

# Telecommunications Handbook for Transportation Professionals

## The Basics of Telecommunications

*Final Report*

*September, 2004*

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**Technical Report Documentation Page**

1. Report No. FHWA-HOP-04-034	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Telecommunications Handbook for Transportation Professionals The Basics of Telecommunications		5. Report Date August, 2004	
7. Author(s) Sheldon Leader		6. Performing Organization Code	
9. Performing Organization Name and Address		8. Performing Organization Report No.	
12. Sponsoring Agency Name and Address		10. Work Unit No. (TRAIS)	
		11. Contract or Grant No.	
15. Supplementary Notes		13. Type of Report and Period Covered	
		14. Sponsoring Agency Code	
<p>16. Abstract</p> <p>This handbook was created to provide individuals responsible for managing and implementing Traffic Signal, and Freeway Management programs with an understand of the basic technologies of telecommunications. The handbook provides a brief look at the history of telecommunications so that its readers may gain an understanding of why various processes exist, and how the technologies evolved. The handbook is not designed to be used as a specification for telecommunication systems.</p> <p>The technologies associated with telecommunications are in a constant state of change. This handbook was written over a two year period between August, 2002 and June 2004. During this time, a number of emerging technologies began to reach maturity. The most significant of these, wireless internet access, and voice over IP have caused the major carriers (telephone companies) to announce the construction of new facilities to provide "Internet Telephony" services.</p> <p>Readers of this handbook should gain an understanding of the basic technologies underlying most telecommunications systems designed to transmit both voice and data information.</p>			
17. Key Word Telecommunications		18. Distribution Statement	
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages 287	22. Price

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## FOREWORD

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**Welcome to the future!**

## ACKNOWLEDGEMENTS

The author would like to acknowledge the invaluable contributions of the following individuals for volunteering their time to review this document:

- Karen Jehanian, KMJ Consulting, Haverford, PA
- Jambala (Jay) Ruit, Edwards and Kelcey, Inc., West Chester, PA
- Jeffery Purdy, Edwards and Kelcey, Inc., West Chester, PA
- Richard Easley, E2 Engineering, Ashburn, VA
- Ray Cauduro, GDI Systems, LLC, Newport, OR

The following individuals supported the overall development of this document:

- Paul Olson, FHWA, San Francisco, CA
- Bill Jones, FHWA, Washington, D.C.
- Lou Neudorf, Siemens ITS, New York, NY
- Robert Reiss, Dunn Engineering Associates, Westhampton Beach, NY
- Robert Gordon, Dunn Engineering Associates, Westhampton Beach, NY
- Warren Tighe, Siemens ITS, Concord, CA

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# 1. CHAPTER ONE - TELECOMMUNICATION BASICS

## *Introduction*

The "Telecommunications Handbook for Transportation Professionals" was originally published in 1987 as the "Communications Handbook for Traffic Control Systems". The first (and only) update was initiated in 1991, and published in 1993. Given the significant advances in the technology of telecommunications, and the complexities of Traffic and ITS systems deployment its is necessary to create a new (rather than a revision) handbook providing a broader view of telecommunications technology as applied for traffic and transportation purposes. This handbook provides a broad overview of telecommunications technology and history.

## *Purpose*

The "Telecommunications Handbook for Transportation Professionals" is intended to provide an introduction to telecommunication technology and process for transportation engineers and project managers involved in the design and deployment of traffic signal and freeway management systems. The handbook can be used as a resource that provides an overview of the various technical issues associated with the planning, design, operation, and management of a communications system. It is intended to provide the user with a better understanding of applied communications technology and the considerations for use in freeway and surface street networks.

The intended audience is transportation professionals who may be involved with, or responsible for any phase in the life cycle of a traffic signal or freeway management control network. This includes all public or private "practitioners" (e.g., managers, supervisors, engineers, planners, or technicians) involved with any issue or decision (e.g., policy, program, funding, or system implementation) and who may directly or indirectly influence the performance of traffic on local arteries or freeway facilities. These activities may include, but not be limited to, planning and design, operational strategies, programs, and services that support continuous management of travel and control of traffic, and the technology infrastructure to provide these capabilities.

### ***Relationship to National Architecture***

Telecommunications systems as part of the National ITS Architecture are the connecting pathways that bind the various elements of traffic signal, freeway management, and transportation systems together. The National ITS Architecture "sausage diagram" indicates how these elements are bound together, but does not specify the telecommunication system. The developers of the National ITS Architecture understood that each telecommunication system would be uniquely designed to meet the needs of each project.

The significant diversity of communications technologies and the overall complexity of traffic signal, freeway management, and transportation systems have created a need for traffic and transportation professionals to implement the Systems Engineering Process (SEP). This handbook provides a summary (Chapter 4) of how to apply an SEP to the development of a telecommunications system, for traffic signal and freeway management systems development.

### ***Open System Interconnection Model (OSI)***

The OSI model is an International Standards Organization (ISO) standard that defines a framework for implementing telecommunication and software protocols. The OSI model is organized into seven hierarchical layers. Control is passed from one layer to the next starting at the application layer and proceeding down to each successive layer and back as required for any given process. Most of the functionality of the OSI model exists in all communications systems - however, two or three layers may be combined into one. The most significant role of the OSI model is to serve as a reference for the development of other protocol stacks. A detailed explanation of the OSI Model is provided in the Addendum section of this handbook. Table 1-1, provides a list of the OSI Model Protocol Stack.

Table 1-1: OSI Protocol Stack

OSI Protocol Stack	
Layer #	Protocol
7	Application
6	Presentation
5	Session
4	Transport
3	Network
2	Data Link
1	Physical

Telecommunications hardware generally utilizes layers one and two of the protocol stack. Modems, multiplexers, bridges, routers, switches, media converters, codecs, etc. are examples of the types of devices that exist at the physical and data link layers of the protocol stack. All media and most of the protocol converters are considered as layer one items. Some communication hardware devices are designed to operate at higher layers. A network router is often referred to as a "layer 3 router". This is one of the few examples of communication hardware that is designed to function above layer two. Most communication systems are not designed using the OSI protocol stack. This is because the hardware vendors have already taken the OSI model into consideration for the design of their products. The RS232 and RJ45 connectors built into the 2070 traffic controller are already layer one compliant. Serving as a protocol stack model, OSI is used as the reference for the development of most other communications protocols. The National Transportation Control Interface Protocol (NTCIP)<sup>1</sup> has a specially developed protocol stack based on the OSI model.

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<sup>1</sup> <http://www.ntcip.org>

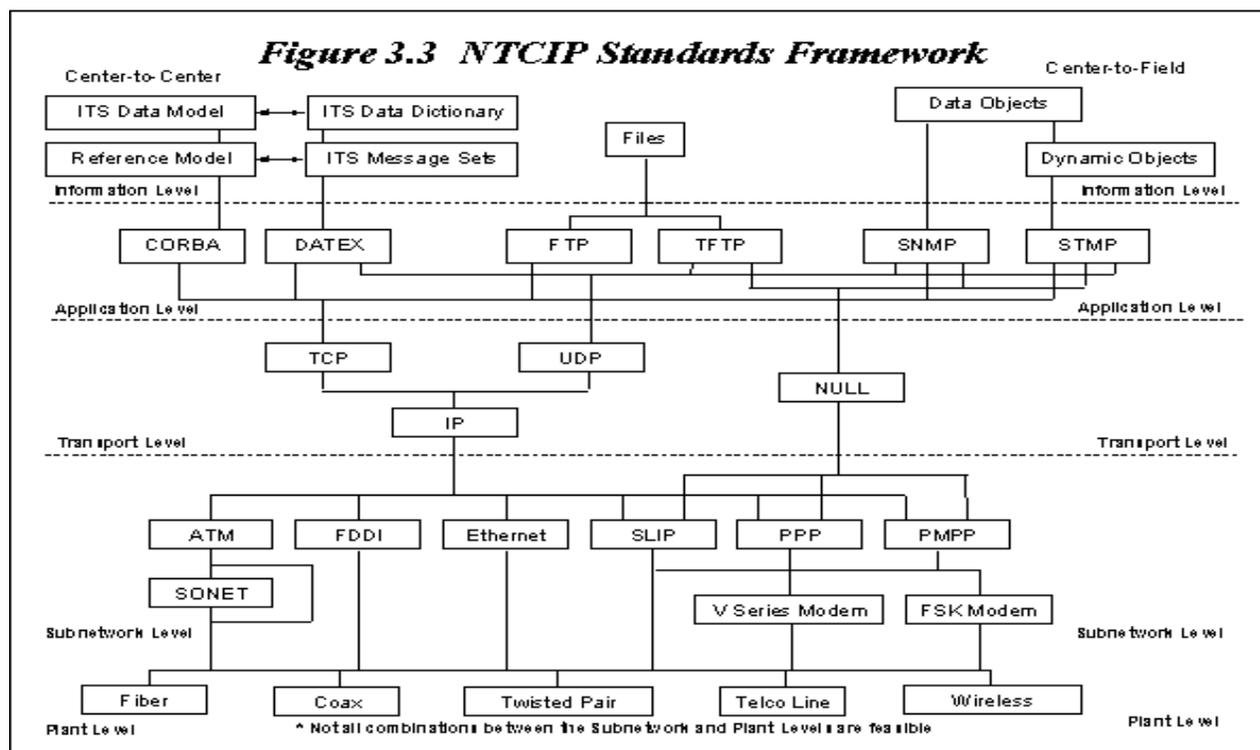


Figure 1-1: Diagram - NTCIP Standards Framework

Notice (figure 1-1) that the NTCIP protocol stack is modeled on the OSI stack, and has embedded telecommunication standards. Communication system designers would simply use the pre-defined telecommunication standards. However, developers of software control systems must be acutely aware of the NTCIP protocol stack. NTCIP and its role in the development of a communication system is explained in Chapter 3.

### Telecommunications History

The history of modern-day communications technology can be said to have started when Samuel Morse invented the wireline telegraph in 1832. However, it was Alexander Graham Bell's invention of the telephone, in 1874, that led to the development of our present day communications technology. Morse had simply created a way for humans to extend their ability to transfer information - instantly - over great distances. Bell gave us the ability to have the most intimate form of communication over distances - the use of our voices.

The concept of the telephone instrument - and the system that allows it to work - was so strong that most communication

technology during the past 125 years was developed to support an efficient voice communication network. It wasn't until 2004 that major telecommunication carriers announced the need to develop, and support, a network designed for the purpose of transporting digital data.

The wireless telegraph (now referred to as radio) was invented by Guillermo Marconi in 1896<sup>2</sup>. When wireless communication was finally able to be used for voice transmission, it emulated the telephone system.

From 1874 to 1980, communication networks around the world were constructed to facilitate the efficient and economical transmission of voice conversations. Multiplexing and digital transmission systems were developed to "cram" more voice conversations into the existing copper wire communication facilities.

The Internet, first developed in 1973 as a project for the U.S. Department of Defense Advanced Research Projects Agency (ARPA), initiated a profound change in the future development of communications networks and technologies. Originally called the Arpanet - linking several Universities and research laboratories - it evolved into the world wide web (WWW). During this period, there were a number of significant technology advances and government enforced corporate reorganizations that helped to change the direction of communications systems development:

1. Computing and communications technologies were provided a big boost by the invention of the integrated circuit (IC) in 1959. The IC permitted development and manufacture of smaller and more automated communication devices at a very low cost.
2. The Carterphone Decision, by the U.S. Supreme Court, in 1968, made it possible for the connection of non-telephone company owned devices (until this point, only devices owned and operated by the telephone companies were permitted).
3. In the 1970s, fiber strands were first used as a communication medium.
4. In 1983, the U.S. Supreme Court mandated reorganization of AT&T was enforced.

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<sup>2</sup> Historically, Marconi is credited with the invention of the wireless telegraph, however, a landmark June 21, 1943 supreme court decision stated that Marconi had violated Nikola Tesla's patents for wireless communications. See "United States Reports; Cases Adjudged in the Supreme Court of the United States," Vol. 320; Marconi Wireless Telegraph Co. of America v. United States, pp. 1-80.

New inventions coupled with increasing business and consumer demand for computer and data communication services forced a change in the nature of the development of communications networks. By 1995, most installation of communications networks was devoted to the efficient transmission of data generated by computers. However, these networks were still based on a voice

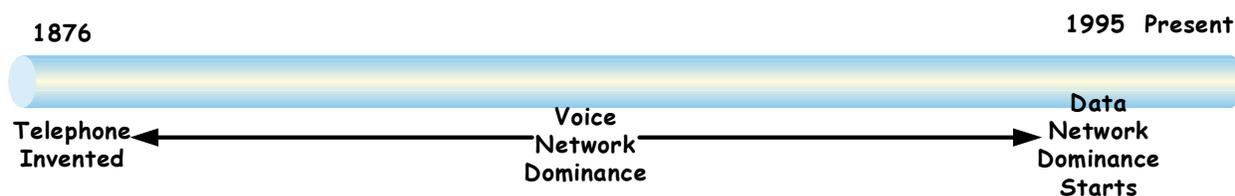


Figure 1-2: Telecommunication Timeline

communication design.

The development and introduction of broadband data communications standards (IEEE 802 Series<sup>3</sup>) helped to create a demand for communications networks designed to support data communications.

By 2003, wireless (cellular telephone) networks were available to almost every location of the United States (remote wilderness areas still lack coverage). According to the Cellular Telecommunications & Internet Association (CTIA), there were more than 148 million wireless subscribers, and 92% were using digital service.

A timeline of the support for traditional voice transmission services versus data transmission services might appear as follows:

By 2003, 63% of Americans use the internet, and 31% of home users have broadband access<sup>4</sup>. In early 2004, Verizon, announced a major upgrade of its basic telephone network to support "Internet Telephony" or Voice over Internet Protocol (VoIP)<sup>5</sup>. Southern Bell Corporation (SBC) also announced similar upgrades for its networks.

### *Handbook Organization*

The Telecommunications Handbook for Transportation Professionals is organized to provide the reader with a logical flow of information with a description of various communication

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<sup>3</sup> <http://www.ieee.org>

<sup>4</sup> Pew Trust - "Internet & American Life", December 2003. - <http://www.pewtrusts.org>

<sup>5</sup> Ivan Seidenberg, CEO Verizon, at the Consumer Electronics Show, Jan 2004.

terms and technologies that are commonly used (or considered) for the deployment of Freeway Management and Traffic Signal systems. Technical descriptions are kept at a minimum engineering level to provide non-communication professionals with a basic understanding of the technologies.

Chapter Two - Telecommunications Fundamentals. Communication technology is provided in a "basic to complex" order. The chapter starts with copper based transmission media and steps the reader through a progression of terminology that includes: fiber optics, wireless, video multiplexing and Ethernet systems.

Chapter Three - Telecommunications & The National Architecture. The chapter is a general look at the relationship of telecommunications systems design and the National ITS Architecture and NTCIP. The reader will be made aware of the fact that NTCIP is not a standard, but a protocol that defines the relationship of the many current (and developing) communications standards for use in a traffic signal, freeway management, or transportation system.

Chapter Four - Developing the Telecommunication System. This chapter provides the reader with a system engineering approach to the design of a communications system that supports traffic and transportation requirements. The chapter provides a step-by-step process that should result in a communication system requirements analysis and preliminary design. The primary axiom that drives the design of a communications system is - "there are no absolutes!" For most communication systems there are usually several ways to achieve the desired results. A qualified communications system designer will generally present several different approaches and ask the project manager to make a decision.

Chapter Five - Communications for Field Devices. The chapter provides an in-depth look at basic system configurations for field devices used in traffic signal and freeway management systems. Each field device has a specific set of communications requirements.

Chapter Six - Communication System Maintenance. Maintenance of a telecommunication system is essential. Operators of these systems must provide for the care and feeding of the networks that connect all field devices and operational centers. The chapter discusses the need to create a budget for maintenance, the relationship of manufacturer warranties to maintenance, and technician qualifications.

### **Chapter 1**

Chapter Seven - System Examples. This chapter presents a look at "real-world" systems deployed by departments of transportation. Two systems are described to show how similar problems use different approaches to a solution.

Chapter Eight - Installation and Testing. A major cost element in the deployment of a communications system is installation (construction). Very often, project managers assume that proper installation procedures are being used by contractors. This chapter provides guidelines for proper handling and installation of communications media. Wireline and wireless media are discussed.

Chapter Nine - The Internet. First conceived and implemented nearly thirty years ago, has had a profound effect on the way individuals, private companies and public organizations communicate on a day-to-day basis. The chapter in this document will provide the reader with a basic understanding of the composition of the Internet, the World Wide Web (WWW), how it works, and how it can be used as part of an overall communications and operational strategy for Traffic Signal, FMS, and ITS systems.

Chapter Ten - The Future. An attempt to provide some insight on the general future of communications systems and the possible implications for the deployment of telecommunications systems to support Freeway Management and Traffic Signal systems.

Appendix A - Contains additional information that readers of this handbook can use for investigation of additional resources. The following items are included in this appendix:

- List of IEEE 802 standards and working groups
- Comparison of analog voice and voice-over-IP (VoIP)
- How to calculate a fiber optic loss budget
- A discussion of rural telecommunications requirements

Glossary - Definitions - will provide a listing of all terminology used in this handbook.

## 2. CHAPTER TWO – FUNDAMENTALS OF TELECOMMUNICATIONS

### *Introduction*

Transmitter, receiver, transmission medium - these are the basic elements that make up a communication system. Every human being is equipped with a basic communication system. The mouth (and vocal cords) is the transmitter, ears are the receivers, and air is the transmission medium over which sound travels between mouth and ear. The transmitter and receiver elements of a data modem (such as the type used in a traffic signal system controller box) may not be readily visible. However, look at a schematic of its components, and you will see elements labeled as "XMTR" and "RCVR". The modem's transmission medium is typically copper wire, fiber, or radio.

Almost all communications networks have as their basis the same set of Telephony (Telepho-Ny) standards and practices. "Ma Bell" (the Bell Telephone System and American Telephone & Telegraph, and others) spent years and billions of dollars creating, perfecting and maintaining a telecommunications network dedicated to providing the most reliable voice communication service in the world. All other communication technology and process evolved based on that communications network. Engineers and scientists involved in the development of new communication technologies and processes had to make certain that their "product" could be used within the existing telephone networks. And, the telephone company required backward compatibility. Telephones manufactured in 1950 still work in today's network. Modems manufactured in 1980 still work in the current system.

Some communication transmission protocols were developed to work independently of the Telephone System. Ethernet, for example was created to facilitate data communication within a closed system that was contained within an office building. The Internet was created as a closed communication network.

As you read through this chapter, and the rest of the handbook, please keep in mind that telecommunication standards, practices, and protocols were developed for the communication industry. All

of these systems must be adapted for use in a traffic signal or freeway management system.

Today, in North America, Mexico, most of Europe and the Pacific Rim, voice services are in fact sent as digital signals and converted to analog just before leaving (and arriving at) the serving central office, at the end-user points. The reader might ask: "If voice is converted to digital isn't that the same as data?" The answer is no - "digital transmission" does not automatically infer data communications compatibility. Analog transmission systems can, and do, carry data. In telecommunications, digital and analog are distinct forms of communication transmission. This chapter provides information about the basics of telecommunications - the transmission media and transmission systems, as well as an explanation of the differences between analog and digital transmission. Transmission media are those elements that provide communication systems with a path on which to travel. Transmission systems are those elements (hardware and software) that provide management of the communication process and the use of the transmission path.

The telecommunications world would be very simple if the distinction between transmission media and systems (protocols) were easily defined. Often, a specific transmission system will only work within a specific medium. Spread Spectrum Radio is one example. Radio (RF) is the transmission medium, and spread spectrum is the transmission system (protocol). Although it is possible to create a spread spectrum communications signal over wireline, the process is not typically used because there are other more efficient methods of transmission signaling. Therefore, spread spectrum transmission signaling is almost always associated with RF. There is always a point at which the Spread Spectrum Radio system must interface with another transmission medium, and/or system. This is accomplished by converting from RF to a wireline signaling protocol. The telecommunications process can be viewed as an excellent example of multi-modalism.

For purposes of this discussion, voice is any transmission that can be switched through the Carrier networks in an analog format. This includes data transmitted within a voice channel using a modem. Data is any digital transmission that cannot be switched through the Carrier networks.

The chapter is divided into sections that cover

- Transmission Media
- Transmission Signaling
- Basic Telephone Service
- Multiplexing
- High Capacity and Broadband Transmission

Sub-topics in the sections look at:

- Media Consideration Factors (why use one over another)
- Differences between voice and data signaling
- Video Transmission (CODECS & Compression)
- T-1 Communication
- SONET, WDM & Ethernet
- Wireless

### ***Transmission Media***

Transmission media are the highways and arteries that provide a path for telecommunications devices. There is a general tendency to say that one transmission medium is better than another. In fact, each transmission medium has its place in the design of any communication system. Each has characteristics which will make it the ideal medium to use based on a particular set of circumstances. It is important to recognize the advantages of each and develop a system accordingly.

Factors to consider when choosing transmission media include: cost, ease of installation and maintenance, availability, and most important, efficiency of transmission.

Transmission efficiency is generally viewed as the amount of signal degradation created by the use of a particular transmission medium. The transmission medium presents a "barrier" to the communication signal. The "barrier" can be measured by many different factors. However, one common question is asked about all communication media. How far will the communication signal energy travel before it becomes too weak (or distorted) to be considered usable? There is equipment available to extend the distance for transmitting a signal, but that adds to the overall cost and complexity of deployment.

### ***Chapter 2***

### ***MEDIA CONSIDERATION FACTORS***

Ease of installation of the communication medium is relatively simple to define. Generally, all communication media require care when being installed. The installation should be accomplished by trained and knowledgeable technicians and managers. For purposes of this discussion, consider the relative degree of difficulty for the placement of the transmission medium. Cables (fiber or copper) require a supporting infrastructure, as does radio or infrared. Consider the following:

If you are planning to use fiber optic (or copper cable) and the system plan calls for crossing the Delaware River, there will be significant installation (construction) challenges. The construction may require a bore under the river, or finding a suitable bridge. Either of these methods may add significantly to your budget. Wireless might seem like a good option. It eliminates the need to find a suitable crossing location for your cable. However, you will need to place the antenna at sufficient height to clear trees buildings and other objects, and account for terrain differences on both sides of the river. Local residents of the nearby Yacht Club condominiums may complain about the radio tower spoiling their view of the sunset. Don't forget to add in the cost of hiring a graphic artist to create a drawing that shows how lovely the rays of the setting sun are when reflected off the radio tower.

Some products may be more readily available than others. For example, the most common type of fiber cable available is outside plant with armor shielding, 96 strands of single mode fiber arrayed in loose buffer tubes, on 15,000 foot reels. Make certain that you allow enough time for product to be manufactured, especially if a special cable or hardware configuration is required. Availability of product due to manufacturing delays will impact on overall project schedule and may impact on overall project costs.

"Put-ups" - the term cable manufacturers use to describe the configuration of a cable. The expression is often used in the following manner: "The cable is available in 5000 foot "put-ups".

Cables that contain combinations of different types of fiber strands such as single mode and multimode fibers, or mixtures of copper and fiber, or odd (different from standard put-ups)

numbers of fiber strands will require more time to produce and could add several months to the delivery cycle.

Fiber, copper, radio, infrared all have different transmission characteristics. Fiber is considered to have the best overall characteristics for transmission efficiency. That is, the effective loss of signal strength over distance. Cable is rated by the manufacturer for signal loss. Signal loss factors are stated in terms of dB per 1000 meters. Typical single mode fiber may have a signal attenuation factor of between 0.25 dB/km and 0.5 dB/km. The cable manufacturer will provide a specification description for each product they offer. In theory, you can send a signal further on fiber than via most other transmission media.

However, consider that radio signals at very low frequencies (below 500 kilohertz) can travel for thousands of miles. This type of radio signal can be used to carry data, but very impractical for use in traffic signal and freeway management systems. VLF radio signals are only capable of efficiently carrying data at very low bit rates. This type of system was used by the Associated Press organization to transmit news articles between Europe and North America, and is also used by the Military for very long distance data communications.

Maintenance and operational costs are two other factors that should be considered when comparing transmission media for any given application. Fiber optic cable can be installed in conduit six feet below grade, and never touched for decades. Maintenance of the fiber cable is minimal. Microwave systems may be constructed in less time and at a lower cost than fiber cable placed in conduit, but the tower sites require significantly more maintenance, including re-painting the tower, and annual inspections for rust.

In summary, take all of the attributes of the potential media that could be used for a specific application and determine which will provide the most "bang for the buck". This does not always mean most bandwidth, highest transmission speed, easiest to install, or lowest cost - all factors that may influence your choice of transmission media. The best media are the ones that will support as many of the system requirements as possible and help to assure satisfaction with overall performance.

