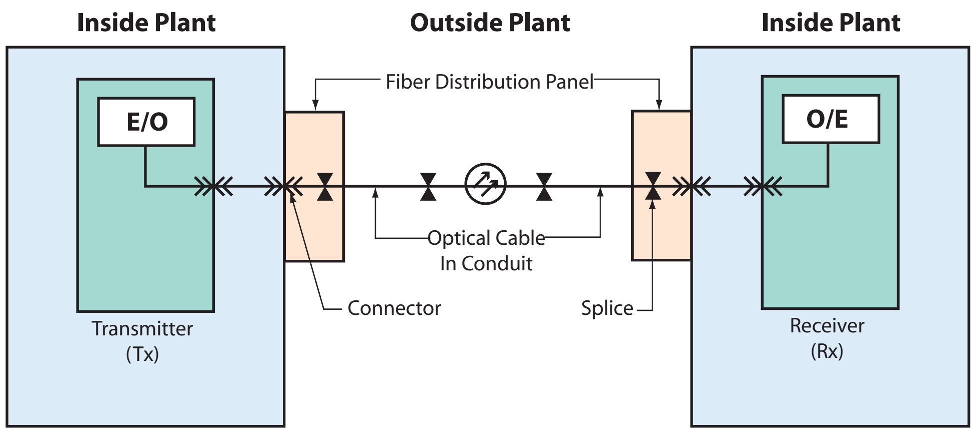
Figure 1.8
Metropolitan network using ring and star topology



Typical DOT Fiber Optic Links

All fiber optic systems consist of a transmitter that converts electrons to photons (E/O) via either Laser or LED. The transmitter is coupled to the optical fiber via an optical connector. The fiber is enclosed in an optical cable designed to protect the fibers. Cables along freeways are installed inside conduits. At the end of the fiber link a photon detector inside the receiver converts the photons back to electrons (O/E). Before the transmitter, and after the receiver, the signals are in an electrical format. This determines both the format (analog or digital) and the protocol (voice, video or data). The fiber is strictly the medium for transmitting the signal between the electro-optical equipment.

Figure 1.9
A network example



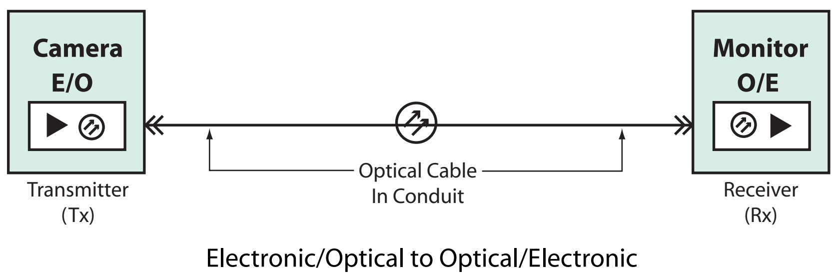
The transmitter converts electrical data to optical data (E/O).

The receiver converts optical data back to electrical data (O/E).

Typical DOT ITS Device

A common ITS device used by state DOTs is a Closed Circuit Television (CCTV) on a freeway. The CCTV system requires several changes of medium between the camera and the monitors at the control center. The camera itself transmits over a coaxial cable to the video transceiver, which converts signals to an optical signal. The optical signal is then transmitted through multimode fibers to the hub of the star topology, which serves multiple cameras. These signals are converted back to their coax medium, cross-connected to a frequency division multiplexer (FDM), electronically combined with many video channels, connected to a laser transmitter, and coupled to a singlemode fiber ring. This signal is sent to a monitoring center where the optical signal is again converted back into an electrical signal, and frequency division de-multiplexed so that each channel is separated for viewing.

Figure 1.10
ITS device example: point-to-point closed circuit TV (CCTV) on freeway



Summary

- State DOTs, which have generally been oriented toward managing the design, construction, operations and maintenance of the Interstate System, must now begin to focus on operating the system to optimize capacity. An Intelligent Transportation System offers many opportunities to greatly improve highway operations and safety, with significant benefits to the taxpayer and the traveling public.
- Telecommunications is a critical element of a functioning ITS, and fiber optic systems to handle telecommunications are the most expensive components. Careful planning and analysis, at the same level as is customary for large civil engineering projects, are required to ensure development of an efficient system that meets both current and future needs.
- Effective techniques to use in addressing telecommunications design issues include development of a regional ITS architecture and an ITS telecommunications architecture. Using the existing National ITS Architecture as a framework for this effort can result in significant time and cost savings.
- Telecommunication systems should be developed in concert with planned and existing facilities, both public and privately owned.
- Determining the most appropriate network topology requires in-depth analysis and balancing of cost and technical performance.
- The typical public agency will benefit greatly from access to qualified professional telecommunications consulting assistance in two areas: performing technical and business analyses, and developing system design.
- Development of a regional ITS architecture and a telecommunications architecture, followed by network topology, will define fiber requirements for current and future use.

Acknowledgments, Resources, and References

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Northern Line Builders
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project photographs

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FHWA-OP-02-069