## **WIRELIN MEDIA**

We begin with basic information about the most common types of transmission media used today:

- Copper Wire
- Fiber Optics
- Radio Frequency (Wireless)
- Free Space Optics

Many engineers will argue that one transmission medium is the best, or better than some of the others. The reader should keep in mind that each medium has advantages and disadvantages. Which medium is best depends upon the purpose of the communications system and the desired end results. In fact, most systems are a hybrid. That is, two or more media are combined to effect the most efficient communication network infrastructure. There are many traffic signal systems that combine a twisted copper pair infrastructure with wireless links to serve part of the system. The decision to create this type of system may have been based on economics, but that is certainly one of the reasons to choose one medium over another, or to combine the use of several.

### **Copper Media**

The electrical properties of copper wire create resistance and interference. The further communication signals travel the more they are weakened by the electrical properties associated with the copper cable. Electrical resistance within the copper medium slows down the signal or flow of current. The electrical properties of copper wire are the key factors that limit communication transmission speed, and distance. However, it was those same properties together with cost, ease of manufacture, ability to be drawn into very thin strands, and others that made copper a logical choice for its selection as a communication transmission medium, and a conductor of electricity. Aluminum and gold are also used for communication purposes, but gold (the most efficient) is too expensive to use for this purpose and aluminum is not an efficient conductor for communication purposes.

There are two primary types of cables containing copper wire used for communication:

### **Chapter 2**

- Twisted Pair
- Coaxial

### Twisted Pair

Communication signals sent over copper wire are primarily direct electrical current (DC) which is modulated to represent a frequency. Any other electrical current near the communication wire (including other communication signals) can introduce interference and noise. Multiple communication wires within a cable bundle can induce interfering electro-magnetic currents, or "cross-talk". This happens when one signal within the cable is so strong that it introduces a magnetic field into an adjacent wire, or communication pair. Energy sources such as power transmission lines, or fluorescent lighting fixtures can cause electromagnetic interference. This interference can be minimized by twisting a pair of wires around a common axis, or by the use of metallic shielding, or both. The twisting effectively creates a magnetic shield that helps to minimize "crosstalk".

Twisted pair is the ordinary copper wire that provides basic telephone services to the home and many businesses. In fact, it is referred to as "Plain Old Telephone Service" (POTS). The twisted pair is composed of two insulated copper wires twisted around one another. The twisting is done to prevent opposing electrical currents traveling along the individual wires from interfering with each other.

Twisted copper pair, is what Alexander Bell used to make the first telephone system work and is generally the most common transmission medium used today.

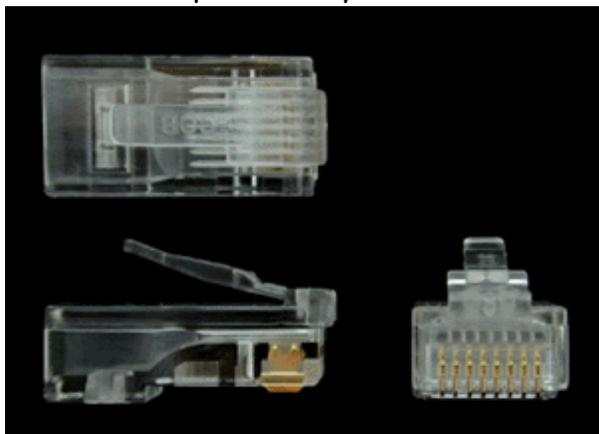


Figure 2-1: RJ-45 Connector

A broad generalization is that twisted copper pair is in fact the basis for all telecommunication technology and services today. Ethernet - originally developed to work over coaxial cable - is now a standard based on twisted pair. By comparison, a basic voice telephone conversation uses one (1) twisted pair, where as an Ethernet session uses at least two (2) twisted pair (more about

Ethernet later in this chapter).

Each connection on twisted pair requires both wires. Since some telephone sets or desktop locations require multiple connections, twisted pair is sometimes installed in two or more pairs, all within a single cable. For some business locations, twisted pair is enclosed in a shield that functions as a ground. This is known as shielded twisted pair (STP). Ordinary wire to the home is unshielded twisted pair (UTP). Twisted pair is now frequently installed with two pairs to the home, with the extra pair making it possible to add another line - perhaps for modem use.

Twisted pair comes with each pair uniquely color coded when it is packaged in multiple pairs. Different uses such as analog, digital, and Ethernet require

EIA/TIA provides a color code and wiring standard for RJ-45 Connectors. The standard is EIA/TIA 568A/568B. These standards utilize 4 twisted pair, because the RJ-45 connector has 8 terminals.

different pair multiples. There is an EIA/TIA standard for color coding of wires, wire pairs, and wire bundles. The color coding allows technicians to install system wiring in a standard manner. A basic single telephone line in a home will use the red and green wire. If a second phone line is provided, it will use the yellow and black wire. The most common cause of telecommunication system problems is incorrect wiring. This wiring protocol is for standard telephone set jack connections. Data systems use different arrangements and color codes. The most common is the EIA/TIA standard. Please note that NEMA and ICEA have color codes for electrical wire. Do not confuse these with telecommunication wire color coding standards.

Cat 3 cable is considered to be the standard for basic telephone and Ethernet services. However, CAT 5 is being deployed as a replacement and in all new installations.

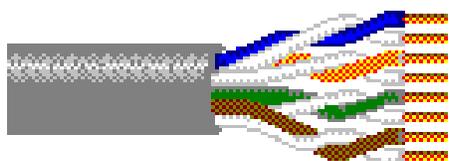


Figure 2-2: Twisted Pair Cable

Twisted pair is categorized by the number of twists per meter. A greater number of twists provides more protection against crosstalk, and other forms of interference and results in a better quality of transmission. For data transmission, better quality equates to fewer transmission errors. Later in this chapter, we'll look at the

effects of transmission errors as they impact on throughput and delay times.

There are two types of twisted pair cables used for most in-building situations today - Category 3 UTP (CAT 3) and Category 5 UTP (CAT 5). However, as of the writing of this handbook, all new and replacement installations use CAT 5. These cables have been developed based on a set of standards issued by the EIA/TIA (Electronic Industry Association/Telecommunications Industry Association). CAT 3 is used primarily for telephone cabling and 10Base-T installations, while CAT 5 is used to support 10/100Base-T installations. CAT 5 wiring can also be used for telephone systems. Therefore, most new installations use CAT 5 instead of CAT 3. The CAT 5 cable is pulled to a cubicle or office and connected to a universal wall plate that allows for installation of data and voice communication systems. Category 5E (CAT 5E) has been developed to accommodate GigE installations. CAT 5E is manufactured and tested under stricter guidelines than CAT 3 or CAT 5. Two new standards - CAT 6 and CAT 7 - have been adopted to meet criteria for 10GigE (and higher) transmission speeds.

Table 2-1: Twisted-Pair Communication Cable Category Ratings

Category	Maximum Data Rate	Usual Application
CAT 1	Less than 1 Mbps	Analog Voice (POTS), Basic Rate ISDN, Doorbell wiring
CAT 2	4 Mbps	Primarily used for Token Ring Networks
CAT 3	16 Mbps	Voice and Data, and 10Base-T Ethernet. Basic telephone service
CAT 4	20 Mbps	Used for 16 Mbps Token Ring
CAT 5	100 Mbps up to 1 Gbps	10Base-T, 100Base-T (fast Ethernet), GigE, FDDI, 155 Mbps ATM
Cat 5E	100 Mbps	FDDI, ATM

CAT 6	Greater than 100 Mbps	Broadband Applications
CAT 7	Emerging Standard	GigE plus

### Coaxial Cable

Coaxial cable is a primary type of copper cable used by cable TV companies for signal distribution between the community antenna and user homes and businesses. It was once the primary medium for Ethernet and other types of local area networks. With the development of standards for Ethernet over twisted-pair, new installations of coaxial cable for this purpose have all but disappeared.

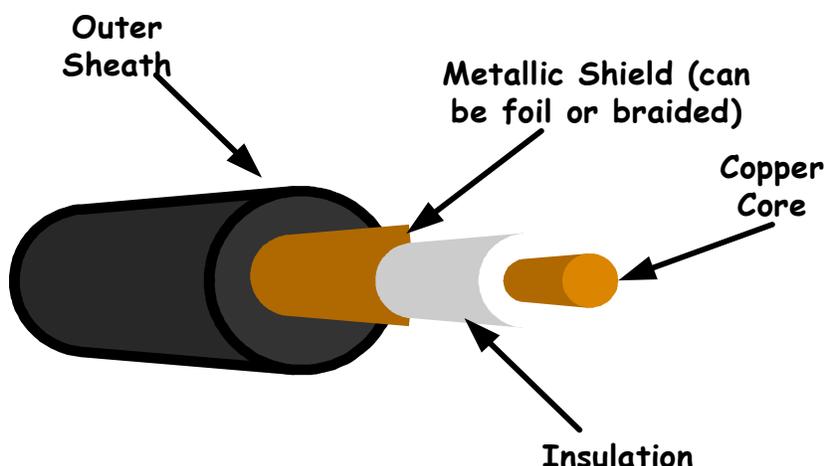


Figure 2-3: Co-Axial Cable Illustration

Coaxial cable is called "coaxial" because it includes one physical channel (the copper core) that carries the signal surrounded (after a layer of insulation) by another concentric physical channel (a metallic foil or braid), and an outer cover or sheath, all running along the same axis. The outer channel serves as a shield (or ground). Many of these cables or pairs of coaxial tubes can be placed in a single conduit and, with repeaters, can carry information for a great distance. In fact, this type of cable was used for high bandwidth and video service by the telephone companies prior to the introduction of fiber in the 1980's.

There are several variations. Triaxial (Triax) is a form of cable that uses a single center conductor with two shields. This composition affords a greater transmission distance with less loss due to interference from outside electrical signals. Twinaxial (Twinax) is two coaxial systems packaged within a single cable.

Coaxial cable was invented in 1929 and first used commercially in 1941. AT&T established its first cross-continental coaxial transmission system in 1940. Depending on the carrier technology used and other factors, twisted pair copper wire and optical fiber are alternatives to coaxial cable.

Coaxial cable was originally used by some traffic departments to provide communications between field controllers and the central controller in an automated traffic signal system. It was also the medium of choice for early implementation of video incident management systems used in ITS. However, with the introduction of fiber optics, the use of coaxial cable has all but been abandoned for this purpose.

Coaxial cable is still used for connecting CCTV cameras to monitors and video switchers. As the cost of using fiber optics has begun to drop, camera manufacturers are installing fiber optic transceivers in the camera. This is especially useful for preventing interference from electrical systems, or creating a secure video transmission network.

### **Fiber Optics & Fiber Optic Cable**

Fiber optic (or "optical fiber") refers to the medium and the technology associated with the transmission of information as light impulses along a strand of glass. A fiber optic strand

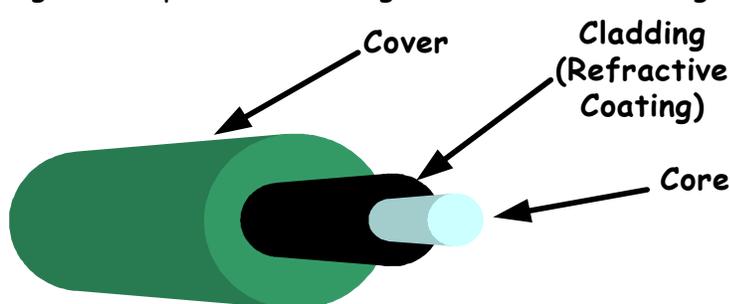


Figure 2-4: Basic Fiber Optic Strand Construction

carries much more information than conventional copper wire and is far less subject to electromagnetic interference (EMI). Almost all telephone long-distance (cross country) lines are now fiber optic.

Transmission over fiber optic strands requires repeating (or regeneration) at varying intervals. The spacing between these intervals is greater (potentially more than 100 km, or 50 miles) than copper based systems. By comparison, a high speed electrical signal such as a T-1 signal carried over twisted-pair must be repeated every 1.8 kilometers or 6000 feet.

Fiber optic cable loss is calculated in dB per kilometer (dB/KM), and copper cables are rated in dB per meter (dB/M). **Note:** *The Appendix of this handbook includes an explanation of how to calculate a fiber optic loss budget.*

The fiber optic strand is constructed (see graphic) in several layers. The core is the actual glass, or fiber, conductor. This is covered with a refractive coating - called cladding - that causes the light to travel in a controlled path along the entire length of the glass core. The next layer is a protective covering that keeps the core and coating from sustaining damage. It also prevents light from escaping the assembly, and has a color coding for identification purposes. The core, coating and covering are collectively referred to as a "strand". Fiber strand sizes are always referred to in terms of the diameter of the core.

## **Fiber Optic Cable**

Fiber strands are typically bundled within a cable. The strands can be placed in a "tight" or "loose" buffer tube array. The loose buffer tube array is the most commonly deployed for outside plant applications. Tight buffered cable is generally used within a building for riser and horizontal cable. Tight buffer cable is also used for an "indoor/outdoor" application. This cable is constructed with a weather/moisture resistant cable sheath, and is generally used to get from a splice box located within several hundred feet of a building utility entrance, and must be run several hundred feet within a building to the main fiber distribution point. If the main fiber distribution point is less than 100 feet from the building entrance, there may be no advantage to using the indoor/outdoor cable.

Inside plant cable is constructed to be flexible and lightweight. The cable may be coated to meet fire protection codes.

Fiber strands are placed in a large (relatively) diameter tube and allowed to "float" with considerable movement. As the fiber cable is pulled into place (in conduit, directly buried, or placed on a pole) the strands are not subjected to the forces of the pulling tension. The strands therefore sustain minimal damage or distortion from stretching.

Fiber cables are (as are all communications cables) manufactured based on their intended use. Each cable will have a standard set of markings indicating its primary use, the name of the manufacturer, a National Electrical Code rating and a UL approval code, the number of fibers contained within the cable, the outside diameter of the cable, and the manufacturer's product nomenclature. All of these items should be checked when the cable is delivered to a storage area and then at the job-site before the cable is installed. Generally, fiber cables fall into one of the following classifications:

Outside plant cable is constructed to withstand immersion in water, will resist exposure to ultraviolet rays, and is protected from rodents and birds.

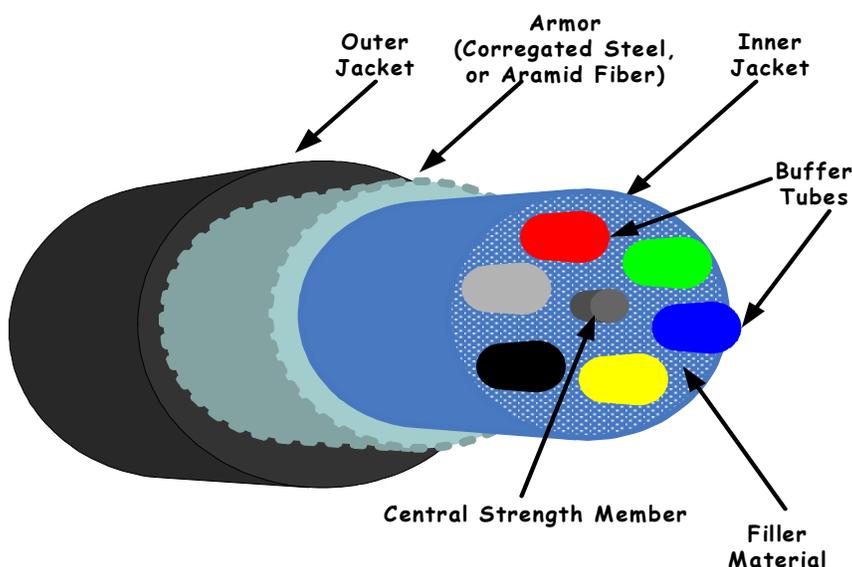
Table 2-2: Fiber Optic Cable Classifications

Fiber Cable Classification	General Purpose
Inside Plant	Device to device wiring
Horizontal, or Intra-office	Run on a single floor and between rooms
Riser or intra-building	Run between floors in a building, usually in an elevator shaft or conduit
Plenum	Specially coated cable to meet fire codes for cable run within an air space.
Aerial Cable	Usually strung on Utility poles and designed to be either self-supporting or lashed to a supporting cable. Cables are usually constructed with materials that are resistant to aging from exposure to sunlight.
Direct-burial	Cables that are designed to be directly buried in a trench.
Duct Cable	Cables that are designed to be installed

	in a conduit
Submarine Cable	Cables that are designed to be submerged.
Inside-Outside	Cables that are used to transition between outside plant and inside plant.

Some cables are manufactured with a metallic armored sheath to provide added strength and protection against rodents. Fiber cable that is placed in underground conduit, is normally filled with a waterproof gel compound. Outside plant cables are generally manufactured with a gel filling in the buffer tubes and a water blocking tape between the inner and outer jackets. Both outer and inner jackets are made of materials designed to withstand immersion and resist corrosion.

Fiber strands and cables are manufactured with a standard color coding. This permits effective management of cables because of the normally high strand counts contained within a cable. There are 24 color combinations used. A loose buffer tube cable with 576 strands would have 24 tubes colored as indicated in the chart below. Within each buffer tube would be 24 fiber strands using the same color scheme. Therefore, strand number would be in an orange buffer tube and have rose with a black tracer colored protective coating.



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Table 2-3: Fiber Cable Identification Chart

Figure 2-5: Fiber Optic Cable Illustration

Fiber Cable Identification Color Chart

Buffer Tube / Fiber Strand Number	Color
1	Blue
2	Orange
3	Green
4	Brown
5	Slate
6	White
7	Red
8	Black
9	Yellow
10	Violet
11	Rose
12	Aqua
13	Blue/Black Tracer
14	Orange/Black Tracer
15	Green/Black Tracer
16	Brown/Black Tracer
17	Slate/Black Tracer
18	White/Black Tracer
19	Red/Black Tracer
20	Black/Yellow Tracer
21	Yellow/Black Tracer

22	Violet/Black Tracer
23	Rose/Black Tracer
24	Aqua/Black Tracer

Another aspect of fiber construction is the actual size of the fiber strand. Most fiber is produced in a diameter of  $125\mu m$  - a combination of the fiber core and its cladding. Most multimode cable used today has a core diameter of  $62.5\mu m$  and most single mode fiber has a core diameter of  $9\mu m$ . Therefore, the fiber strand size will normally be listed as  $62.5\mu m/125\mu m$  for multimode and  $9\mu m/125\mu m$  for single mode fiber.

The strand diameter is kept consistent to help with the manufacturing and installation processes. The core diameter varies because of differences in some of the transmission characteristics of the fibers. When purchasing fiber cable to be added to an existing system, make certain that strand diameter and the core diameters match. Fusion splicing (see chapter 8 for an explanation of splicing) fibers with different core diameters is possible. However, there will probably be a misalignment that is the cause of poor system performance. If you must use fibers with different core diameters it is best to use a mechanical splice to assure proper alignment. Never splice multimode fiber to single mode fiber. If you must place single mode and multimode in the same system use a "mode converter" to facilitate the transition.

### Fiber Cable Types

Fiber cables are produced in two basic forms:

- Loose Tube Buffered Cable
- Tight Buffered Cable

Loose tube cables are primarily used in outside plant applications. They are designed to protect the fibers from damage (stretching and kinking) that might result from an overly aggressive cable puller. The tube arrangement also allows for easier transition to fiber drops at buildings or communication cabinets. The fiber strands float within the buffer tubes and are not part of the cable structure. Loose tube cables are ideal for metropolitan and long distance cable installations.

Note: Many manufacturers will provide both loose tube and tight buffered cable. Some only provide one type. Specify and purchase the type of cable that best meets your needs. Remember, "in telecommunications, there is no single solution for all requirements!!!"

Tight buffer cables are specified for inside plant use. These types of cables are designed for use within a controlled environment such as a building or inside plant equipment cabinets. Because the cable is used within a building the cable it requires less physical protection and has greater flexibility. The fibers within the cable are susceptible to damage from aggressive cable pulls because the fiber strands are part of the cable structure. The strands are tightly bound in a central bundle within the outer cable sheath.

Fibers are assembled into either stranded or ribbon cables. Stranded cables are individual fibers that are bundled together. Ribbon cable is constructed by grouping up to 12 fibers and coating them with plastic to form a multi fiber ribbon. Stranded and ribbon fiber bundles can be packaged together into either loose or tight buffering cable.

Table 2-4: Fiber Optic Cable Buffer Types

<b>Cable Buffer Types</b>	
<b>Loose Buffered Cable</b>	<b>Tight Buffered Cable</b>
Individual fibers move freely within a buffer tube	Fibers are tightly bound into a bundle
Large cable diameter to	Smaller cable diameter

accommodate buffer tubes	
Fibers protected from cable pulling forces	Fibers sensitive to pulling forces
Used primarily for outside plant	Used for inside plant and distribution

**Fiber Strand Types:**

Fiber strands are produced in two basic varieties: Multimode and Single mode. Each variety is used to facilitate specific requirements of the communication system.

Multimode is optical fiber that is designed to carry multiple light rays or modes concurrently, each at a slightly different reflection angle within the optical fiber core. Multimode fiber transmission is used for relatively short distances because the modes tend to disperse over longer lengths (this is called modal dispersion). Multimode fibers have a core diameter of between 50 & 200 microns. Multimode fiber is used for requirements of less than 15,000 feet. Multimode fiber became available during the early 1980's and is still being used in many older systems. With the advances in fiber technology and the number of product choices available, multimode fiber is almost never deployed for new systems. There are mechanical devices available that accommodate a transition from multimode fiber to single mode fiber. Multimode fiber is generally "lit" with LED (Light Emitting Diodes) which are less expensive than LASER transmitters. Multimode fiber is generally manufactured in two sizes 50 $\mu$ m and 62.5 $\mu$ m.

Single mode is optical fiber that is designed for the transmission of a single ray or mode of light as a carrier. Single mode fiber has a much smaller core than multimode fiber. Single mode fiber is produced in several variations. The variations are designed to facilitate very long distances, and the transmission of multiple light frequencies within a single light ray. Following chapters will discuss transmission system capabilities - See: Ethernet, SONET and DWDM. Single mode fiber is generally manufactured with core diameters between 7 and 9 microns.

During the past 10 years, a number of variants of single mode fiber have been developed. Some of the fibers are used for long distance systems, and others are used for metropolitan systems. Each of these has been developed with special characteristics designed to enhance performance for a specific purpose. The most widely used all purpose single mode fiber is SMF-28 which can be used for all purposes, except long reach DWDM systems.

Note: SMF-28 is a trademarked nomenclature of Corning Cable, that has become a generic term used to describe an all purpose single mode fiber. Nearly all traffic signal and freeway management systems will use an all purpose single mode fiber. Fiber optic product characteristics are in a constant state of change. Investigate before finalizing system specifications. The Resource Section of this handbook contains a list of fiber optic cable manufacturers and their web sites.

Freeway Management and Traffic Signal Control would be considered - from a communications perspective - as general purpose systems. Designers of

Transportation Management Systems using fiber should strongly consider specifying SMF-28 type single mode fiber. This fiber is very available and normally is lowest in price.

Fiber optic cable is priced on the basis of strand feet. A 5,000 foot cable with two fiber strands is 10,000 fiber strand feet. A 5,000 foot cable with 24 fibers is 120,000 strand feet. The cost of the first cable might be \$5,000, or 50 cents per strand foot. The cost of the second cable might be \$24,000, but the cost per strand foot is only 20 cents. Therefore, when purchasing fiber optic cable, it is always best to consider potential system additions in order to incur a lower overall materials cost. Remember, price per fiber strand foot is not the only factor to consider in overall system costs. Digging a four (4) foot deep trench, placing conduit in the trench, and repairing the street carries the same cost regardless of the strand count, and that's about 90% of the total cost of deploying fiber optic cable. If construction costs \$100 per linear foot, then the overall cost per strand foot is \$50.50 per foot for two (2) strands and \$4.37 for twenty-four (24) strands. Items not included in this calculation are the costs associated with splicing, optimization and engineering. Those are 10% of the total cost.

## Single Mode vs. Multimode Fiber

Following is a general comparison of Single Mode and Multimode fibers:

*Single mode fiber has a very small core causing light to travel in a straight line and typically has a core size of 8 to 10 microns. It has (theoretically) unlimited bandwidth capacity, that can be transmitted for very long distances (40 to 60 miles). Multimode fiber supports multiple paths of light and has a much larger core - 50 or 62.5 microns. Because multimode fibers are five to six times the diameter of single mode, transmitted light will travel along multiple paths, or modes within the fiber. Multimode fiber can be manufactured in two ways: step-index or graded index. Step-index fiber has an abrupt change or step between the index of refraction of the core and the index of refraction of the cladding. Multimode step-index fibers have lower bandwidth capacity than graded index fibers.*

*Graded index fiber was designed to reduce modal dispersion inherent in step index fiber. Modal dispersion occurs as light pulses travel through the core along higher and lower order modes. Graded index fiber is made up of multiple layers with the highest index of refraction at the core. Each succeeding layer has a gradually decreasing index of refraction as the layers move away from the center. High order modes enter the outer layers of the cladding and are reflected back towards the core. Multimode graded index fibers have less attenuation (loss) of the output pulse and have higher bandwidth than multimode step-index fibers.*

*Single mode fibers are not affected by modal dispersion because light travels a single path. Single mode step-index fibers experience light pulse stretching and shrinking via chromatic dispersion. Chromatic dispersion happens when a pulse of light contains more than one wavelength. Wavelengths travel at different speeds, causing the pulse to spread. Dispersion can also occur when the optical signal gets out of the core and into the cladding, causing shrinking of the total pulse.*

*Single mode shifted fiber uses multiple layers of core and cladding to reduce dispersion. Dispersion shifted fibers have low*

*attenuation (loss), longer transmission distances, and higher bandwidth.*

Table 2-5: Comparison Single Mode Fiber & Multimode Fiber

Comparison Single Mode Fiber - Multimode Fiber		
Characteristic	Single Mode	Multimode
Bandwidth	Virtually Unlimited	Less than virtually unlimited
Signal Quality	Excellent over long distances	Excellent over short distances
Primary Attenuation	Chromatic Dispersion	Modal Dispersion
Fiber Types	Step Index & Dispersion Shifted	Step & Graded Index
Typical Application	Almost anything (including Ethernet)	Analog Video; Ethernet; Short Range Communications

### **Wireless Media**

Since the invention of the Wireless Telegraph in 1896 communication system designers have sought to use wireless because of the reduced infrastructure cost and complexity, when compared to wireline communication systems. There is no need to construct miles of telephone line poles or cable trenches. Simply put in a few strategically positioned radio towers and transmit around the world. Today, wireless systems are significantly more complex because we want to allow millions of users to make telephone calls or receive feature length movies via wireless systems. There are four general types of wireless (radio) communication systems:

- Cellular Telephone
- Basic 2-Way Radio
- Point-to-point
- Wi-Fi (Wireless Fidelity), and recently, Wi-Max

Traffic signal and freeway management systems use three of the variants to support operations, and are considering the use of

Wi-Fi. The Wi-Fi/Wi-Max systems are becoming increasingly ubiquitous in their deployment, and a part of most telecommunication deployment strategies. Chapter 7 provides a description of a proposed use of Wi-Max for the Irving, Texas traffic signal system. Wi-Fi/Wi-Max systems are Ethernet based and allow for a seamless transition from wireless to wireline.

### **Cellular Systems**

Cellular wireless telephone networks provide users with a mobile extension of their wireline voice networks. During the past 10 years, cellular telephone systems moved from a luxury that only wealthy individuals or corporations could afford to a commodity service that is affordable, and used by majority of adults (also large numbers of children and teenagers) in North America Europe and the Pacific Rim countries. Many third world countries are expanding their telephone networks via the creation of an extensive wireless system that eliminates the cost of constructing the "wired" systems.

Cellular telephone systems come in two basic varieties: Analog or Digital. Analog uses two standards - AMPS (advanced mobile phone system), and GSM (global system for mobile communication). AMPS was deployed in North America and GSM was deployed in most of the rest of the world. The two systems are not compatible. Different telephone handsets are required, or at least a hand set that will incorporate both systems.

Many digital variants are in the process of being deployed. Because the cost of deployment is so high cellular carriers have been building the required infrastructure in several stages. The first stage is called 2nd generation. Carriers took the existing analog service with one user per radio channel and added a system that would allow several users per radio channel. These are multiplexing schemes called TDMA (time division multiple access) - an analog service, and CDMA (code division multiple access) - a digital service. The basic plan was to move from 2nd to 3rd generation within a short period of time. The upgrade would provide users with voice and data services. The data services would provide significantly higher throughput - greater than 56 Kbps - for internet and e-mail access. However, the cost of the upgrade was so high that carriers decided to take an intermediate step - 2.5G - to provide improved voice and low bandwidth data services. Carriers were hoping that the internet

boom of the late 1990's would create a consumer demand for wireless internet services. However, this demand did not materialize, and the carriers slowed their deployment of 3G systems. With the advent of inexpensive Wi-Fi/Wi-Max systems, general consumer and commercial demand, and laptop computers that can run for 5 hours on battery, wireless carriers are deploying "overlay systems" that can provide broadband internet access and general networking services. Wi-Fi/Wi-Max will be discussed later in this chapter, and an example of a Wi-Fi/Wi-Max system used for traffic signal control will be discussed in Chapter 7.

### **CDPD**

CDPD (cellular digital packet data) is an analog data overlay that has been in operation since 1993. This service provides data throughput at 9.6 Kbps (in theory up to 19.2 Kbps), and is an overlay to the analog cellular telephone system. CDPD is being used by a number of communities as a wireless communication link to control traffic signal systems. As the analog cell systems are converted to digital, CDPD is being phased out. The wireless carriers are not providing a substitute. If you have an existing system that relies on CDPD service, you will need to change to a new service.

An "overlay system" is one that is built upon an existing infrastructure. Because there is a basic cellular transmitter site infrastructure in place, wireless carriers can deploy Wi-Fi systems for substantially less money than upgrading to 3G.

### **Point-to-Point Radio Systems**

These are radio systems that communicate between fixed locations. Generally, they are used as a replacement for wireline systems. Point-to-Point systems can be established using almost any radio frequency. However, most systems are developed using frequencies in the microwave spectrum of 800 MHz to 30 GHz.

The Federal Communications Commission has designated groups of frequencies throughout the usable radio spectrum for "fixed service" use.

#### **Microwave**

Microwave is a fixed point-to-point service that provides connectivity between major communication nodes. Telephone and

long distance companies use the service to provide backup for their cabled (wireline) infrastructure and to reach remote locations. Public Safety agencies use microwave to connect 2-way radio transmitter sites to a central location. Businesses also use these systems for the same purposes.

The frequencies allocated for this service are in the 6 and 11 gigahertz ranges. All users are required to obtain a license for use from the FCC (Federal Communications Commission). Frequency licenses are granted on a non-interfering (with other users) basis. Systems can be designed to operate over distances of about 20 miles between any two points. Other frequencies available in the 900 megahertz, 2 and 23 gigahertz range do not require a license. Because these frequencies do not require a license it is up to users to resolve any interference problems without support from the FCC. As with all microwave, the FCC permits only point-to-point uses. Many DOTs are using spread spectrum systems in the 900 MHz and 2 GHz bands.

### ***Spread Spectrum Radio***

Spread spectrum radio is a technology that "spreads" the transmission over a group of radio frequencies. Two techniques are used. The most common is called "frequency hopping" The radio uses one frequency at a time but at pre-determined intervals jumps to another frequency to help provide a "secure" transmission. The second system actually spreads the transmission over several frequencies at the same time. The method helps to prevent interference from other users. These systems are generally used for distances of less than 2 air miles.

Spread spectrum technology for telecommunication systems was originally developed during World War II<sup>6</sup>. Most notably, the technology has inherent features that provide for a very secure means of communicating even in "unfriendly" RF environments. Despite widespread military use, the technology was not made available for commercial use until 1995 when the U.S. Federal Communications Commission (FCC) issued ruling 15.247 permitting the use of spread spectrum technology for commercial applications in the 900, 2400 and 5800 MHz frequency bands.

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<sup>6</sup> Hedy Lamarr, once considered as the most beautiful woman in Hollywood was a co-inventor of the frequency hopping technique for spread spectrum radio. Hedy and her co-inventor George Antiel, a musician) created the technique as part of a guidance system for torpedoes during WWII.

The basic concept of spread spectrum refers to an RF modulation technique that spreads the transmit signal over a wide spectrum (or bandwidth). Contrary to conventional narrow band modulation techniques that are evaluated by their ability to concentrate a signal in a narrow bandwidth, spread spectrum modulation techniques use a much wider bandwidth.

A typical spread spectrum transmitter will integrate the actual signal with a sequence of bits that codes (referred to as pseudo-random code) and spreads the signal over a bandwidth usually from 20 to 30 MHz.

The spreading is actually accomplished using one of two different methods - direct sequence or frequency hopping. Direct sequence spread spectrum uses the pseudo-random code, integrated with the signal, to generate a binary signal that can be duplicated and synchronized at both the transmitter and receiver. The resulting signal evenly distributes the power over a wider frequency spectrum. Direct sequence spread spectrum is usually used to transmit higher speed digital data for T1, or high-speed wireless data networks.

The second popular type of spread spectrum modulation is frequency hopping. This technique is similar to a conventional narrow band carrier with a narrow transmit bandwidth. The difference from the former is a random hopping sequence within the total channel bandwidth. Spread spectrum modulation techniques have a principal advantage over other radio techniques: the transmitted signal is diluted over a wide bandwidth, which minimizes the amount of power present at any given frequency. The net result is a signal that is below the noise floor of conventional narrow band receivers, but is still within the minimum receiver threshold for a spread spectrum receiver. While the receiver is able to detect very low signal powers, the receivers are also designed to reject unwanted carriers, including signals which are considerably higher in power than the desired spread spectrum signal. Each transmitter and receiver is programmed with unique spreading sequences which are used to de-spread the desired signal and spread the undesired signal, effectively canceling the noise.

## Two-way Radio

Two-way radio systems have been in common use since the 1930's. Originally used by the military, various federal agencies, police, fire and ambulance, and local governments, its use has expanded to include almost every aspect of our social infrastructure, including individual citizens using "Ham Radio" systems. Most commonly used frequencies are in the 30, 150, 450 - 512 and 800 megahertz ranges. Coverage is usually expressed in terms of "air mile radius". Systems in the 150 MHz band can typically cover 15 to 30 air miles in radius from a single transmitter location.

Coverage for all radio systems is expressed in terms of "air miles", because radio waves tend to travel in straight lines.

The FCC has been encouraging the use of regional systems that incorporate all state, county and municipal agencies into a single group of radio channels. The available radio spectrum is being re-allocated to accommodate these systems. At the same time, the FCC is restricting transmitter power outputs and antenna height. Many of the early (1970s & 1980s) system designs sought to use maximum transmitter power outputs of more than 100 watts and very high antenna sites. This usually created interference problems with other users on the same radio frequency.

Today, many Departments of Transportation are joining forces with public safety agencies to create a common radio communication system. This allows for easier coordination of resources to resolve traffic incidents.

## Wi-Fi

Wi-Fi Systems is a term that is applied to a generic point-to-multipoint data communication service. The Federal Communications Commission (FCC) has set aside radio spectrum in the 900 MHz, 2GHz and 5 GHz frequency range. The frequencies are available for use by the general population and commercial enterprise. No licenses are required, and the only restrictions are that systems not exceed power or antenna height requirements. Complete rules governing the use of Wi-Fi systems are listed under FCC rules: Title 47 CFR Part 15.

In its 1989 revision of the Part 15 rules, the Commission established new general emission limits in order to create more flexible opportunities for the development of new unlicensed

transmitting devices. These more general rules allow the operation of unlicensed devices for any application provided that the device complies with specified emission limits. This revision also established new "restricted bands" to protect certain sensitive radio operations, such as satellite downlink bands, and federal government operations, and prohibited transmissions by unlicensed devices in those bands. The rules have been further modified to add spectrum and encourage the growth of Wi-Fi systems. The FCC Spectrum Policy Task Force issued a report from its Unlicensed Devices and Experimental Licenses Working Group in November 2002.

The full report is available at the following web site: <http://www.fcc.gov/sptf/files/E&UWGFinalReport.doc>. The report takes note of the significant growth of Wireless ISPs and the increasing use of this service to provide broadband internet access in rural areas. The report makes recommendations for consideration of increasing authorized power output in rural areas as well as making additional spectrum available.

Table 2-6: Frequencies for Unlicensed Radio Systems

Bands Available for Unlicensed Spectrum		
Band	Authorized	Frequencies (MHz)
ISM/ Spread Spectrum	1985	902-928, 2400-2483.5 & 5725-5850
Unlicensed PCS	1993	1910-1930 & 2390-2400
Millimeterwave	1995	59,000-64,000
U-NII	1998	5150-5350 & 5725-5825
Millimeterwave (Expansion)	2001	57,000-59,000

Many traffic signal and freeway management systems are currently using spread spectrum radio systems in the ISM bands. The following table provides some estimates of the number of devices used in the unlicensed spectrum - this information was provided by the Consumer Electronics Association (CEA) to the FCC in September, 2002:

Table 2-7: CEA Estimates of the Number of Low Power Radio Devices

CEA Estimates of Low Power Device Usage			
Product	Penetration	Number per Household	Total Installed Base (millions)
Cordless Phones	81.0%	1.50	130.01
Garage Door Openers	40.8%	1.29	56.26
Wireless Routers	NA	NA	1.14
Remote Control Toys	19.5%	2.61	54.47
Toy Walkie-talkies	15.1%	1.85	29.81
Baby Monitors	10.5%	1.38	15.52
Home Security Systems	18.0%	1.10	21.21
Keyless Entry Systems for Cars	26.5%	1.40	39.71

The IEEE is working on developing and improving a number of wireless transmission standards for Wi-Fi. The most widely used are the 802.11 series. The reader should check the IEEE web site for the latest standards being issued, and consult with equipment vendors and systems engineers to determine which are applicable for their specific requirements. A continuing theme throughout this handbook is that no single system or standard is a solution for all problems.

## **WLAN**

A wireless LAN lets users roam around a building with a computer (equipped with a wireless LAN card) and stay connected to their network without being connected to a wire. The standard for WLANs put out by the Institute of Electrical and Electronics Engineers (IEEE) called "802.11B" or "Wi-Fi" is making WLAN use faster and easier. A WLAN can reach 150 m radius indoors and 300 m outdoors. WLANs require a wired access point that connects all the wireless devices into the wired network.

802.11A, is supposed to transfer data at even higher speeds of up to 54 Mbps in the 5 GHz band.

802.11B transfers data at speeds of up to 11 Mbps in the 2.4 GHz radio band (a license is not required for this band).

802.11G, offers up to 54 Mbps data rates, functions in the 2.4 GHz range, and is compatible with 802.11B. Equipment using the 802.11B standard will work in an 802.11G system.

WLANs are used on college campuses, in office buildings, and homes, allowing multiple users access to one Internet connection. WLAN hubs are also deployed in many airports, and popular commercial establishments such as coffee shops and restaurants. These hubs allow laptop users to connect to the Internet.

A major drawback of WLANs is the lack of security. Research has found flaws in the 802.11 systems. Transmissions can be intercepted making it easy for hackers to interfere with communications. Another problem is overcrowding of the bandwidth. Too many people or businesses using WLANs in the same area, can overcrowd the frequency band. Problems with signal interference can occur and there are fears that the airwaves may become overloaded. Despite these drawbacks, WLANs are a successful and popular technology, which are widespread and being incorporated into most new laptop and personal digital assistant (PDA) computers.

Note: two good sources of information on these types of systems are the Wi-Max organization at <http://www.wimaxforum.com>, and the Wi-Fi organization at <http://www.wi-fi.org>.

## **Wi-MAX**

Based on the IEEE 802.16 series of standards, Wi-MAX is a wide area wireless system with a coverage area stated in terms of

miles rather than feet. The standard was developed to provide for fixed point-to-multipoint coverage with broadband capabilities. For the latest information on the evolving 802.16 standards, check the IEEE web site: <http://grouper.ieee.org/groups/802/16/index.html>

“802.16 is a group of broadband wireless communications standards for metropolitan area networks (MANs) developed by a working group of the Institute of Electrical and Electronics Engineers (IEEE). The original 802.16 standard, published in December 2001, specified fixed point-to-multipoint broadband wireless systems operating in the 10-66 GHz licensed spectrum. An amendment, 802.16a, approved in January 2003, specified non-line-of-sight extensions in the 2-11 GHz spectrum, delivering up to 70 Mbps at distances up to 31 miles. Officially called the WirelessMAN™ specification, 802.16 standards are expected to enable multimedia applications with wireless connection and, with a range of up to 30 miles, provide a viable last mile technology.”<sup>7</sup>

Chapter seven provides a presentation of how the City of Irving Texas is using an 802.16 based system to reduce the overall cost of deploying a new centrally controlled traffic signal system.

### **Free Space Optics (FSO)**

(FSO) Free Space Optics is another wireless system being used today. Instead of using radio frequencies, this system uses a LASER transmitted through the air between two points. The LASER can be used for transmission of broadcast quality video. These systems are limited to an effective range of 3 air miles.

### ***Transmission Signaling Interfaces***

All Freeway Management and Traffic Signal systems rely on a communications process to support their operations. Some use a very simple process with “low speed” data transmitted between a single device and a central computer. The basic transmission of the data, accomplished by transmitting bit by bit over a single path (wire or some other transmission medium) between two communication points, is called “serial”. Other systems use a more complex process with multiple bits transmitted simultaneously over multiple paths between two points, or “parallel”. This section looks at the transmission of voice, data, and video and the various types of physical and logical interfaces used for this purpose.

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<sup>7</sup> IEEE 802.16 web site – description of 802.16 service.

### **DATA & VOICE SIGNALING - BASICS**

Carrier (the telephone company) operated communication networks are primarily designed to facilitate the transmission of voice in either analog or digital formats. During the 1990s, many new telecommunication companies were formed dedicated to providing efficient transmission of data. Some of these companies attempted to build their own communications networks, but ran out of financial resources because of the enormous expense for construction, operation and maintenance. Many of their customers wanted to use one network for both voice and data, and only wanted to deal with one communications provider.

Voice signaling interfaces are very simple. They are either 2 or 4 wire, and pass frequencies in the 0 to 4,000 Hz range. This same frequency range is used by modems to interface with the telephone networks. The modem converts the output of a computer to voice frequencies. Traffic signal controllers have used modems to communicate over voice based telephone networks for many years. They use a combination of dial-up and private line services. The digital output of the traffic signal field controller is converted to an analog format by the modem.

In the early 1960s, the Telephone Companies (Carriers) recognized that customers would want to transmit data via the existing networks. The Carriers began to add equipment and processes to their networks that would support the need. They started with the use of private fixed point-to-point services and then added switched data communication services via the PSTN (Public Switched Telephone Network).

Data is information content.  
Analog and digital are formats  
for transmitting information.

Data can be transmitted in either an analog or digital format and, transmitted via 2 or 4 wire circuit. In an analog system, most data is transmitted using a dial-up modem via the PSTN. Private line systems (leased from a Carrier) normally use a 4 wire communication circuit. Some carriers do offer 2 wire private line services. Private line service is provided as either analog, or digital. Private-line circuits are always point-to-point and never run through a switch.

Analog Private-line circuits are normally referred to as 3002 or 3004. The 3000 designation refers to available bandwidth. The 2

and 4 refer to the number of wires in the circuit. Digital Private-line services are: DDS (Digital Data Service - 56 Kbps or less); T-1/T-3; DS-1/DS-3; Fractional T-1; SONET; Ethernet (a recent addition to the types of available services).

Very often, the terms T-1/T-3 and DS-1/DS-3 are used interchangeably. However, there is a fundamental difference between the service offerings. T-1/T-3 circuits are formatted by the Carrier into voice channel equivalents. All multiplexing equipment with maintenance and operation is provided by the Carrier. Pricing for these services is usually regulated by state public utility commissions (called a tariff). DS-1/DS-3 circuits are provided without format. The end-user is responsible for supplying the multiplexing equipment to format the circuit. Maintenance and operation is the responsibility of the end-user. The Carrier is only responsible for making certain that the circuit is always available for use. Fees for DS-1/DS-3 circuits are typically not regulated, and are based on market competition.

**ELECTRO-MECHANICAL SIGNAL INTERFACES**

Electro-mechanical interfaces for data transmission and signaling normally fall under the following standards: RS-232; RS-422; RS-423; RS-449; RS-485. Each of these standards provides for the connector wiring diagrams and electrical signaling values for communications purposes. These standards were developed by the EIA (Electronic Industries Alliance) and the TIA

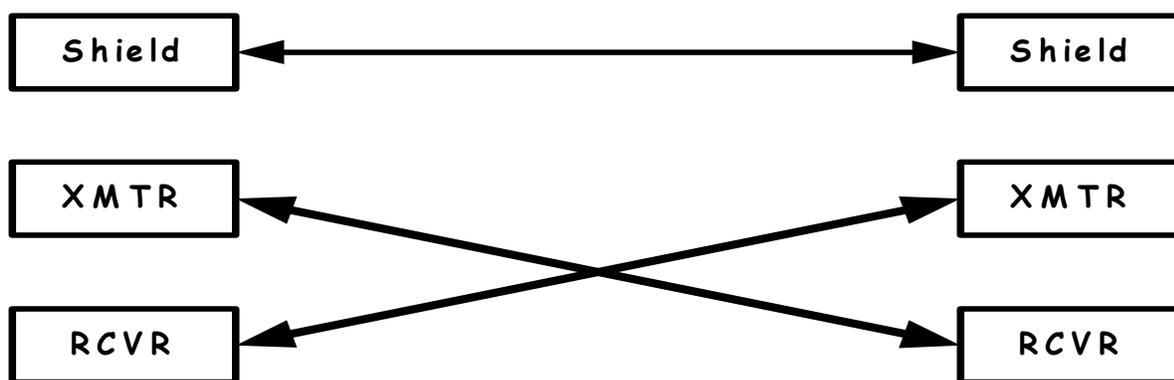


Figure 2-6: Diagram of Basic Connector Wiring

(Telecommunications Industry Association). More information can be found at the EIA web site - <http://www.eia.org>, and the TIA web site - <http://www.tiaonline.org>. Notice in the following diagram that all 25 pins of a 25 pin connector have an assigned function. This

is due to the fact that the connector standard was developed prior to the development of software that would control most of the functions. Most personal computers (PC) use a 9 pin variation. There are also variations that use 3 or 5 pins. Please check the equipment manufacturer's recommendations. Many communication system problems occur because the connectors are not properly wired. Following is a listing of some of the connector standards that use a d-sub miniature type connector:

- RS 449 (EIA-449)
- RS 530 (EIA 530)
- RS-232D
- RS232
- RS366
- RS422 37pin
- RS422 9pin
- Serial (PC25)
- Serial (PC9)

If you are encountering a communication problem - check the connectors and their wiring pattern. Remember the basic elements of all communications systems: transmitter; receiver; medium. If the transmitter wire is connected to the same numbered pin at both ends, the receivers can't hear.

All of the above are based on a similar standard and there is latitude for manufacturers to use some of the leads in these connectors for a special function.

If your system is connected via a carrier network the transmitter-receiver cross over is done in the network. In a private network the crossover is accounted for in the basic network design. Double check to make certain that the design accounts for transmitter to receiver connections.

### **VIDEO TRANSMISSION**

During the past 15 years, traffic and freeway management agencies have been integrating the use of CCTV cameras into their operational programs. The heavy use of this technology has created a need to deploy very high bandwidth communication networks. The transmission of video is not very different from voice or data. Video is transmitted in either an analog or digital format. Video transmitted in an analog format must travel over

coaxial cable or fiber optic cable. The bandwidth requirements cannot be easily handled by twisted pair configurations.

Video can be transmitted in a digital format via twisted pair. It can be transmitted in a broadband arrangement as full quality and full motion, or as a compressed signal offering lower image or motion qualities. Via twisted pair, video is either transmitted in a compressed format, or sent frame-by-frame. The frame-by-frame process is usually called "slow-scan video".

Full color broadcast analog video requires a substantial amount of bandwidth that far exceeds the capacity of the typical twisted pair analog voice communication circuit of 4 KHz. Early commercial television networks were connected via Coaxial cable systems provided by AT&T Long Distance. These networks were very costly to operate and maintain, and had a limited capability.

Transmission of analog video requires large amounts of bandwidth, and power. The most common use of analog video (outside of commercial broadcast TV) is for closed circuit surveillance systems. The cameras used in these systems use less bandwidth than traditional broadcast quality cameras, and are only required to send a signal for several hundred feet. For transmission distances (of analog video) of more than 500 feet, the system designer must resort to the use of triaxial cable, or fiber optics. Depending upon other requirements, the system designer can convert the video to another signal format. The video can be converted to a radio (or light) frequency, digitized, or compressed.

Cable companies have traditionally converted television broadcast signals to a radio frequency. With this technique, they can provide from 8 to 40 analog channels in a cable system using coaxial cable (more about multiplexing later in this chapter). Cable company operators wanting to provide hundreds of program channels will convert the video to a radio frequency, and then digitize. The cable company is able to take advantage of using both fiber and coaxial cable. These are called HFC (hybrid fiber coax) systems. Fiber is used to get the signal from the cable company main broadcast center to a group of houses. The existing coaxial cable is used to supply the signal to individual houses.

Early freeway management systems used analog video converted to RF and transmitted over coaxial cable. Later systems used

fiber optic cable with either RF signal conversion, or frequency division multiplexing (see Multiplexing in this chapter).

With the introduction high bandwidth microprocessors and efficient video compression algorithms, there has been a shift from analog video transmission systems to digital systems. New processes such as Video over IP (Internet Protocol) and streaming video allow for the broadcast of video incident images to many user agencies via low (relatively) cost communication networks. Before looking at the systems, let's take a look at the various types of video compression schemes.

### **VIDEO COMPRESSION**

**Compressed Video** - Since the mid-1990s, FMS system designers have turned to digital compression of video to maximize resources, and reduce overall communication systems costs. The digital compression of video allows system operators to move video between operation centers using standard communication networks technologies.

Video compression systems can be divided into two categories - hardware compression and software compression. All video compression systems use a Codec. The term Codec is an abbreviation for coder/decoder. A codec can be either a software application or a piece of hardware that processes video through complex algorithms, which compress the file and then decompress it for playback. Unlike other kinds of file-compression packages that require you to compress/decompress a file before viewing, video codecs decompress the video on the fly, allowing immediate viewing. This discussion will focus on hardware compression technologies.

### **VIDEO CODECS**

Codecs work in two ways - using temporal and spatial compression. Both schemes generally work with "lossy" compression, which means information that is redundant or unnoticeable to the viewer gets discarded (and hence is not retrievable).

Temporal compression is a method of compression which looks for information that is not necessary for continuity to the human eye. It looks at the video information on a frame-by-frame basis for changes between frames. For example, if you're working with video of a section of freeway, there's a lot of redundant

information in the image. The background rarely changes and most of the motion involved is from vehicles passing through the scene. The compression algorithm compares the first frame (known as a key frame) with the next (called a delta frame) to find anything that changes. After the key frame, it only keeps the information that does change, thus deleting a large portion of image. It does this for each frame. If there is a scene change, it tags the first frame of the new scene as the next key frame and continues comparing the following frames with this new key frame. As the number of key frames increases, so does the amount of motion delay. This will happen if an operator is panning a camera from left to right.

Spatial compression uses a different method to delete information that is common to the entire file or an entire sequence within the file. It also looks for redundant information, but instead of specifying each pixel in an area, it defines that area using coordinates.

Both of these compression methods reduce the overall transmission bandwidth requirements. If this is not sufficient, one can make a larger reduction by reducing the frame rate (that is, how many frames of video go by in a given second). Depending on the degree of changes one makes in each of these areas, the final output can vary greatly in quality.

Hardware codecs are an efficient way to compress and decompress video files. Hardware codecs are expensive, but deliver high-quality results. Using a hardware-compression device will deliver high-quality source video, but requires viewers to have the same decompression device in order to watch it. Hardware codecs are used often in video conferencing, where the equipment of the audience and the broadcaster are configured in the same way. A number of standards have been developed for video compression - MPEG, JPEG, and video conferencing.

### **VIDEO COMPRESSION**

MPEG stands for the Moving Picture Experts Group. MPEG is an ISO/IEC working group, established in 1988 to develop standards for digital audio and video formats. There are five MPEG standards being used or in development. Each compression standard was designed with a specific application and bit rate in

mind, although MPEG compression scales well with increased bit rates.

Following is a list of video compression standards:

- MPEG-1 - designed for transmission rates of up to 1.5 Mbit/sec - is a standard for the compression of moving pictures and audio. This was based on CD-ROM video applications, and is a popular standard for video on the Internet, transmitted as .mpg files. In addition, level 3 of MPEG-1 is the most popular standard for digital compression of audio--known as MP3. This standard is available in most of the video codec units supplied for FMS and traffic management systems.
- MPEG-2 - designed for transmission rates between 1.5 and 15 Mbit/sec - is a standard on which Digital Television set top boxes and DVD compression is based. It is based on MPEG-1, but designed for the compression and transmission of digital broadcast television. The most significant enhancement from MPEG-1 is its ability to efficiently compress interlaced video. MPEG-2 scales well to HDTV resolution and bit rates, obviating the need for an MPEG-3. This standard is also provided in many of the video codecs supplied for FMS.
- MPEG-4 - a standard for multimedia and Web compression - MPEG-4 is an object-based compression, similar in nature to the Virtual Reality Modeling Language (VRML). Individual objects within a scene are tracked separately and compressed together to create an MPEG4 file. The files are sent as data packages and assembled at the viewer end. The result is a high quality motion picture. The more image data that is sent the greater the lag-time (or latency) before the video begins to play. Currently, this compression standard is not suited for real-time traffic observation systems that require pan-tilt-zoom capability. The "forward and store" scheme used in this system inhibits eye-hand coordination. However, this is an evolving standard. The latency factor between image capture and image viewing is being reduced. The latency factor can be reduced to a minimum if the image and motion quality do not have to meet commercial video production standards. Most surveillance systems can

function without this quality and can use pan-tilt-zoom functions.

- MPEG-7 - this standard, currently under development, is also called the Multimedia Content Description Interface. When released, it is hoped that this standard will provide a framework for multimedia content that will include information on content manipulation, filtering and personalization, as well as the integrity and security of the content. Contrary to the previous MPEG standards, which described actual content, MPEG-7 will represent information about the content.
- MPEG-21 - work on this standard, also called the Multimedia Framework, has just begun. MPEG-21 will attempt to describe the elements needed to build an infrastructure for the delivery and consumption of multimedia content, and how they will relate to each other.
- JPEG - stands for Joint Photographic Experts Group. It is also an ISO/IEC working group, but works to build standards for continuous tone image coding. JPEG is a lossy compression technique used for full-color or gray-scale images, by exploiting the fact that the human eye will not notice small color changes. Motion JPEG is a standard that is used for compression of images transmitted from CCTV cameras. It provides compressed motion in the same manner as MPEG, but is based on the JPEG standard.
- H.261 - is an ITU standard designed for two-way communication over ISDN lines (video conferencing) and supports data rates which are multiples of 64Kbit/s.
- H.263 - is based on H.261 with enhancements that improve video quality over modems.

### **STREAMING VIDEO**

Streaming video relies on the video compression standards listed above, and primarily on the MPEG-4 video CODEC. Streaming video is not a transmission technique. Streaming video is a protocol for the efficient movement of entertainment (or news broadcasts) to individual users via the internet.

A streaming video system requires the use of a video server to store content that is downloaded to the end user via a

communications network. The first few seconds of the program are forwarded to the viewer, with the additional information downloaded as the first images are being viewed. This provides the end user with a continuous program, or "stream" of information - hence, the term streaming video.

Streaming video can be used to provide travelers with delayed (by five to ten seconds) images from traffic intersections, or live reports from transportation management centers. This technique can also be used to connect public safety agencies to direct video feeds from traffic incident locations via the internet, or an intranet. The video codecs used to support streaming are software based, not hardware based. Several common video codec applications are in use throughout the world. Your desktop PC probably has two (or more) of these applications. Microsoft's "Windows Media Player" and Apple's "Quicktime" are two of the most popular. Real Networks has a very popular media player. These media players are designed to play multiple types of media files. Almost all PC manufacturers include media player software as part of their package. A discussion of Video over IP and Ethernet will be presented in chapters 7 and 9.

### ***Basic Telephone Service***

This section will look at the various aspects of basic voice and analog telephone services including dial-up and special service voice and data circuits. The primary reason for existence of traditional telephone (including cellular) carriers is to provide person-to-person voice communications. This fact will continue to remain true as long as our present system of telecommunications endures. Certainly, the methods and processes used to provide that communication have gone through tremendous change in the past 25 years, however, we can count on the basic process to continue to be used into the foreseeable future. Voice over IP (VoIP) is beginning to emerge as a replacement for traditional switched analog voice services. During the writing of this handbook, most of the major communication carriers announced that construction investments would be shifted to "Internet Telephony" systems (the carrier term for VoIP).

P.O.T.S., or dial-up, is the term for the primary telecommunication service that we all use today. The service is always analog (to the end user), is always switched, and is always 2-wire. The call process involves a protocol that keeps telephone sets in an "idle" status until a user wants to make a call. It is important to understand this protocol, because the dial-up

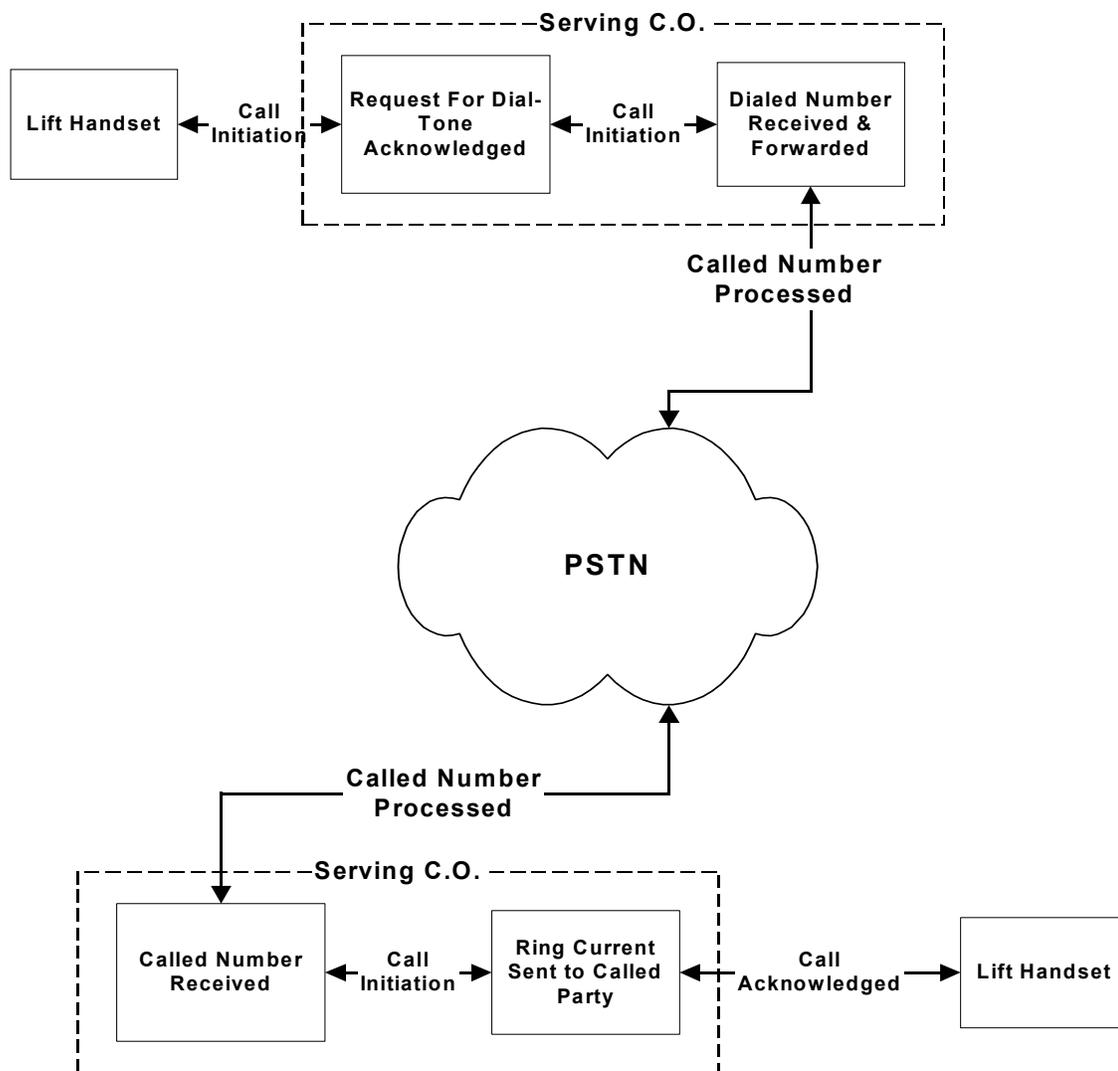


Figure 2-7: Illustration of Basic Telephone Call Process

modems used on a 170, 2070, or NEMA traffic signal controller, or an ITS device such as a Variable Message Sign, must follow the same process. The process involves using a telephone number to identify the other end of the communication circuit. When making a normal voice telephone call this may not seem like a very lengthy process. However, use this protocol in a system that

requires polling with fast turn-around times, and the process won't work. The reader should note that P.O.T.S. is a shared system and that connections between any two points are not guaranteed. Also, a dial-up connection presents the possibility of a security breach that can be used to corrupt the system.

Special service or fixed point-to-point telephone circuits are used to directly connect field devices to a control point, or one traffic control center to another, or in any process where immediate and guaranteed communication is required. These circuits are specifically designed and constructed for the use of a single customer. They are never routed through a switch. Customers pay an initial fee for installation of the service (this is called a non-recurring charge), and a monthly (recurring charge) use, distance, and maintenance fee.

Several types of special service circuits are available. The most common are 2 and 4 wire - generally referred to as 3002 and 3004. Others provide for special signaling such as E&M (Ear & Mouth), FXO/FXS (Foreign Exchange Office/Station), ARD (Automatic Ring-down).

Traffic Signal, Freeway Management and ITS systems requiring the use of analog special service generally use 3002 and/or 3004 telephone circuits. In circumstances where a direct voice link is required between a TOC and a field office, or Public Safety Dispatch Point, an ARD circuit can be used.

### ***Multiplexing***

Multiplexing is the process of combining two or more information channels into a single transmission medium. There are a number of different standards that can be applied to the process. Many standards are common and are applied by manufacturers and carriers on a world-wide basis. This assures that a multiplexing protocol used in Japan can also be used in Brazil, Kansas, New York, or Tulsa.

This section will focus on two of the most common types of multiplexing - TDM (time division multiplexing), and PDM (packet division multiplexing). Additionally, this section will describe the primary multiplexing protocol in use in North America: T-1.

T-1 was the basic type of multiplexing scheme selected by Bell Labs for high capacity communication links. It is so pervasive in the world wide telephone network, that replacement protocols are

just being introduced. A second type of multiplexing - Packet - will also be discussed, because this is now being used to support the conversion of the telephone networks from analog to digital. Packet multiplexing is used to support IP and Ethernet.

### **TIME DIVISION MULTIPLEXING**

Time Division Multiplexing is a method of putting multiple data streams in a single communication channel, by separating it into many segments. Each segment is of a very short duration and always occurs at the same point in time within the main signal. In TDM, there is a direct relationship between the connections (ports) on the multiplexing hardware and the multiplexing protocol. The data for port number one of the multiplexer always falls within the same time period (time frame #1) - because the originating end multiplexer always places the data for each communication port at the same place.

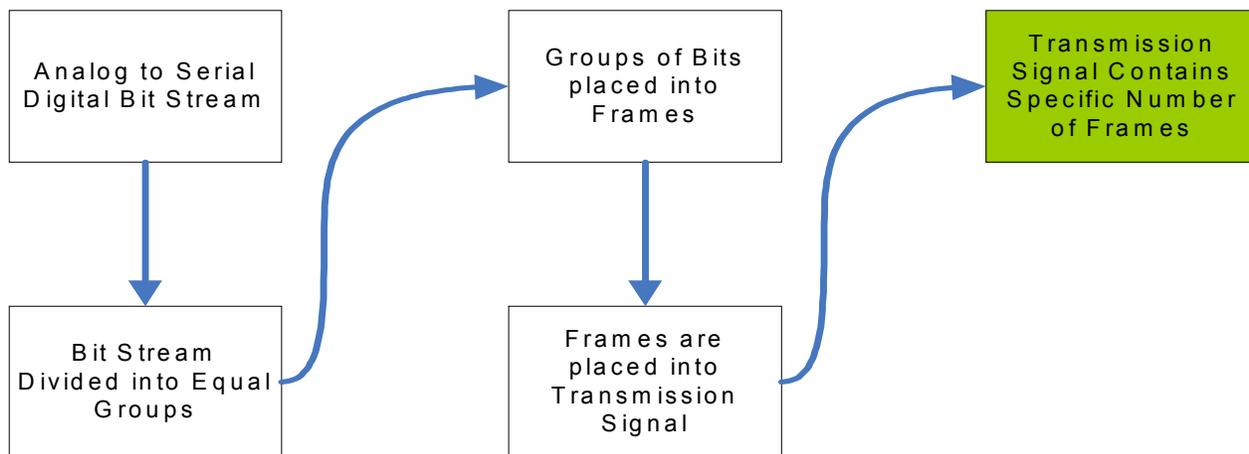


Figure 2-8: TDM Process Flow Chart

In time, the receiving end multiplexer is able to funnel data to the correct port. There is no data added to the bit stream to identify the data. With TDM, the general rule is "time slot (frame) one = communication port one". A T-1 multiplexer has 24 ports (one for each time slot). Therefore, time slot one = port one; time slot two = port two; etc. In a TDM transmission, each time slot is always present even if only one time slot actually has data. The bandwidth is always used.

### **PACKET DIVISION MULTIPLEXING**

Packet Division Multiplexing (PDM) is a method of breaking the data into multiple groups. Each group is given an identity at the origination so that the multiplexer at the receiving end can assemble groups of data to re-create the information as it was originated. In theory, many information sources can be funneled through a single communication port on both ends. In some packet multiplexing schemes, the size of the packet - the amount of data included - can vary to provide greater throughput of information. With packet multiplexing, the bandwidth used never exceeds the total amount of data in all packets being transmitted. The PDM scheme is important because it is the basis for the new generation of broadband communication processes. Ethernet is an example of a transmission protocol that relies on packet division multiplexing.

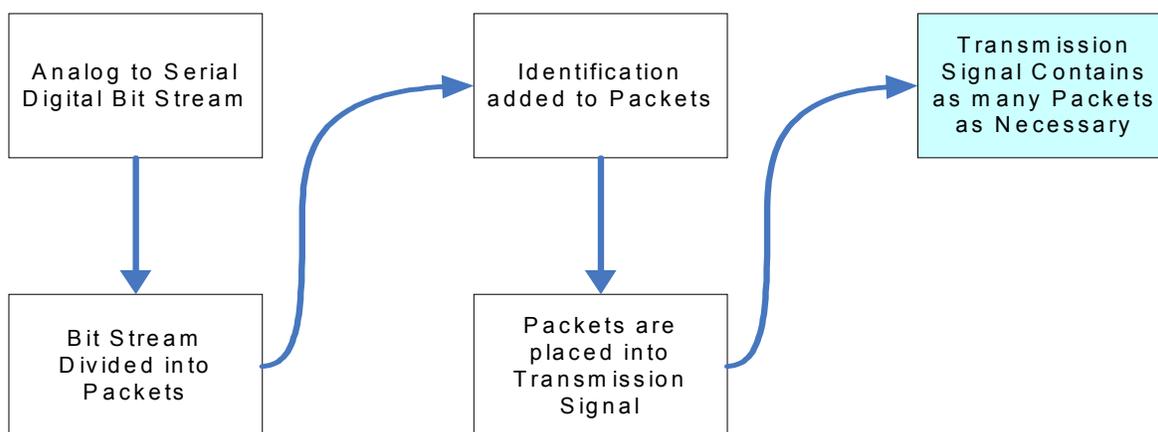


Figure 2-9: Flow Chart - PDM Process

TDM is excellent for supporting voice communications and broadcast quality video, because each service gets the amount of bandwidth required. PDM is excellent for data transmission because it only uses the bandwidth required and requires less hardware. The technologies of TDM and PDM have both been available for many years. TDM was more broadly deployed because it suited the requirement of the telephone companies to provide high quality voice communications. However, with recent advances in communication technology this is changing.

The following table provides a comparison of packet and time division multiplexing:

Table 2-8: Comparison of TDM & PDM

Time Division Multiplexing	Packet Multiplexing
Fixed Bandwidth	Bandwidth Varies Based on Need
Data Placed in Time Frames	Data Placed in Packets
Data for individual channels always in same place	Data for individual channels identified within packets
Ideal for transporting voice & video	Ideal for transporting data

### T-1 COMMUNICATION SYSTEMS

The T-1 based digital network has been under development for more than 40 years. During this time, a hierarchy of transmission levels has been implemented through a wide variety of equipment.

The primary device is a channel bank which can be arranged to carry many different voice, analog data, or digital data signals. Port cards in the channel bank are used to support the type of inputs into the T-1. The most common are voice (POTS), and digital data (DDS).

T-1 Analog to Digital Conversion Process A voice signal is changed from analog to digital within a channel bank by two processes. First, the analog signal is sampled 8000 times each second. Each sample is converted to a discrete voltage level. Second, each voltage is converted to a binary code represented by an 8 bit word. Therefore, 8000 samples times 8 bits is 64,000 bits - a DS-0 communication channel.

A T-1 contains 24 signals (or channels). Each channel is represented by 8 bits, for a total of 192 bits within a single frame. A bit is added for management (synchronization, error checking, etc), and the result is a T-1 frame. Because the sampling rate of each channel is 8000 times per second, a T-1 contains 8000 frames, or 1,544,000 bits. In a TDM system, each channel is recognized within each frame at

exactly the same point in time. That is - for example - channel one never appears in a channel five time slot.

This most common form of multiplexing is used primarily for voice channel services. In fact almost all P.O.T.S. and Special Service communication circuits are multiplexed for transport between Telephone Company Central Offices. Multiplexing (from the telephone company perspective) was developed to obtain efficiency in the use of the available communication cable plant. The telephone companies were able to provide services to more customers without the expensive installation of new communication cables.

There were a number of early attempts at providing an efficient multiplexing protocol; for voice based services, but the carriers had to consider the overall quality of the voice communication. Ultimately, the standard for "toll-grade" voice was set as the transmission of frequencies between 0 Hz and 4000 Hz.

The voice frequencies are digitized for multiplexing via a process that samples the frequencies at 8000 points in one cycle (Hz) in a period of one second. Each digital sample point is produced as an 8 bit character. Therefore, each voice channel uses 64,000 bits per second. Twenty-four voice channels are combined into a single multiplexed communication channel referred to as a T-1.

Because the telephone company needs to monitor and manage the T-1 circuit, it "steals" 8000 bits. A few bits are taken from each sample point, and the caller never notices a reduction in quality.

Most data transmission is accomplished using a dial-up modem. The modem converts the data output of a computer (or other device - traffic signal field controller, dynamic message sign, etc.) to a VF (voice frequency) signal. This signal is treated as if it were a P.O.T.S telephone call. The modem dials a telephone number associated with another modem and a connection is made via the switched voice network. The telephone network does not

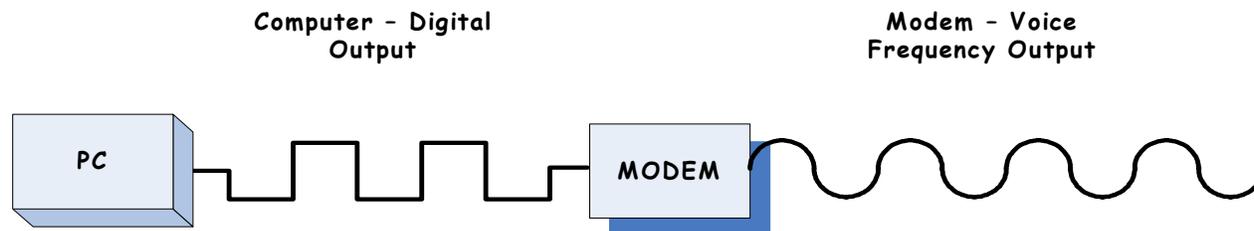


Figure 2-10: Diagram of Computer Digital Output Converted to Analog using a MODEM

treat the call as if it were something special. In terms of T-1 multiplexing, it is treated as if it were a normal telephone call.

Multiplexing does reduce some of the overall quality of the transmission, but does not affect its usability. Unfortunately, each step in the process of getting data transmitted from one location to another can introduce a problem. Therefore, when troubleshooting, it is important to check every segment of the transmission path and all attached equipment - especially if the trouble cannot be found at either of the termination points. T-1 multiplexers are designed to convert analog signals to digital, therefore, data output by a computer must be converted to analog before being multiplexed.

In addition to dial-up data transmission, the telephone companies offer two additional services: 2/4 wire analog circuits (as mentioned above) and DDS (Digital Data Service). The 2/4 wire services are generally used for transmission rates of 9600 bits per second, or slower. DDS (originally offered for data rates from 2400 bits per second and higher) is used primarily for data transmitted at 56,000 bits per second. A DSU/CSU is required to condition a digital output from a computer to a format that will travel over telephone lines. Because the signal is no longer analog, a special interface card must be installed in the T-1 multiplexer (see below).

### ***TRANSPORTING DIGITAL COMMUNICATIONS VIA AN ANALOG NETWORK***

Whenever a digital signal is to be transported via the public telephone network it must be "conditioned" for travel. This is because the basic wiring infrastructure was designed to transport an analog communication signal. Analog communication is accomplished by providing a variable electrical signal which varies as the frequency of a human speaking. Changes in volume and pitch are represented by a smooth flowing electrical current with positive and negative values. A dial-up modem converts your computer output to a series of analog tones which can be transported via the network in the same manner as a voice telephone call.

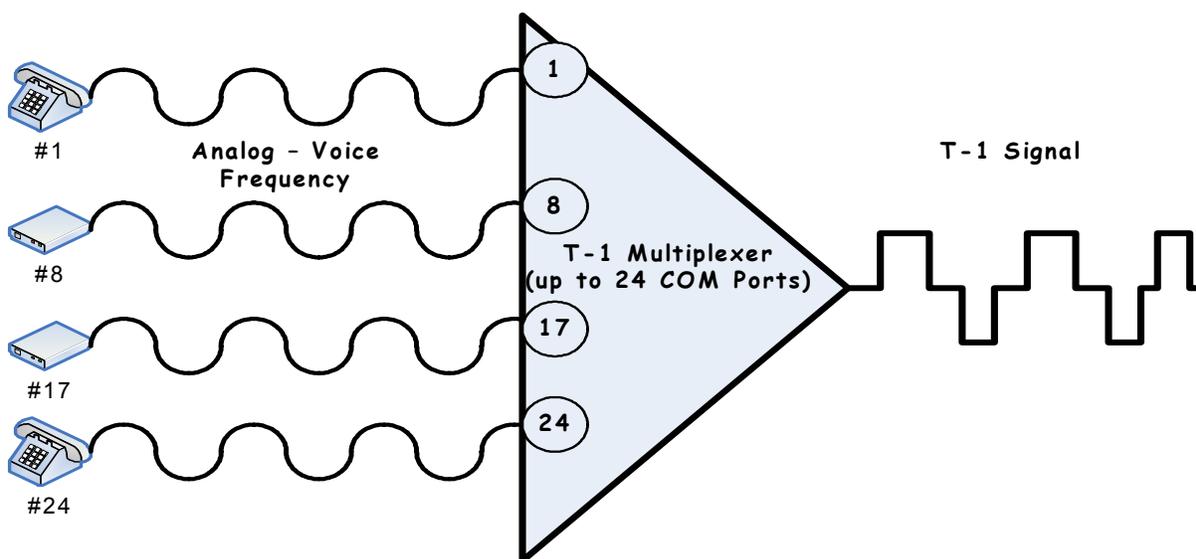


Figure 2-11: Diagram of Analog Inputs to T-1 Mux

Digital signals are different. Data is represented by the presence, or absence of an electrical signal - "on or off". "On" represents 1, "off" represents 0. Electrical signals can have either a positive, or a negative value. The digital output of your computer must be converted to something that is compatible with the existing telephone network. A Data Service Unit (DSU) is used to convert the on/off electrical signal to something that looks like an analog signal. Electrical voltages representing 1 are given alternating positive and negative values. The momentary absence of an electrical signal is assigned a zero value. The DSU is normally used in conjunction with a Channel Service Unit (CSU). The CSU is used as a management tool to make certain that the communications link is performing to specification.

### ***High Capacity Broadband Transmission***

This section describes various high capacity and broadband transmission systems. When the telephone companies first deployed T-1 services, they called this "High Capacity" digital services. Video transmission for broadcast or conferencing used multiple T-1s, or multiple T-3 circuits. With the deregulation of telephone companies and the rise in demand for very high capacity, a new type of service was developed - broadband. As explained, T-1's are formatted by the telephone carriers, but large corporate users, government entities, and even the home user want un-formatted bandwidth to be available for a large number of services.

#### ***Chapter 2***

### **T-1/DS-1 & T-3/DS-3**

T-1 and DS-1 services are fixed point-to-point systems, and dedicated to a single customer. These types of services are most often used to connect Traffic Operations Centers. They may also be used to bring the data and video images from a section of freeway back to a TOC.

DDS are digital voice channel equivalents as described previously and are used as a fixed point-to-point service. T-1 service is channelized to accommodate 24 DDS circuits.

The terms T-1 and DS-1 are often used interchangeably, but each is a distinctly different service provided by telephone companies and carriers. T-1 service is channelized with the carrier providing all multiplexing (channel banks) equipment. The customer is provided with 24 DS-0 interfaces. Each DS-0 interface has a maximum data capacity of 56 kbps (or can accommodate one voice circuit). The customer tells the carrier how to configure the local channel bank (multiplexer).

DS-1 service allows the customer to configure the high speed circuit. The customer provides (and is responsible for maintaining) all local equipment - multiplexer, and DSU/CSU. The carrier provides (and maintains) the transmission path. The customers can channelize the DS-1 to their own specifications as long as the bandwidth required does not exceed 1.536 mbps, and the DS-1 signal meets applicable AT&T, Bellcor (Telcordia) and ANSI standards (these standards are now maintained and available through Telcordia).

Customers may purchase fractional service to save money. In this case, they don't pay for a full T-1 or DS-1. However, the economies for this type of service are only realized for longer distances. The local loop (link) for Fractional T-1 is still charged at the full service rate.

T-3 and DS-3 services are essentially higher bandwidth variants of T-1 and DS-1. The T-3 provides either 28 T-1s or 28 DS-1s, and the DS-3 provides about 44 mbps of contiguous bandwidth. DS-3s are used for Distance Learning and broadcast quality video. They are also used in enterprise networks to connect major office centers.

T-1, DS-1, T-3, and DS-3 have the following characteristics:

- They are all private line services

- They are all provided on a fixed point-to-point basis
- Most users pay for the installation of the service
- Users pay a monthly fee based on distance - very large corporate customers are able to negotiate favorable rates for DS-1 and DS-3 services.
- Users pay a fixed monthly connection and maintenance fee

### **DSL**

DSL (Digital Subscriber Loop) services are DS-1 and Fractional DS-1 variants that use existing P.O.T.S. service telephone lines to provide broadband services at a substantially lower cost. Local DS-1 service starts at \$500 per month. Basic DSL service starts at less than \$50 per month. The primary difference between the services is that DS-1 is setup as a private line system with fixed communication points. DSL service is typically used to provide broadband internet connectivity. Some carriers will create a "quasi" private circuit by linking two customer locations to a common Central Office. The primary advantage of DSL for the homeowner or small business is that it shares the existing telephone lines and it keeps the cost of installation at a much lower level.

DSL service has the following characteristics:

- Typically provided in an ADSL (Asymmetrical DSL) format with the link toward the customer (download) at a higher rate than the link toward the Internet (upload).
- DSL can be provided as SDSL (Symmetrical DSL) when the user needs to have equal bandwidth bi-directionally.
- DSL is a shared service. At peak use times, the available bandwidth is reduced. Many users have complained that they get better service via dial-up.
- DSL offerings start at 384 kbps/128 kbps and can rise to 6.0 mbps/6.0 mbps. (the monthly rates start at \$30 and rise to \$400).
- DSL can only be used when the customer is no more than 18,000 "wire feet" from the Serving Central Office. Best service is available when the customer is less than 12,000 "wire feet" distant.
- DSL is most often used to provide internet access.

## **SONET**

SONET (Synchronous Optical Network) is the first fiber optic based digital transmission protocol/standard. The SONET format allows different types of transmission signal formats to be carried on one line as a uniform payload with network management. A single SONET channel will carry a mixture of basic voice, high and low speed data, video, and Ethernet. All of these signals will be unaffected by the fact that they are being transported as part of a SONET payload.

The SONET standard starts at the optical equivalent of DS-3. This is referred to as an OC-1 (Optical Carrier 1). The optical carrier includes all of the DS-3 data and network management overhead, plus a SONET network management overhead. In North America, the following SONET hierarchy is used: OC-3; OC-12; OC-48; OC-96; OC-192. The number indicates the total of DS-3 channel equivalents in the payload.

Within the payload, SONET network management allows for the shifting of DS-1 circuits. SONET is a point-to-point TDM system, but it has the ability to allow users to set up a multipoint distribution of DS-1s and DS-3s. Therefore, it is possible to direct a DS-1 from one location to many locations within the SONET network. The reader should note that SONET does not provide "bandwidth-on-demand". The routing of portions of the SONET payload to multiple points must be planned and built into a routing table.

A SONET network management program provides the ability to set up multiple routing plans. These plans can be executed as part of a program to restore service in the event of an outage in a portion of the network. Some early adopters of SONET attempted to use this feature to provide for "time-of-day" routing changes. Often users were disappointed with the results.

Normally, SONET is transmitted in groups of DS-3s (OC-3, OC-12, OC-48, etc). In this mode, the SONET payload is segmented within the DS-3. However, it is possible to combine DS-3s into a single channel. An OC-3C (concatenated) is a group of DS-3s combined into a single payload to allow for the total use of the OC-3 as a single data stream.

## **ATM**

Asynchronous Transfer Mode (ATM) is a widely deployed communications backbone technology based on Packet Multiplexing. ATM is a data-link layer protocol that permits the integration of voice and data, and provides quality of service (QoS) capabilities. This standards-based transport medium is widely used for access to a wide-area (WAN) data communications networks. ATM nodes are sometimes called "Edge Devices". These Edge Devices facilitate telecommunications systems to send data, video and voice at high speeds.

ATM uses sophisticated network management features to allow carriers to guarantee quality of service. Sometimes referred to as cell relay, ATM uses short, fixed-length packets called cells for transport. Information is divided among these cells, transmitted and then re-assembled at their final destination. Carriers also offer "**Frame Relay**" service for general data requirements that can accept a variable packet or frame size. Frame Relay systems use variable cell (packets) based on the amount of data to be transmitted. This allows for a more efficient use of a data communications network.

ATM services are offered by most carriers. A number of DOTs are using this type of service - especially in metropolitan areas - to connect CCTV cameras (using compressed video), traffic signal systems, and dynamic message signs to Traffic Operations Centers. The stable packet size is well suited for video transmission. ATM is generally not used by telephone companies for toll grade voice, although its stable packet size was developed to meet requirements for voice service,

In a WAN (wide area network), ATM is most often used as an "edge" transport protocol. ATM devices typically have ports that allow for easy connectivity of legacy systems and the newer communications systems. In a private (or enterprise) network, as

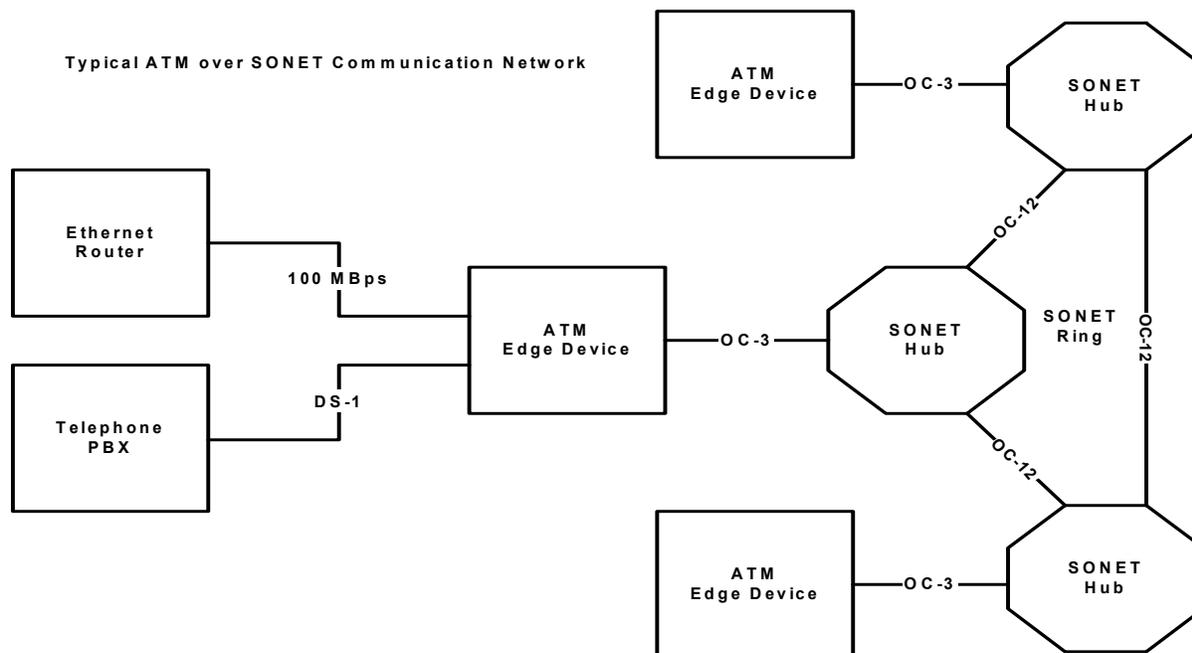


Figure 2-12: Diagram - ATM over SONET Network

shown in figure 2-12, ATM is effectively used for voice and video transport as well as data.

ATM has fixed-length "cells" of 53 bytes in length in contrast to Frame Relay and Ethernet's variable-length "frames." The size of cell that represents a compromise between the large frame requirements of data transmission and the relatively small needs of voice calls. By catering to both forms of network traffic, ATM can be used to handle an end user's entire networking needs, removing the need for separate data and voice networks. The performance, however, can also be compromised, and the network may not be as efficient as dedicated networks for each service. ATM systems usually require DS-1 circuits, but can be made to work in a lower speed environment.

ATM does have a reputation for being difficult to interface to an existing network. However, competent network technicians can usually overcome most difficulties. Missouri DOT is using an ATM based network for its ATMS.

## **FDM**

Frequency Division Multiplexing (FDM) is used when large groups of analog (voice or video) channels are required. The available frequency bandwidth on an individual communications link is simply divided into a number of sub-channels, each carrying a different communication session. A typical voice channel requires at least 3 kHz of bandwidth. If the basic communication link is capable of carrying 3 megahertz of bandwidth, approximately 1000 voice channels could be carried between two points. Frequency Division Multiplexing was used to carry several low speed (less than 2400 bits per second) data channels between two points, but was abandoned in favor of TDM which has an ability to carry more data channels with more capacity over greater distances with fewer engineering problems.

Many older Cable TV systems use FDM to carry multiple channels to customers. This type of system was used by Freeway Management Systems to carry video over coaxial cable. However, most coaxial systems have been replaced by fiber optic systems. Fiber has a greater bandwidth capability than coaxial cable, or twisted pair. The FDM scheme allows for multiple broadband video channels to be carried over a single strand of fiber.

## **WDM – CWDM & DWDM**

Wave Division Multiplexing (WDM) is an optical variant of FDM. A beam of light is divided into segments called lambdas. The Greek letter Lambda ( $\lambda$ ) is used to represent the wave channels. These lambdas are actually different colors of light. Because a wavelength is inversely proportional to frequency WDM is logically equivalent to FDM.

Light transmitted over a fiber is normally a group of frequencies that can be used to create a single communication channel, or multiple channels. The frequency group can be broken into several sub groups. The LASER output of a multiplexer is "tuned" to a specific set of frequencies to form a single communication channel. These channels are then transmitted with other

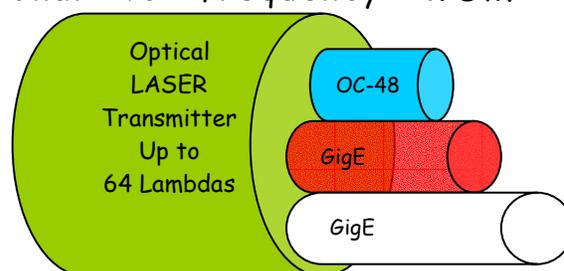


Figure 2-13: DWDM Channels

frequency groups via a wave division multiplexer. Unlike FDM, the information sent via the frequency groups is digital.

Two variables of WDM are used, CWDM (coarse wave division multiplexing) and DWDM (dense wave division multiplexing). DWDM systems can carry as many as 64 channels at 2.5 gigabits per second per channel over a pair of fibers. Each DWDM lambda is equal to one OC-48 (48 DS-3s), or one Gigabit Ethernet channel (future systems will allow 2 GigE channels per lambda).

### **ETHERNET**

Ethernet is a packet based network protocol, invented by the Xerox Corporation, in 1973, to provide connectivity between many computers and one printer. Ethernet was designed to work over a coaxial cable that was daisy-chained (shared) among many devices. The original Xerox design has evolved into an IEEE series of standards (802.XXX) with many variations that include 10Base-T, Fast-Ethernet (100Base-T), and GigE (Gigabit Ethernet).

The Ethernet system consists of three basic elements:

1. The physical medium used to carry Ethernet signals between computers,
2. A set of medium access control (MAC) rules embedded in each Ethernet interface that allows multiple computers to fairly arbitrate access to the shared Ethernet channel,
3. An Ethernet frame that consists of a standardized set of bits used to carry data over the system.

The most current configurations use twisted pair with devices networked in a star configuration. Each device has a direct connection to an Ethernet hub, or router, or switch. This system then provides each user with a connection to a printer, file server, another user computer (peer), or any other device on the network.

Ethernet works by setting up a very broadband connection to allow packets of data to move at high speed through a network. This assures that many users can communicate with devices in a timely manner. The Ethernet is shared, and under normal circumstances, no one user has exclusivity.

Traditional Ethernet networks of the 1990s used a protocol called CSMA/CD (carrier sense multiple access/collision detection). In this arrangement, the transmitting device looks at the network to determine if other devices are transmitting. The device "senses" the presence of a carrier. If no carrier is present, it proceeds with the transmission. The CSMA protocol is not perfect, hence the need for Collision Detection.

Note: When Ethernet is used to connect only two devices via a common communication channel CSMA is not used. This is because the two devices can coordinate communication so that one does not interfere with the other. This type of system can be used to transmit broadband video over long distances to take advantage of the bandwidth and economics of using Ethernet.

Freeway Management Systems using incident detection CCTV cameras may use this type of arrangement to facilitate Video over IP. This allows video from the field to be transported to the TCC for further distribution.

Occasionally, more than one device transmits simultaneously and creates a "collision". If the originating device does not receive an acknowledgement from the receiving device, it simply retransmits the information (not as part of the Ethernet protocol, but part of an application protocol). In an office environment, where users are trying to access a printer, or a file-server, this is normally not a problem. Most users are not aware of any significant delays. In this arrangement all devices are wired to the network through a "hub". The hub provides a central meeting point for all devices and users on the network, but has very little intelligence for managing activity on the network. In fact all communications on the network are sent to all devices on the network.

Each Ethernet-equipped computer, also known as a station, operates independently of all other stations on the network: there is no central controller. All stations attached to an Ethernet are connected to a shared signaling system, also called the medium. Ethernet signals are transmitted serially, one bit at a time, over the shared signal channel to every attached station. To send data, a station first listens to the channel, and when the channel is idle the station transmits its data in the form of an Ethernet frame, or packet.

After each frame transmission, all stations on the network must contend equally for the next frame transmission opportunity. This ensures that access to the network channel is fair, and that no single station can lock out the other stations. Access to the shared channel is determined by the medium access control (MAC) mechanism embedded in the Ethernet interface located in each station. The medium access control mechanism is based on a system called Carrier Sense Multiple Access with Collision Detection (CSMA/CD).

Modern networks still use CSMA/CD, but are managed by routers and switches. Routers are not actually Ethernet devices - they operate at layer 3 of the OSI protocol stack. The router is able to manage the flow of data between devices and has the intelligence to route information between specific devices. A request to view a file from an individual computer is routed to the specific file server storing the information. None of the other computers on the network see the data request. However, the router will simply route the request, it won't manage several users trying to access the same file server simultaneously.

Management of users in a network is accomplished by a Switch. The Switch has the intelligence and computing "horsepower" to manage users and allocate bandwidth. A Switch can be set to block some users from the system based on various factors, such as priority and time-of-day requirements.

Following is a description of the most commonly used Ethernet protocols:

- 10Base-T was (as this handbook was being developed, 100Base-T was most common, with GigE catching on fast). This is typically run over twisted pair copper and is adequate for most small office data communication requirements.
- Fast Ethernet or 100Base-T can be run over the same twisted pair infrastructure. The 10Base-T protocol allows for a maximum throughput of 10 megabits of data and the 100Base-T allows 100 megabits of data throughput. However, various factors keep these systems from exceeding more than 70 percent of stated capacity. Chief among these problems is overloading of the number of users and the condition of the wired infrastructure.

- 100Base-TX is a two twisted copper pair (4 wire) transmission standard. Identical to 10Base-T, it is also referred to as "fast Ethernet", and provides 100 Mbps throughput.
- 100Base-FX is a fiber optic transmission standard for Local Area Networks.
- GigE (gigabit Ethernet) is a very high bandwidth service (One gigabit per second) and is being deployed in many large office networks. In addition to allowing more users onto the network, GigE is capable of facilitating video between desktops, and desktop to desktop conferencing between users. GigE is also the preferred communications protocol for linking one office building to another. Metropolitan Networks (MAN) using DWDM facilitate a "real-time" GigE link. IT departments can create a storage area network (SAN) to link together many databases. Large financial institutions connect locations in a region to facilitate electronic commerce using DWDM and GigE. Many telephone carriers are beginning to add GigE services to their network offerings.
- 10GigE protocols and standards are being developed by IEEE under 802.3ae and 802.3AK. The 10GigE standards are being developed to use the protocol for broadband metropolitan area network (MAN) connectivity. At this time, there is no intention to use the standard to support desktop applications, however, all things change. 10GigE systems will be deployed using fiber optic transmission networks. Following is an example of a 10GigE Network.

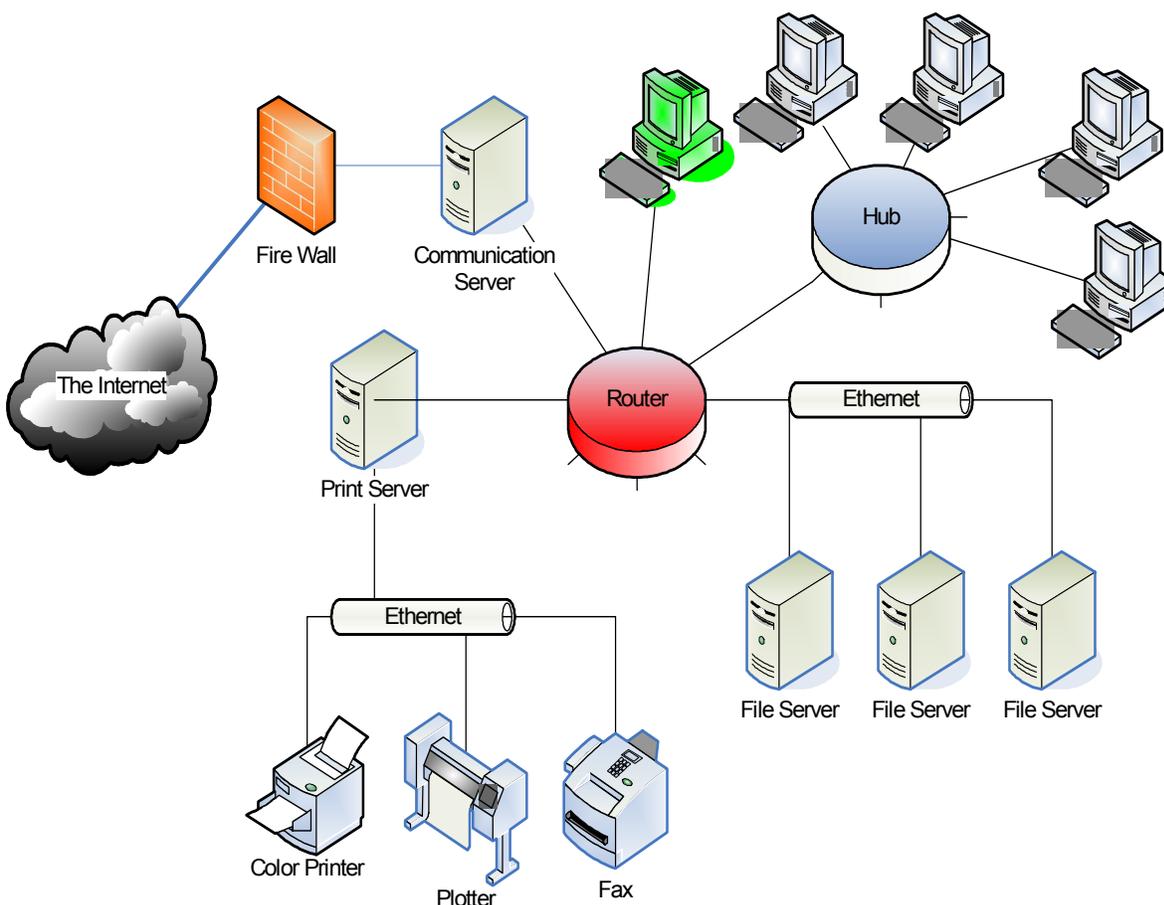


Figure 2-14: Diagram - Typical Office LAN

Because most of these networks are deployed in office buildings, the twisted pair cables tend to be run close to interference-causing electrical fixtures. The drawing shows a typical LAN for a small office. Notice that most of the office computers are connected via a hub, and that the printers, and communications services are connected via dedicated servers. This is simply one type of network that can be established using Ethernet. In very small offices, every device can be directly connected to a router. Large corporations will network several routers. The actual network configuration is based on completing a requirements document (see chapter 4). In this system every computer has access to every device, but the router can be programmed to restrict access based on the unique identity of each computer work station.

Figure 2-15 provides a look at how multiple building networks are connected via a metropolitan area network (MAN) Notice that

there is one primary router in each building connected to a 10GigE network - each building is a node on the network. The common basis of Ethernet protocols provides an easy expansion path. The system shown is actually a network of networks.

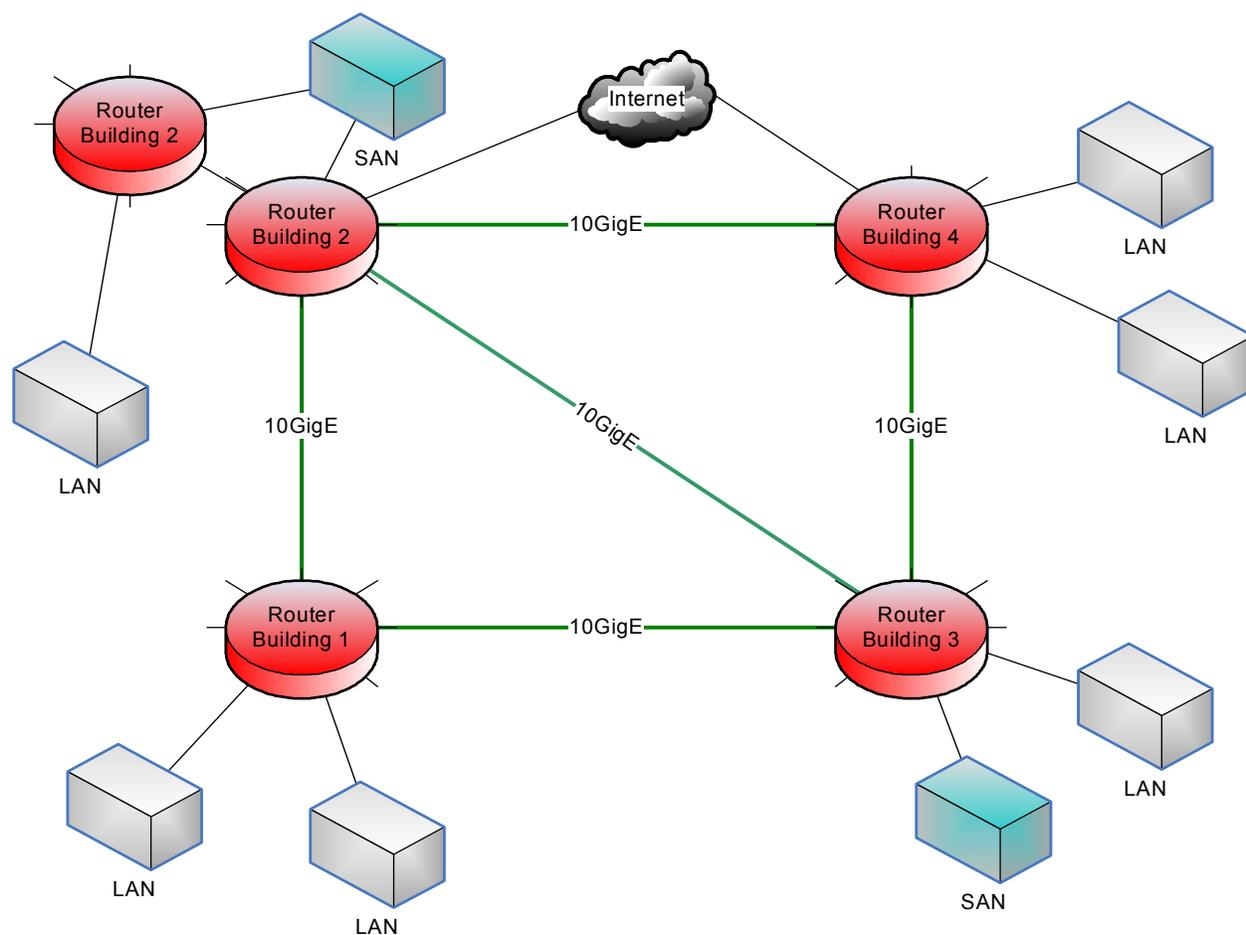


Figure 2-15: Diagram - Metro Area Network (MAN)

### Conclusions

The design of telecommunications systems is an iterative process. Each piece of a system is dependent upon the others. A simple example of this dependency can be found in the use of a modem. Basic modems rely on the cables that connect them to a computer (a serial cable) and the twisted-pair cable that connects them to a telephone network. Each of these elements is dependent upon the other to provide a working system. These types of dependencies can be found in all telecommunication systems. This chapter was organized to provide basic information about **Chapter 2**

individual elements and their relationships. Recognition of these relationships will help to provide an effective design of a telecommunications network.

### 3. CHAPTER THREE – TELECOMMUNICATIONS & THE NATIONAL ITS ARCHITECTURE

#### Introduction

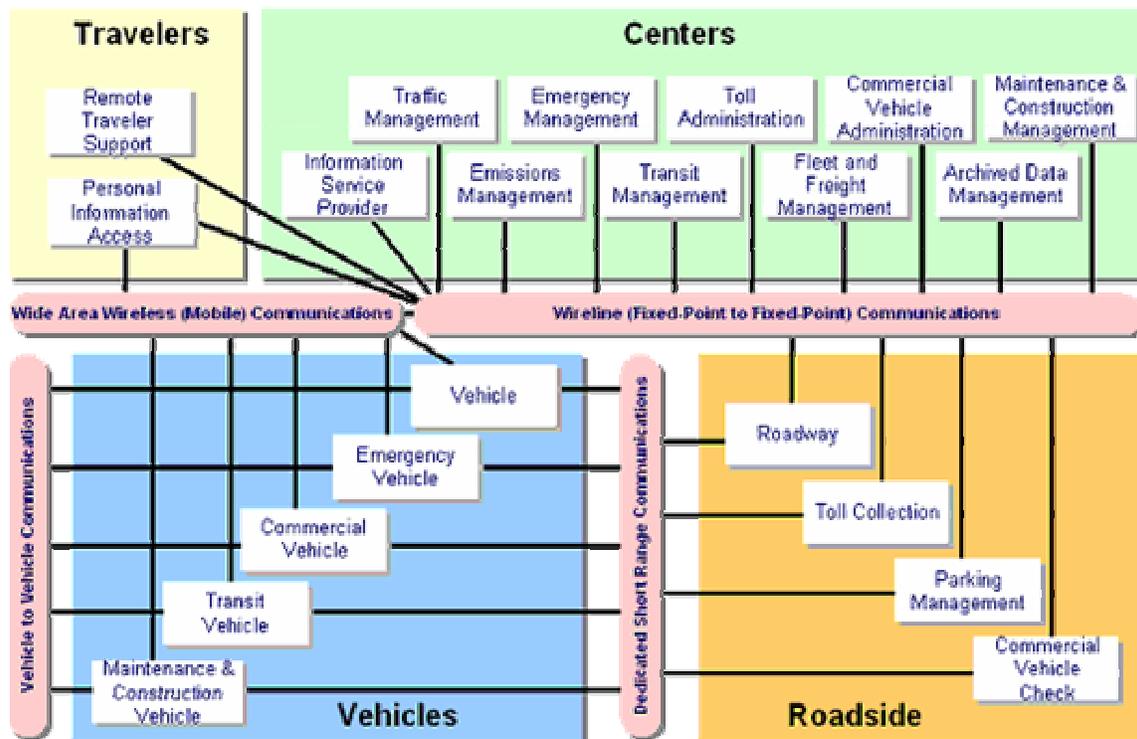


Figure 3-1: National ITS Architecture Communications Sausage Diagram

During the past 20 years, a number of technology based systems have evolved to support transportation operations, traffic management, traveler information, fleet management, and incident control. These include:

- Automated Traffic Signal Systems
- Commercial Vehicle Operations (CVO)
- Freeway Management
- Traveler Information
- Remote Weather Information Systems (RWIS)
- Incident Management
- Special Events

#### Chapter 3

- Ramp Metering
- Electronic Toll Collection.

Automated traffic signal systems have been in use for over 50 years, while traveler information systems are still in the process of developing - especially since the FCC allocated 511 as a universal traveler information telephone number for the U.S. In fact, all systems are in a continuous evolutionary process because technologies supporting the systems are always changing. As a direct result of the change, telecommunications systems that support transportation operations are also evolving.

Chapter 3 will look at the relationship of the National ITS Architecture to the process of engineering and specifying communication links and services for a transportation management system. This chapter will also provide information on the developing standards within NTCIP and how they will impact on the design of communications systems supporting transportation.

### ***Overview – The National ITS Architecture***

The National ITS Architecture is a flexible framework for the interrelationship of operational transportation systems. Various telecommunications strategies can be used within the context of the National Architecture. These include urban and rural system deployments, for local and regional transportation management systems. Functionally, there are very few differences between urban and rural systems. Vehicle speed and volume detectors function the same in both situations, as do CCTV cameras, changeable message signs, and almost any other device used in transportation management systems. However, telecommunications strategies do vary based on location. A telecommunications architecture that supports urban deployments may not be suitable for a rural system. The key factors to consider when creating a design are distance of field devices to a control center, availability of electrical power resources, and availability of public telephone infrastructure.

The National ITS Architecture provides system developers with a detailed view of the relationships between travelers and associated transportation organizations. Each of the relationships has a communications requirement. Communications can be thought of as the glue that binds required operational functions. The National Architecture can be viewed in several

different ways: Logical Relationship; Physical Relationship; Market Package Relationship; and Functional Relationship. The one constant in each type of relationship is communications. The Architecture makes no distinction in the type of communications systems that can be used. The system designer is free to use any telecommunications systems and devices that will support overall requirements.

The National Architecture provides a diagram of the general relationships ("Sausage Diagram) listing four (4) generic types of telecommunications systems:

- Vehicle-to-Vehicle
- Dedicated Short Range Communications (DSRC)
- Wide Area Wireless
- Wireline

Wireline and Wireless are the two primary types of telecommunications architectures shown in the diagram, with Vehicle-to-Vehicle (VtV) and DSRC being two applications of wireless. There is no distinct requirement to use RF, Copper, or Fiber Optics as a transmission medium. Nor is there any suggestion as to the network topology: point-to-point, star, ring, mesh, etc.

### **VEHICLE-TO-VEHICLE (VTV)**

These are wireless systems and use radio frequencies (RF) as the medium. There are some systems that use light or sound for communication, but the systems used in traffic and transportation management are predominantly RF. VtV systems can use one, or a combination of radio systems for communication.

### **Mobile 2-Way Radio**

Generally used between vehicles for wide area communication in a Private Land Mobile Radio Service (PLMRS) on frequencies set aside by the Federal Communications Commission (FCC) for that purpose. The system is used by DOT maintenance groups to facilitate operations between work crews and a central (or regional) dispatch center. Under the definition of the National Architecture, this is a wide-area mobile communication system. These same systems can also be used to coordinate joint operations between Police Departments and the DOT. These systems can also provide for an exchange of digital data information.

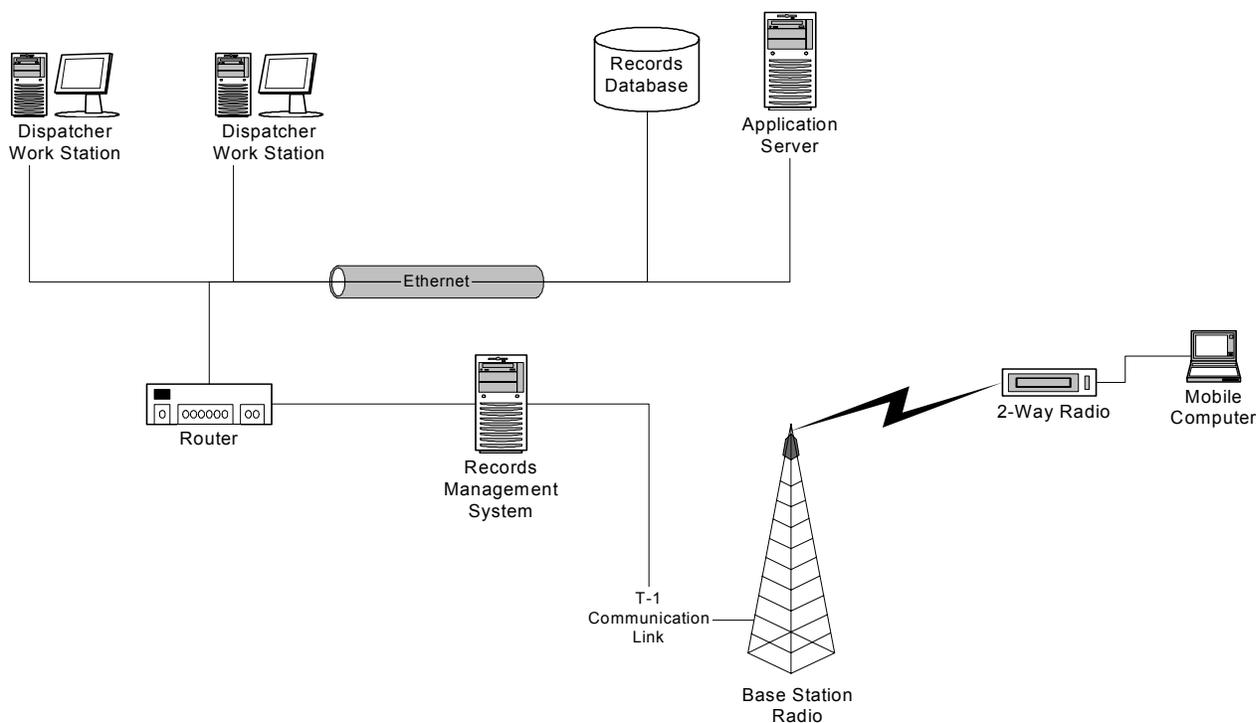


Figure 3-12: Diagram - Mobile 2-Way Radio Network

### **Cellular Telephone Service**

Can be used for communication between the occupants of two (or more) vehicles. This system can be utilized to provide secure personalized travel and transportation information to individual

travelers. The FCC requires that all wireless carriers provide location information when a request for emergency services is requested (the caller dials 9-1-1). The system may also be used to provide traffic management centers with general congestion information (not a requirement under FCC regulations).

**DSRC**

The sausage diagram shows this as a vehicle to roadside architecture, however, this is also considered as a very low power, very short range communication system between vehicles. DSRC generally refers to radio systems that operate on frequencies set aside by the FCC (in the US) between 5.8 and 5.9 GHz. However, toll collection and vehicle identifications systems currently operating in the 900 MHz range are considered - by the transportation industry - as DSRC. Automobile manufacturers have developed VtV systems using radar in the 35 GHz and 70 GHz frequency bands, and are looking at the possibility of using 5.8 GHz.

Dedicated Short Range Communication Systems (DSRC) are wireless systems used to communicate over distances of less than 1000 feet (300 meters). They can be used for vehicle-to-roadside (VtR ) or VtV. The systems are primarily deployed using RF, but can be deployed using infra-red (IR), or low power LASER as the communication medium. The National Architecture diagram shows DSRC in a relationship between the categories of Automotive Vehicles and Roadside Services:

Table 3-1: DSRC Vehicle-Roadside Relationships

Vehicles	Roadside
Passenger Car	Traveler Information
Emergency Vehicle	Toll Collection
Commercial Vehicle	Parking Management
Transit	Commercial Vehicle Check
Maintenance & Construction	

These relationships are not fixed. Any vehicle using DSRC should be able to access a suite of services which include passing information between vehicles and the roadside. Standards for DSRC are being developed and tested by ASTM using IEEE 802.11a, as a basis. A major difference between the DSRC standard and 802.11a is the frequency range being used. DSRC will operate within a frequency spectrum set aside for this purpose, and requires licensing. 802.11a systems operate in a frequency spectrum that is set aside for general use and requires no license. Detailed information about DSRC is available at the following [web site:](http://www.leearmstrong.com/DSRC/DSRCHomeset.htm)

### ***Wide Area Wireless Systems (WAWS)***

WAWS are RF communication systems that can cover several square miles to thousands of square miles. They generally include Cellular and standard 2-Way Radio systems. Most of these systems are designed to provide full voice service and some data services. The National Architecture shows WAWS as providing VtV and vehicle to center communications (VtC). DOT Maintenance, Mass Transit, and Public Safety use WAWS as a tool for field to center communications. Additionally, Police and Fire agencies use these systems to enhance field unit communications.

All WAWS have a similar architecture - a central base station that can communicate with mobile and handheld radios. The base station is a high powered transmitter and receiver combination placed in the center of the required coverage area. The base station utilizes an antenna placed at a relatively high (above ground) location (normally on top of a tower or building rooftop). Cellular systems are very similar in design except that there are many base stations interconnected by a wireline network designed to provide continuous service to callers using handheld radios (handsets). The overall system is interconnected to the PSTN to facilitate voice communication.

WAWS systems can also be used for field operational control of Freeway Management systems in rural settings. Oil and gas transmission companies use these types of systems for monitoring pipelines. These systems are called SCADA (system control and data acquisition). All incident and traffic flow detection systems

are, in fact, SCADA systems in that they use various types of sensors to detect a change of state (vehicle speeds and lane occupancy) to alert TMC operators that a specific section of roadway may have a congested condition.

### ***Wireline Systems***

A generic reference to any type of system that uses a physical connection of copper wire or fiber optic cable as the communication link. Generally, wireline systems can be divided into three categories: Wide Area Network (WAN); Metropolitan Network (MAN); Local Area Network (LAN).

### ***National ITS Architecture Flows & Telecommunications***

This section will provide an examination of how market packages and flow models, as presented by the National ITS Architecture, can be used to create requirements for telecommunications systems and services. The NA is very large and has many components. The creators of the NA have developed "Market Packages" to help users work with the document. The Market Packages provide a graphical representation for easy visualization and can be a valuable tool in the design of a telecommunications system.

### MARKET PACKAGES

The market packages contained within the NA provide a good reference to how individual items (control center operators, roadway devices, data, and control systems) are positioned within a system, and their linked relationships. The system engineer must start at a very high level to produce an overview telecommunications architecture. As individual items within a market package are examined, their requirements will be added to the overall system. Modifications to the initial overview are made until a working telecommunications architecture is established. This is a "top-down" approach to help the engineer gain an understanding of the system that will be needed. In fact, the system is designed using a "bottoms-up" approach, because the system must provide communications services for every device in the market package. Let's take a look at a typical market package, and apply a telecommunications system.

The Roadway Service Patrol Market Package (EM-4) describes a service that assists motorists with vehicle problems (flat tire,

EM4 - Roadway Service Patrols

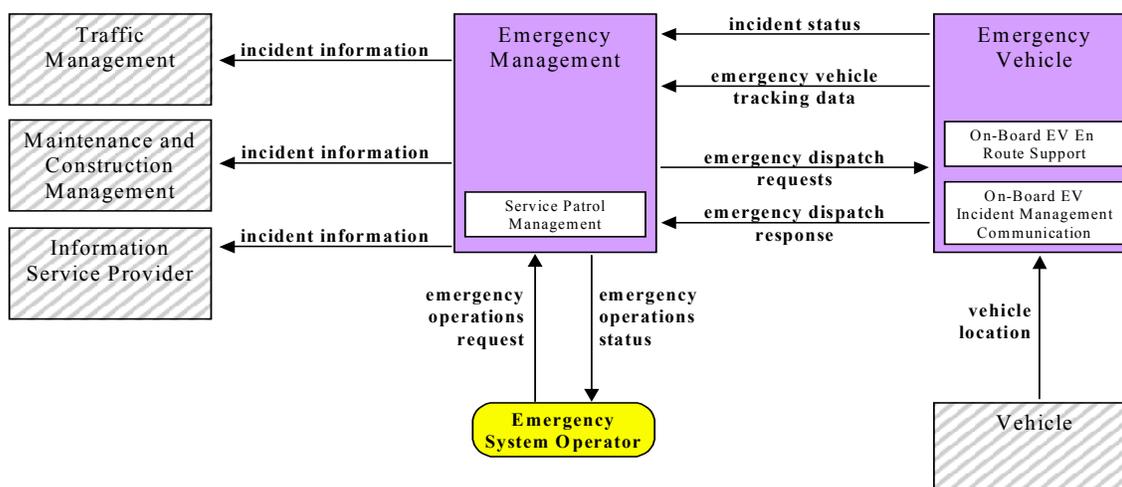


Figure 3-3: National Architecture EM-4 Market Package

out of gas,) and is part of the incident clearance solution to help minimize congestion. Note that the selected market package is part of an overall "center-to-center" architecture. Ultimately, the solution for the situation described by this market package will have to become part of a larger communication system. In chapter Four, the process of breaking the overall communication system design problem into its basic elements is discussed. The graphic<sup>8</sup> shown is presented in the NA.

The above graphic represents only a small portion of the overall system that provides traffic management, incident detection, and incident response and clearance. The arrows indicate how information flows between the responsible agencies. These same arrows also provide an indication of the required communication links. Looking at the sausage diagram, it is easy to see that this system will utilize a combination of wireline and wide area wireless telecommunications systems. The NA does not specify the actual type of communications systems to be used. This is up to the individual developers of a system. The NA recognizes that the type of communication will be standard (and conform to FHWA requirements), but that each individual system will have different deployment variables. These include:

- Location - urban or rural
- Scope of services offered by the agency operating the TMC
- Budget - extensive or limited
- Regional or Local - system is "stand-alone" or part of a larger operation
- Coordination - level of cooperation between service providers.
- Legacy

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<sup>8</sup> Source: <http://itsarch.iteris.com/itsarch/html/mp/gatms08.htm>

**EXAMPLE ILLUSTRATION**

For purposes of illustration of the telecommunication system:

- The TMC is part of a regional operation with roadway service patrols offered by commercial contract organizations.
- The service patrols are dispatched by local Police Departments.
- The EM4 diagram shows several active boxes (purple and yellow).
- The Traffic Management box is grayed, but we'll change it to active (blue) for this discussion.
- Add several communication arrows not shown in this diagram. Take a second look at the EM4 diagram (Figure 3-4):

Notice that incident detection and incident response request flows have been added.

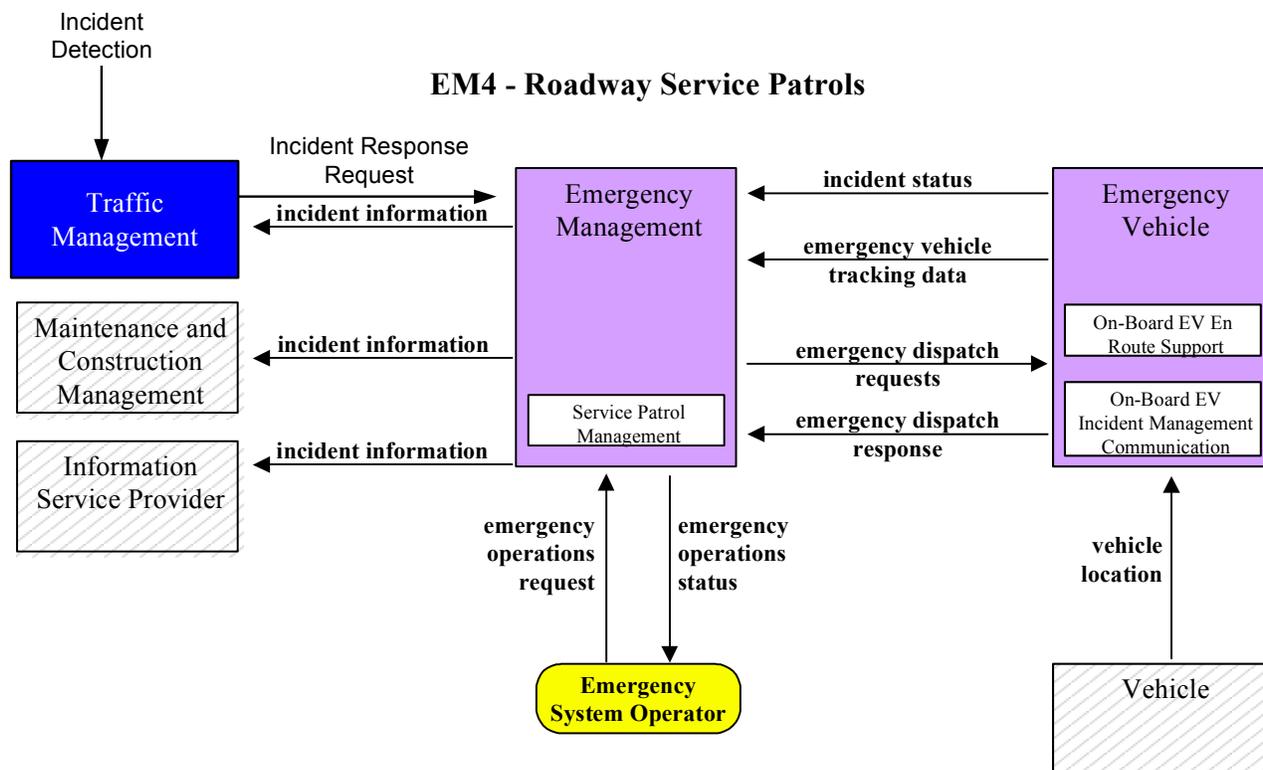


Figure 3-4 EM-4 Market Package with Telecommunications Flows

Next, assume the following:

- Traffic Management is a function of the DOT Transportation Management Center.
- Emergency Management is the responsibility of a County Emergency Management/ 911 Center.
- The dispatching is accomplished by a local Police Department (Emergency System Operator),
- The Emergency Response Vehicle is operated by a private contractor.
- Add the telecommunications sausage diagram elements (green) to complete the diagram (Figure 3-5):

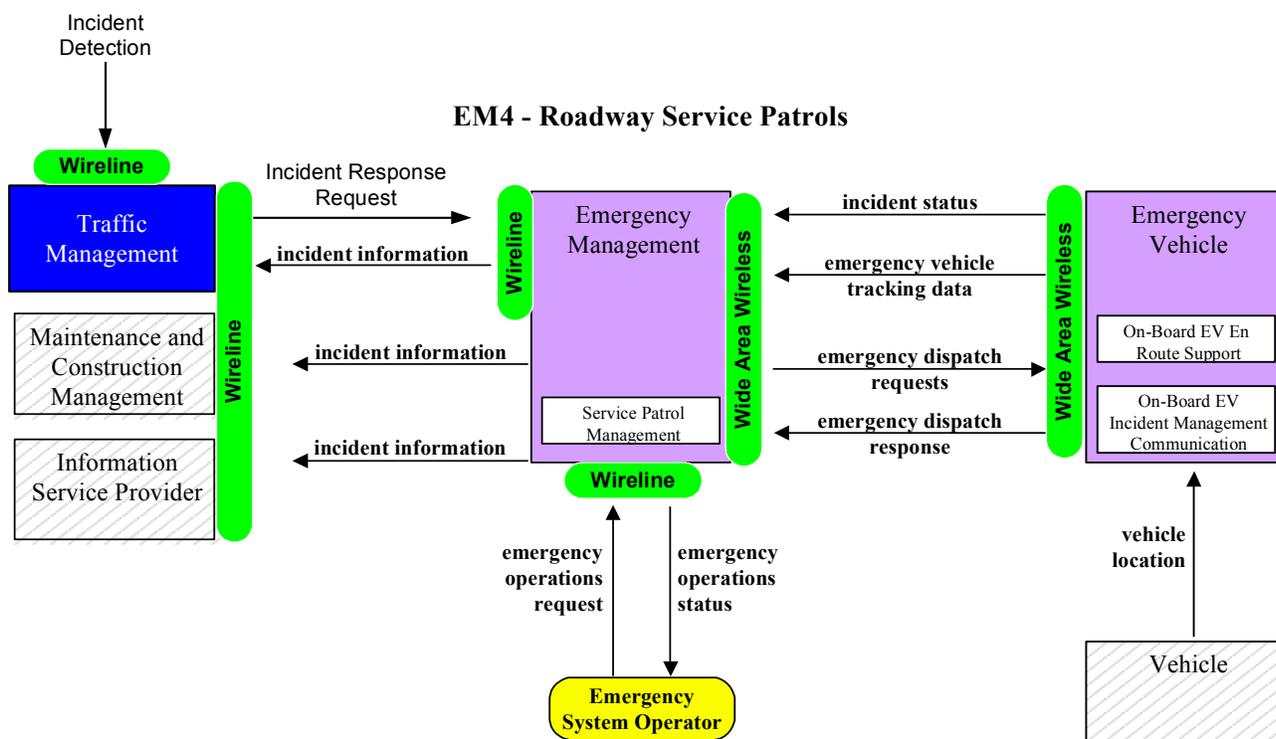


Figure 3-5: EM-4 Market Package with "Sausage Diagram" Elements

The NA does not provide any details on telecommunication requirements or specifications. However, it does provide a good starting point via the Market Package Diagrams. Taking the diagrams and adding the telecommunications function is a good way to visualize the requirements. Program managers are provided a concept of the elements that must be detailed in the overall

project. The importance of this is discussed in chapter Four. In the next section, we'll apply the telecommunication elements to the diagram.

### Application of Telecommunications Using the National Architecture Flows

A good way to go from the market package concept to a telecommunication requirements document is to create a table based on the above diagram. The table will contain the "points-of-communication", and a brief description of needs. The developer of the table should also note that the Market Package describes information flows. These flows are not descriptive of the communication links, but can be used to help define the

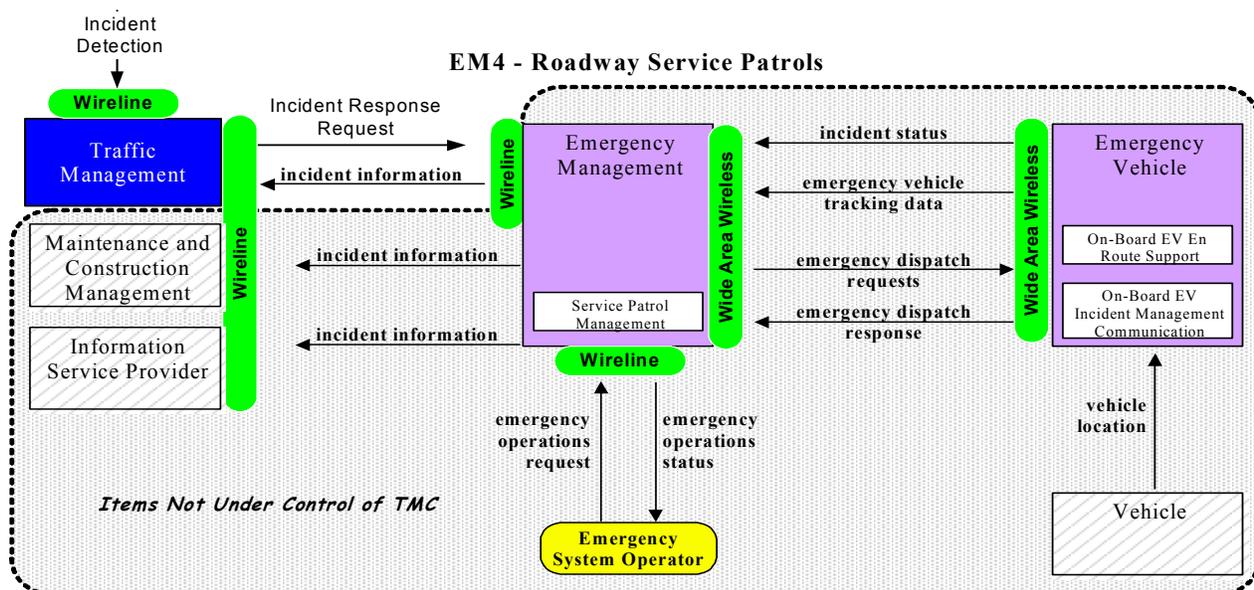


Figure 3-6: TMC Area of Responsibility

telecommunication links. The definition will include bandwidth requirements and the type of communication - voice or data or both. The following is an example of the table:

Table 3-2: Communication Needs & Requirements

Communication Points	Needs	Requirements
Incident Detection to TMC	In place (existing system)	None (uses existing)
TMC to EM	Wireline Comm Link	Voice & Low Speed

		Data (unless video is part of the package)
EM to Maintenance	Wireline Comm Link	Low Speed Data

The items listed in the above table are the responsibility of the DOT, because the emergency management function is being provided by another agency. It is helpful for the system designer to have a complete understanding (for purposes of coordination) of the entire system, but it is only necessary to focus on the elements which must be provided by the DOT.

The TMC is responsible for creating the incident detection information, initiating a request to the EM and providing necessary information, plus coordination of support from the DOT. There is also the connection between the incoming incident

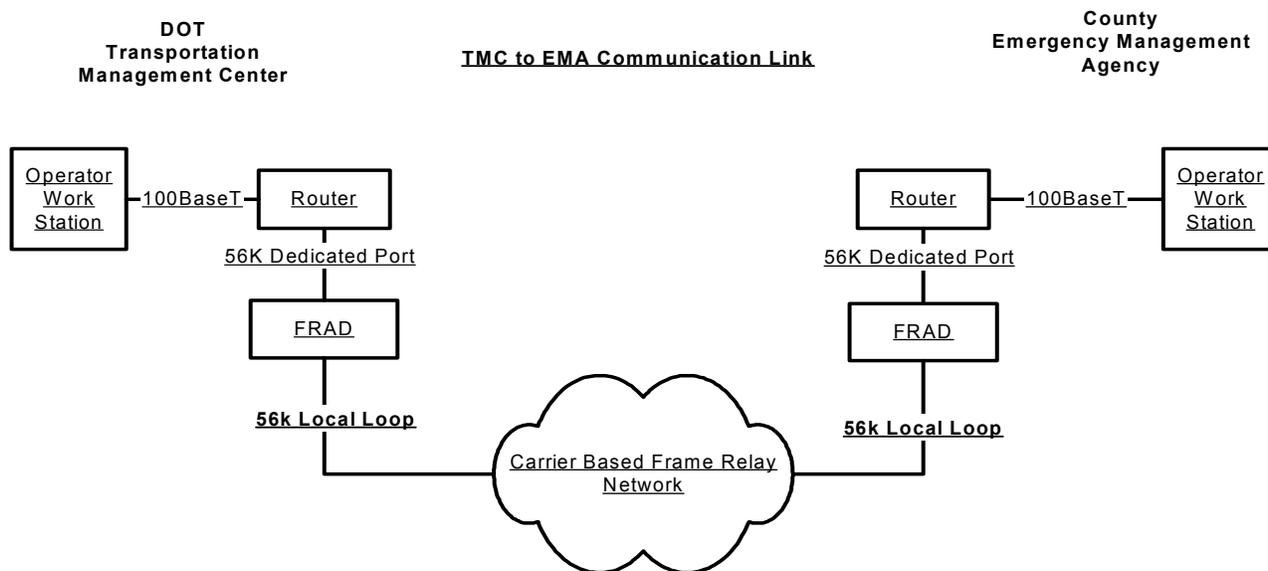


Figure 3-7: Diagram - TMC to EMA Link

detection information and the outgoing request for EM assistance to clear the incident. The system designer must provide for a communications link between the "in-house" TMC systems.

Notice that a dedicated communication port on the router is assigned to the link between the TMC and the EMA. This assures that the "incident response request" and "incident information" links are always available. Also, the use of a dedicated leased 56 Kbps digital circuit from a local carrier and the Frame Relay network assure secure transfer of information. The NA defines the requirements for each link as individual one way flows, but

the telecommunications system design provides for a single bi-directional flow. The difference is that the NA is showing how information flows and the communication diagram is detailing a physical link. Also note that the above diagram represents one of several possible solutions. It essentially assumes that only text and database information are transferred between the TMC and the EMA. A system that provides for the transfer of "real-time" video from the TMC to the EMA would use a broadband communication solution.

In the diagram, the Carrier based solution has been replaced with a direct private fiber communication link. This could also be a

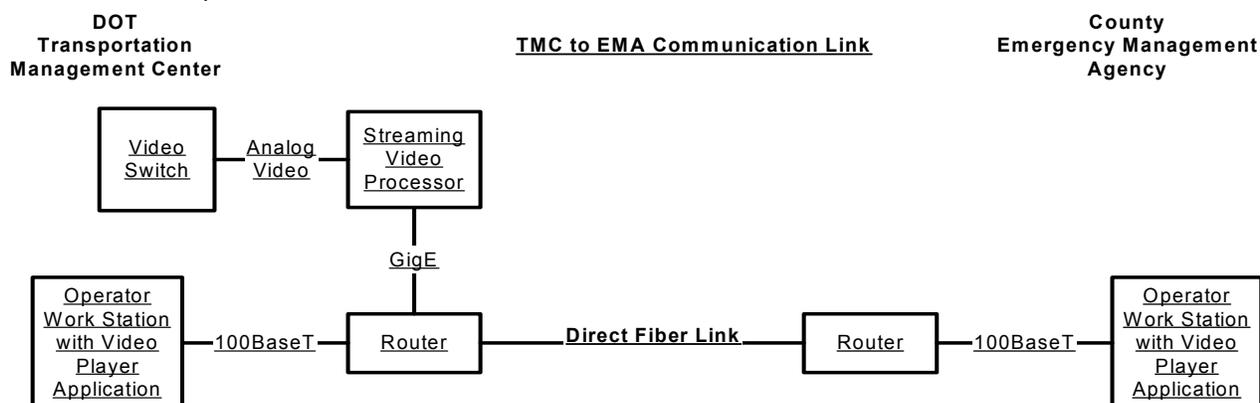


Figure 3-8: Diagram - TMC to EMA with Fiber Communication Link

link leased from a carrier.

Looking at the EM4 Market Packages, you will notice that a link is provided between the EMA and the Maintenance and Construction Management organizations. In a "real world" scenario, the link could be via the TMC. The NA is showing this link as a reminder that more than one transportation organization needs information. The overall design needs to account for each communication link.

Based on the NA, the Maintenance and Construction group receives information from the EMA, but does not send information back. We have to assume that construction and maintenance information is submitted to the EMA via another channel. This information is probably routine traveler information about lane and road closings and general repair work. For this case, the EM4 Market Package is a good model, but does not show all of the potential communication links. There may be a number

of internal links that are not shown in the Market Packages. Do a thorough search of all of the requirements for communication.

### ***Comparison of Rural and Urban Telecommunications Requirements Using the National Architecture Flows***

In this section we will examine how the National Architecture works for both Rural and Urban telecommunication systems scenarios. The market packages and architecture flows are designed to remain unaffected by the location of the system. The variables are accounted for by making the market package and the architecture flows work in a particular situation - that is, meeting the needs of a rural or an urban/suburban location, and/or a local or regional system.

Using the EM4 Market Package, let's examine alternatives based on location. The Department of Transportation (for this scenario)

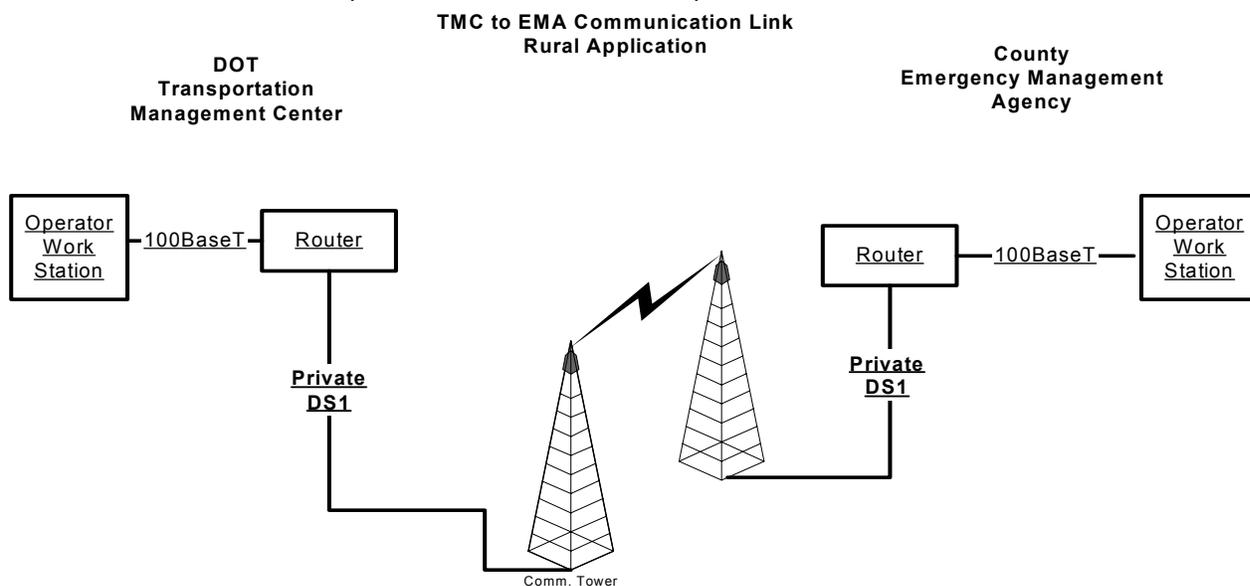


Figure 3-9: Diagram - TMC to EMA Comm Link Rural Setting

is responsible for the Traffic Management function, and the County (for this scenario) is responsible for the Emergency Management function. The TMC and the County EMA are separated by several blocks or several miles. In an urban situation they are probably in separate buildings in the rural setting they may be in the same building, or separated by 20 miles. Let's look at the urban and rural separate building scenario and develop a communication link.

The diagram in the figures above are designed to facilitate the urban/suburban deployment. This single link will provide a physical path for the "incident response request" and the "incident information response" data flows. Please note that this information can be transferred in the form of voice or data. The final system requirements document will provide the details. For purposes of this illustration we will assume that the communication is a data transaction using a specific software application.

### RURAL SYSTEMS

The rural setting is characterized by a lack of available electrical power and telephone company infrastructure. This places a greater financial burden on the development of a telecommunications system. The rural communication links can use

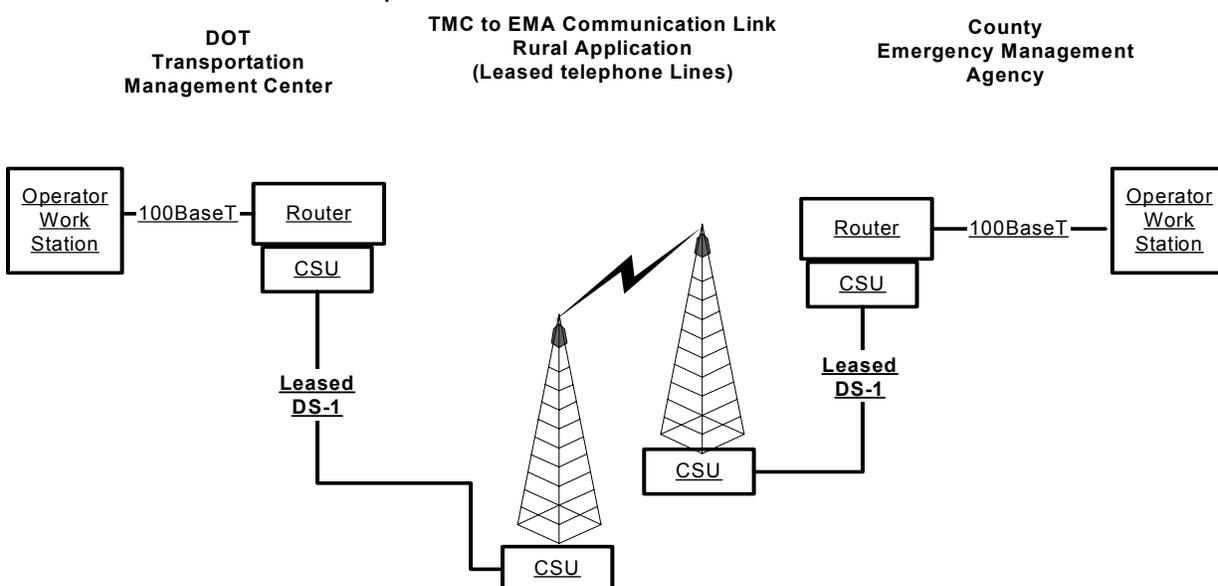


Figure 3-10: Diagram - TMC to EMA Rural using Leased Telephone Lines

the same type of wireline system (as the urban example). However, a portion of the leased DS-1 link monthly fees are based on distance. In the urban system, the TMC and the EMA may only be separated by several city blocks. A rural situation could have the TMC and the EMA separated by 10 to 15 miles. The monthly cost of the leased line becomes a major consideration - a 56 KBps leased line may cost more in the rural setting than the DS-1 in the urban setting because leased telephone line services have a mileage based price component. Although the monthly fees

are primarily based on bandwidth, a one mile DS-1 may have a lower overall cost than a 20 mile 56 Kbps leased line.

Several alternatives can be considered to help lower the overall cost of the communication link. Voice communication via a telephone is one way to keep costs down. A dial-up modem could be used for low bandwidth data communication. If a microwave system is available, a hybrid wireline-microwave system could be created. Many states have microwave backbones that can be accessed by multiple agencies. The key concept to understand is that the National Architecture flows are not affected by the telecommunications infrastructure. The following is an example of a hybrid block diagram

The above diagram assumes that the TMC and EMA are located within 1000 feet of a microwave site. A privately constructed communications link to the tower sites would be very cost efficient. If the buildings are several miles from the sites, it may be more cost efficient to lease a DS-1 between the buildings and the tower sites. A comparison of communications systems used in rural and urban settings will show that rural systems are more expensive to construct. The variance in cost is accounted for on a distance basis. One of the primary engineering problems for telecommunications systems is that of overcoming distance. By comparison, rural systems must overcome significantly longer distances than urban systems. There are a number of other problems which must be overcome. Additional material about telecommunication problems associated with rural ITS deployments can be found in the addendum chapter<sup>9</sup>.

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<sup>9</sup> *Written Testimony of Stephen Albert, Director Western Transportation Institute, Montana State University to United States Senate Committee on Environment and Public Works Subcommittee on Transportation, Infrastructure and Nuclear Safety.*

## National Transportation Communication for Intelligent Transportation Systems Protocol (NTCIP)

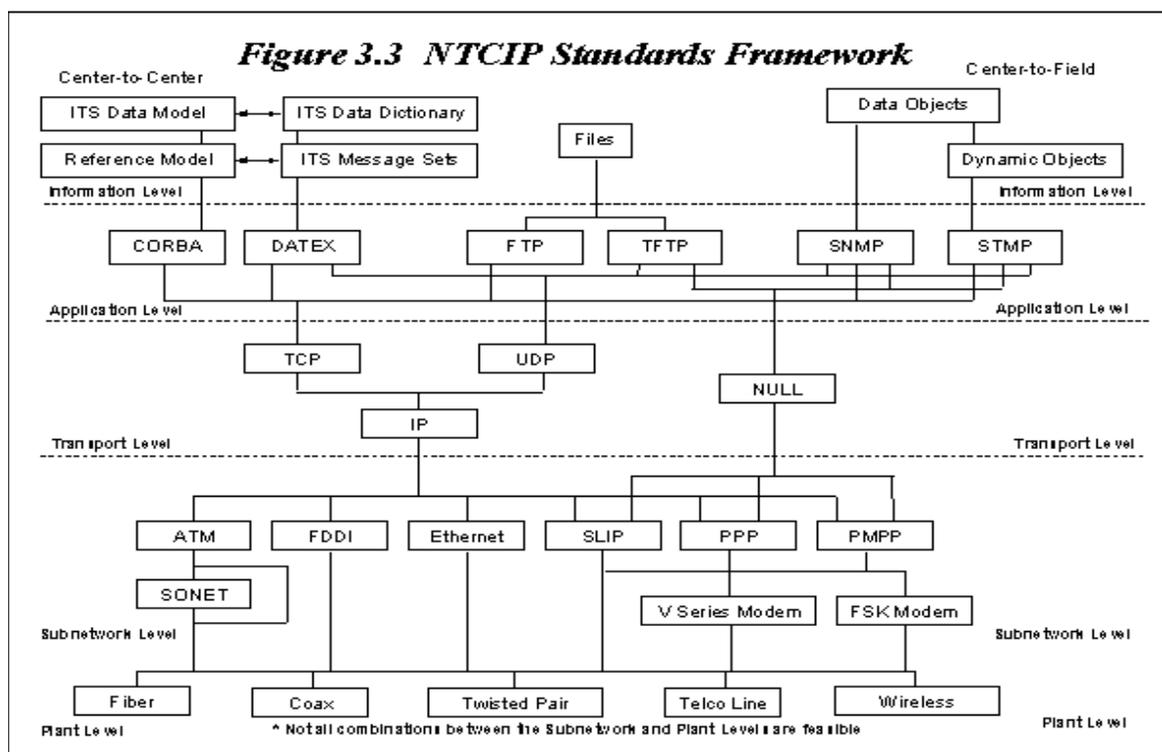


Figure 3-11: NTCIP Standards Framework

The following statement is provided on the NTCIP introductory web page<sup>10</sup>: "The NTCIP is a family of standards that provides both the rules for communicating (called protocols) and the vocabulary (called objects) necessary to allow electronic traffic control equipment from different manufacturers to operate with each other as a system. NTCIP standards reduce the need for reliance on specific equipment vendors and customized one-of-a-kind software. To assure both manufacturer and user community support, NTCIP is a joint product of the National Electronics Manufacturers Association (NEMA), the American Association of State Highway and Transportation Officials (AASHTO), and the Institute of Transportation Engineers (ITE)."

For telecommunication purposes, the NTCIP User Guide provides a further definition: "NTCIP is a family of communication

<sup>10</sup> <http://www.ntcip.org>

*standards for transmitting data and control information between microcomputer controlled devices used in Intelligent Transportation Systems".* These standards are specific to transportation, and build upon existing (and developing) telecommunication standards and protocols.

A traffic signal control system using twisted pair (see chapter 2) communication links and an RS 232 interface before the implementation of NTCIP will continue to use the same wiring protocol after the implementation of NTCIP. This will also be true for an incident management system using CCTV transmitted via fiber optic cable. The physical interface for the transmission of data and their associated standards and protocols do not change.

Implementing NTCIP as part of the telecommunications infrastructure requires careful calculation of bandwidth. NTCIP protocols add "overhead" to the communication process. Some systems that exist today can handle this added overhead without re-configuration. Others will require changes.

Overhead is any information that is added to a communication transmission and is not part of the original message. This information is used to identify transmission origin and destination, assist with network management, look for transmission errors, etc.

A traffic signal system that has 15 controllers sharing a single 9.6 Kbps multi-drop communication circuit may, (depending upon the specific NTCIP protocol) need to be reconfigured. The re-configuration may require the use of more bandwidth, or a reduction of the number of controllers on the circuit. The NTCIP User Guide provides a careful examination of the issues related to bandwidth calculation and the implementation of NTCIP. The NTCIP User Guide can be found at the following web address: <http://www.ntcip.org/library/guide.asp>

The material contained in this section was developed from information available from the National Transportation Communication ITS Protocol (NTCIP) web site. The reader is referred to <http://www.ntcip.org> for specific information and resources.

The National Transportation Communications for ITS Protocol (NTCIP) is a group of communications protocols developed for traffic and transportation systems. The transportation

community has long needed a mechanism whereby interchangeability and interoperability for the various components of transportation systems could be achieved. It is for this reason that NTCIP is being widely embraced and is being specified for new system deployments.

NTCIP protocols allow for the interchange of devices of similar purpose and different manufacture to be placed in systems. The protocols allow for many different devices to share a common communication channel.

Interchangeability is defined as the capability to exchange devices of the same type (e.g., a signal controller from different vendors) without changing the software. Interoperability is defined as the capability to operate devices from different manufacturers, or different device types (e.g., signal controllers and dynamic message signs) on the same communication channel.

NTCIP is a suite of communications protocols and data definitions that have been designed to accommodate the diverse needs of various subsystems and user services of the National ITS Architecture. It is intended principally to handle these needs in two areas: communications between a management center and field devices, and communications between two or more management centers. Examples of the first application include transfer of command and configuration data between a transportation management center and field devices such as traffic signal controllers, dynamic message signs, environmental sensor stations, ramp meters, etc. Examples of the second application include transfer of data between multiple management centers within one agency, as well as transfer of data between management centers operated by different agencies.

NTCIP differs from past practice in defining communications protocols for management systems in that it is not a single communications protocol designed for one purpose. Rather it consists of a whole suite of protocols covering the spectrum from simple point-to-point command/response protocols to quite sophisticated object oriented techniques. This is because of the diversity of the applications into which NTCIP is being deployed, and the resulting diversity of application specific characteristics such as type and quantity of data to be transferred, criticality of data transfer times, acceptable cost of communications infrastructure, criticality of data security and integrity issues,

to name a few. Insofar as data definitions are concerned, NTCIP does not completely define the functionality of the central or field devices to which it applies. It only specifies the data objects to be transferred and limited functionality directly related to these objects. For example, NTCIP does not define the details of how a traffic controller operates, e.g., it does not define that a green must be terminated by a yellow and that a red must be displayed after a yellow. However, it precisely defines the data that may be communicated between traffic controllers and traffic management centers, and thereby defines the aspects of functionality (e.g., it requires that the length of the yellow clearance interval must be as indicated by the phase Yellow Change object).

NTCIP standards and protocols are not designed to replace the general suite of communication standards and protocols developed by other standards organizations (e.g.: IEEE; ASHTO; etc.). In fact, it incorporates many of those standards.

The introduction to this chapter indicated that the use of protocols adds the "cost of bandwidth". The primary rule that needs to be followed in the design of a communication system is - "nothing is free!" Every communication protocol adds to the total amount of data being transported. The requirement for additional bandwidth to accommodate "overhead" protocols should not be considered in negative light. But, it must be considered!

"Overhead" is anything that adds to the communication requirement. Any protocol for network management, any information that identifies a device, any information that is used for command and control, and routing information is considered as overhead. If the information is not part of the message - it's overhead! Note: The actual amount of overhead required by the use of NTCIP, or any other OSI layer support is dependant upon the actual configuration of the NTCIP, or OSI Model, layer protocol.

NTCIP is used for device management and systems message management. The following tables provide examples of NTCIP protocols:

Table 3-3: NTCIP Device Management Protocol List

<b>Device Management</b>	
1	Traffic signal management system communicating with traffic signal controllers at intersections.
2	Transit management system communicating with monitoring devices and passenger information signs on transit vehicles and at transit stations and stops.
3	Freeway management system communicating with detectors and ramp meters on freeways.
4	Traffic management system controlling CCTV cameras, dynamic message signs, advisory radio transmitters, environmental sensors, and traffic count stations on roadways.
5	Provide a synchronized time source for all devices (especially traffic signal controllers) in a single system.

Table 3-4: NTCIP List of Systems Management Protocols

<b>Systems Message Management</b>	
1	Two or more traffic signal management systems exchanging information (including second-by-second status changes) to achieve coordinated operation of traffic signals managed by the different systems and to enable personnel at one center to monitor the status of signals operated from another center.
2	A transit system reporting schedule adherence exceptions to kiosks, to a transit customer information system, and to a regional traveler information system, while also asking a traffic signal management system to instruct its signals to give priority to a behind-schedule transit vehicle.
3	An emergency management system reporting an incident to a freeway management system, to a traffic signal management system, to two transit management systems, and to a

	traveler information system.
4	A freeway management system informing an emergency management system of a warning message just posted on a dynamic message sign on the freeway in response to its notification of an incident.
5	Center - to - Center Communications
6	Center - to - Field Device Communications

As of the date of this handbook, individual NTCIP system packages are still under development. The reader should check at the web site for the latest information.

### ***Conclusion***

From a telecommunications perspective, neither the National ITS Architecture, nor NTCIP provides answers to design problems. NTCIP is a recommended set of communication protocols based on existing (telecommunication) standards. The National ITS Architecture provides significant detail on communication flows, but does not provide a design of the telecommunications system. The developers of the architecture understood that the design of a communication system would be unique for each ITS system.

## 4. CHAPTER FOUR – DEVELOPING THE TELECOMMUNICATION SYSTEM

### *Introduction*

Telecommunication systems can be very complex and difficult to design because there is usually more than one way to meet requirements. Often, several communication protocols must be used in the final design. This chapter attempts to provide the traffic engineer, and traffic system project manager, with a suggested process for developing the design and specification for a communications network to support traffic signal and freeway management systems. A theme that is repeated throughout this handbook is that the design of a communications network to support roadway and transportation functions is not a stand-alone process. The determination of functionality and selection of options must be done as an integrated part of the overall traffic management system design. Personnel responsible for the development of the communications system should be full members of the overall project team.

Central to the development of the communication system is the fact that it is there to serve the requirements of the overall project. Communication project personnel should attend general project planning meetings. If new roadway construction, or roadway modification, is part of the overall project, communication engineers should be included.

This chapter is organized into six primary sections. First, a recommendation of qualifications for a telecommunications consultant, including types of experience and education. The next three sections are devoted to the Requirements Document. The development of a complete requirements document is essential to the proper implementation of a telecommunications system. The final section concludes this chapter with some basic recommendations for managing the communication project.

### *Selecting the Consultant*

This section provides guidelines for selecting an engineering / communications consultant with the right qualifications. Three basic qualification areas must be considered when selecting a qualified communication consultant: experience, education,

project background. And, these four (4) basic rules apply in making the selection:

***THERE'S NO SUBSTITUTE FOR EXPERIENCE.***

Qualified applicants need to demonstrate a good understanding of how each element of a communication system will impact on the viability of a whole system. There are only a few engineering schools offering degree programs in telecommunications. Technology changes faster than the professors can write new text books.

*Communication Engineers don't design traffic (or freeway management) systems don't use a traffic engineer to design a communication network.*

There's no substitute for experience. Consulting firms (or individuals) should have at least 10 years (as individuals or combined with other team members) of experience in analysis, design and implementation of communications systems. Ten years may seem like a very heavy requirement, but will assure that the engineer (or firm) will have a broad range and depth of experiences. Most communication system engineers are used to the idea of wearing many hats. And, as technology changes, there is a greater need to have a broad application experience than a specific focus. There is also a need to understand legacy technologies. In many circumstances, the communication engineer must design a system that allows for the use of legacy technology, adds current technologies, and provides for implementation of future technologies.

During the course of writing this handbook, more than a dozen new IEEE standards relating to Ethernet and the application of Ethernet to wireless and broadband wireless were either published, or sent to committees for final acceptance, and there are about a dozen more in development. Since the early-1990s there has been a focus - by the telecommunication carriers - to move from primary support of analog voice based services to data transmission services. During that same period, Transportation agencies - on a broad scale - embraced the use of technology to support their operations. Their use of telecommunication technologies has very rapidly evolved from analog systems to digital data systems and the use of wireless. There is a general convergence of voice based and data based telecommunications services. This creates a greater need for communication

**Chapter 4**

engineers to develop a broad based background. During the transition period, it is important for telecommunication system designers to have an understanding of both analog and digital communication systems.

### ***DIFFERENT TELECOMMUNICATION DESIGN SPECIALTIES***

Many specialties have engineers that primarily do design and others that focus on construction or manufacturing. The same is true for telecommunications. There are engineers that only do design and those that work on the construction of the systems. For most ITS projects it's a good idea to have at least one member of the design team that has experience in both the design and implementation of communication systems. Most communication system designers have learned valuable lessons by actually having to make their design work. Larger firms may have significant breadth of experience in developing traffic signal and freeway management systems. However, you'll want to look closely at their experience with communications systems design and deployment. If you are making a choice between two or more qualified firms, take a hard look at both corporate and individual personnel experience.

Many IT personnel have significant experience with the deployment of Local Area Networks, but they may lack a background with the types of systems required for freeway management and traffic signals. Local area networks are generally deployed within a building. The personnel designing those systems don't have to worry about location of the media infrastructure, or bringing power to a communications cabinet, or using equipment that can survive extremes of temperature and moisture. On the other hand, make certain that an experienced IT person is involved in design of the control center.

### ***TYPES OF TELECOMMUNICATIONS EXPERIENCE***

Communication system engineers should have the following experience (this can be defined as either direct experience or the management of individuals and firms doing the work):

- **Construction:** Direct burial; conduit design; pole mounting of cable; towers and roof mounting of antennas for radio systems.

- Equipment installation: multiplexers (analog, digital, and fiber optic); modems; DSU/CSU; routers; switches.
- System Design: VF (voice frequency); Digital (T-1/T-3, Compressed Video); Fiber Optic (SONET, ATM, Video); Wireless; Ethernet, Video Over IP (VIP); Voice over IP (VoIP).
- Experience in creating alternatives analysis to provide several options for meeting requirements.
- Design and deployment of communications systems for traffic and transportation purposes. Very important - a communication engineer with no concept of traffic and transportation systems won't understand what the communication system has to support.
- The project background of a communication consulting engineer is important. Projects denote experience.
- Overall project experience should be a combination of general communications systems design and deployment as well as specific.
- Look for projects that relate to the objectives of the current project.
- Any other relevant experience that directly relates to the specific project.

#### ***KNOWLEDGE OF TELECOMMUNICATIONS SYSTEMS RELATIONSHIPS***

Seek out engineering talent with a good understanding of how each element of the communication system will impact on the viability of the whole system. The following should be applied in the search for qualified firms and personnel:

- There is almost never a situation in which one type of communication system (or element) will provide a solution for all system requirements. Very few communications systems use only one type of technology - look for personnel with a variety of system design and deployment experience.
- Most systems use combinations of technologies. An existing large traffic signal control system may use twisted copper pair connections between local controllers and field masters, and a fiber connection between the field masters and the central computer. The local DOT may have decided to

upgrade the system by adding intersections and using wireless for the new communication links. The new communication system may also have to be capable of adding CCTV and traveler information signs. The communication engineer responsible for completing the design should have experience with all of the proposed equipment, the legacy equipment, and the necessary communication protocols.

- An experienced communication system engineer will understand how all of the elements can be made to work together. Traffic engineers may have significant experience with the legacy portion of the system, but won't understand how to integrate with the fiber and possibly Ethernet and broadband wireless systems. System designers lacking sufficient experience and education in only one piece of the communication requirements for the above system will probably make a mistake and there will be a need to spend additional money to correct the problem.
- An experienced communications engineer will ask questions. They will want to know how the traffic signal or freeway management system is supposed to work and the communication needs of each element of the system before creating a design. When working with a communications engineer, tell them what you want the communication system to provide, not the type of technology required.

#### **EDUCATIONAL QUALIFICATIONS**

Education is important, however, there are only a few Universities offering degree programs for communication system design and/or engineering. Most engineering schools offer courses in communication technology. However, the courses are designed to provide the student with a fundamental understanding of how the technologies work. Additional points:

- Universities can't make curriculum changes that keep pace with the changes in communications technology. The implementation of new technologies is occurring within a short time frame after their invention. Coincidentally, universities are at the forefront of both the development of new communication technologies and their immediate implementation.

- Universities offer courses in communication technologies to provide students with knowledge that will assist in the design of communication hardware. These courses are normally associated with the Electrical Engineering program.
- Many universities offer management level course work in telecommunications technology, but these are generally focused on the economic aspects, and strategies for their use. The Rochester Institute of Technology, Rochester, New York, offers Undergraduate and Graduate degree programs in the field of Telecommunications. The school also offers several certificate programs. More information is available at <http://www.rit.edu>.
- There are no Professional Engineering licenses for Communication Engineers. The Electrical P.E. license exams don't cover telecommunications.
- An individual with an Electrical Engineering Degree and a PE is not necessarily a communications engineer. However, an individual with a Civil Engineering Degree, a PE and 5 to 10 years of experience in the construction of communication networks should be heavily involved in both the design and deployment of communications infrastructure.
- Many qualified communication engineers have a Bachelors, or Masters Degree, in a non-engineering field. However, their qualification for communication system design was learned on the job. Many have attended technical courses provided by equipment manufacturers or professional development companies. Taking these professional courses or seminars is a good way to keep "current" on new communication technologies.
- Many Community Colleges offer Associate Degree Programs in communication and technology engineering. These programs generally focus on the construction of telecommunication infrastructure, the installation of media and use of test equipment.
- The Armed Forces offer excellent training programs and an opportunity to design and implement telecommunication systems. Many individuals working in telecommunications have been through these programs. There's a lot of good experience gained by installing, operating and maintaining a telecommunications network in a combat area.



## Requirements Analysis

The communication system requirements document is based on the overall concept of operations for the traffic/transportation system. Keep in mind that the communication system is a supporting element of the overall system. It is important for the

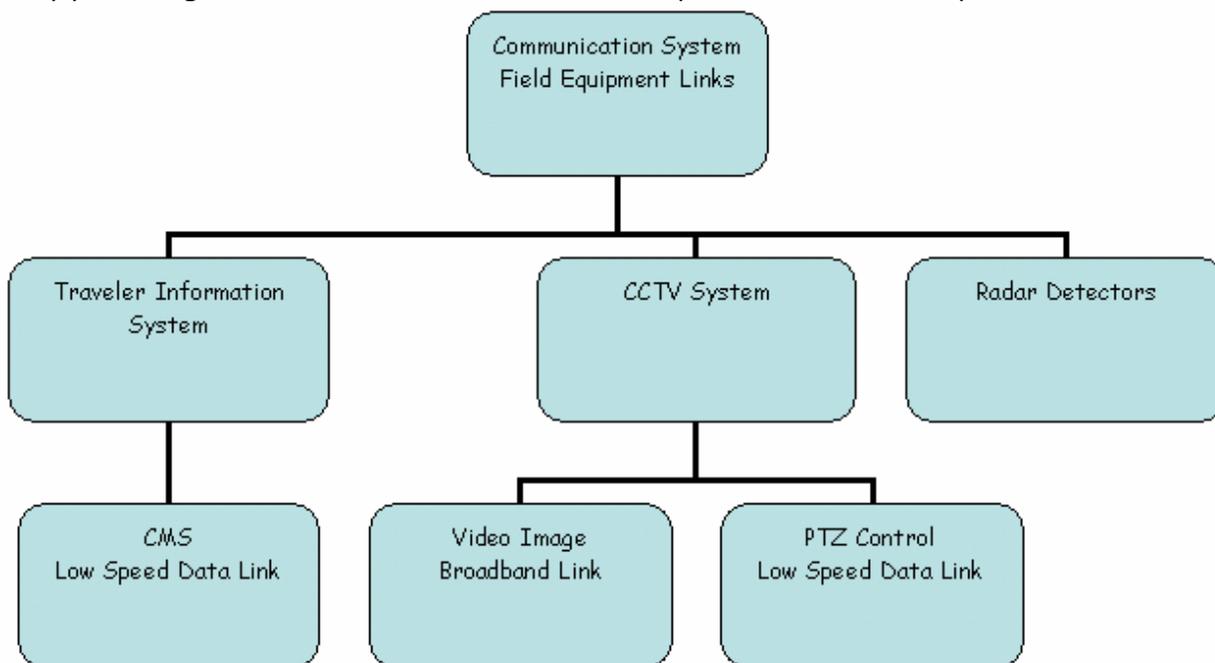


Figure 4-1: Field Devices Communication Link Requirements

project team to make certain that the communication engineer is fully aware of the *concept of operations* for the main project.

The requirements analysis sets the tone for the whole project. Organizing the requirements analysis into primary elements will help the project team visualize the interactive relationships. The organization chart (figure 4-1) is a suggested representation of one method of creating the visualization. The reader may have another preferred way to show the relationships. There is no "right" or "wrong" way to present the information. Simply be aware that creating a requirements analysis for the communications system starts with the overall program requirements analysis.

Figure 4-2, shows the relationships of the major functional elements of a proposed system and the general communication link required. In chapter 3 we looked at how the National Architecture is used to structure a relationship between various elements of a freeway management system. The requirements

analysis is the process for telling systems designers what system functionality is needed. If the whole project was laid out in a block diagram, the figure 4-3 would represent one portion of the overall diagram. This diagram represents the communication links for the field equipment.

Once the role of the communication system - in terms of the overall program - is established, the communication engineer should focus on developing this aspect of the requirements document. Following is an example of a communications system centric requirements relationship diagram:

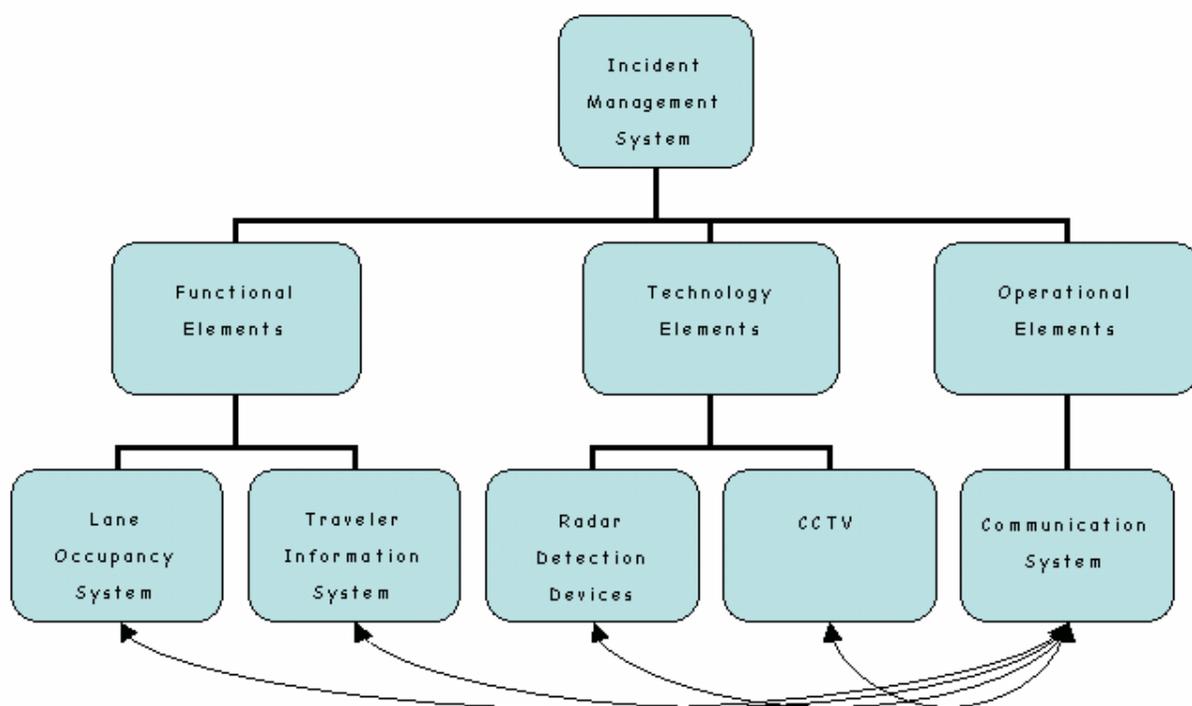


Figure 4-2: Chart Relationship Communication to Overall System

The chart is generic. There is no attempt to specify technology only general requirements. Communication technology strategy is determined by examination of the specific system requirements. The communication system is one of the operational elements of the Incident Management System. The chart shows the relationship of communications systems to the whole project and individual elements. The design engineer will be forced to explain all of the links and not overlook any requirements.

### ***THE "GEE-WHIZ" FACTOR***

It is important to approach the communications system design with the right attitude. There is a tendency to look at the "gee-whiz" of communications technologies and assume they will support project requirements. Project managers and engineers should get past this phase of the requirements analysis as quickly as possible. Streaming Video over an IP Multi-cast network is not the only solution to provide for the distribution of video. The communications systems are designed, and implemented, in support of the traffic management system - not vice-versa!

However, there is a valid reason for using the "gee-whiz" factor. Properly employed, it can lead to some innovative uses of technology. An example of the innovative use (within the transportation environment) is presented in Chapter 7. The project team should look at the "if anything is possible" scenario. It is perfectly acceptable to ask the communication engineer to look at system options using leading (sometimes called "bleeding") edge technology. The communication engineer gains an understanding of project team expectations. In return, the project team is provided with enough information to make the right decisions.

Completing the requirements analysis will provide the project development team with a clear understanding of the viable alternatives, the role of the communication system as part of the overall project and a potential budget for the communication system.

The communication requirements analysis should be completed as a part of the overall project concept of operations and requirements analysis. When practical, wait until the project requirements analysis is almost complete. The communication system is there to serve the needs of the overall traffic/transportation system.

### ***KEEP EXPECTATIONS REALISTIC – ASK QUESTIONS***

- Does the system have to be up and running 99.999% ("five nines") of the time? Does the added cost and complexity make sense considering that a "five nines" tolerance is the equivalent of 315.36 seconds (or 5.256 minutes) per year of outage?

- Is QoS (Quality of Service) really an issue or is that just the Ethernet/ATM/SONET account manager talking? Constant monitoring of all system elements is more expensive to implement than a simple ability to locate problems.
- Are there different requirements for each link and each device in the system? Don't let one element of the system create problems for all of the other elements. Compromise will be necessary.
- Is specification of end to end system latency of 1ms realistic? Consider a video system with PTZ. For the PTZ control a specification of 1ms latency may seem reasonable. However, a codec that delays the image by 2 seconds will make PTZ control unusable.
- Traffic signal systems have typically operated on a point to multipoint poll/response protocol that requires a response within 50ms or less. Is it realistic to expect wireless or internet based systems to meet the polling latency requirements of a traffic signal system?

Recognize that system reliability and quality are necessary and desirable. But, also recognize that many features and benefits have a cost. Use the "KISS" (keep it simple stupid) principle of system design whenever practical. The requirements document should help answer the following:

- Are there viable alternatives that can help to lower the overall cost?
- Can you obtain better functionality and greater value using an alternative even though it adds cost?
- Will the use of alternatives add to, or reduce, overall system complexity?
- Can the system allow for future growth or technology changes?

### ***A Systematic Engineering Approach to the Requirements Analysis***

There is no magic formula, just the tried and true "five Ws and H" question and answer technique - what, where, when, who, why, and how. The questions are not complex, but the individual answers may point to a series of complex design and implementation issues for the required communications system.

#### ***Chapter 4***

**KEY POINTS TO CONSIDER:**

- View the communication system as a part of the overall traffic/transportation project. There are many examples of adding the communications network as an afterthought. This eventually causes dissatisfaction with the communications system. The end result is a requirement to spend additional money to correct problems.
- Look at the whole system, not just the immediate construction project. Many ITS programs are developed as part of a roadway construction project. DOTs have been able to build long lengths of highway by breaking the construction into a series of small projects. However, those project sections are in fact part of a larger plan. The communications system should be part of the larger plan. There are too many examples of DOTs adding a different type of communication system to each construction project.
- The communications network must be analyzed and designed to serve the long-term traffic management needs (e.g., what will the ultimate system provide in terms of geographic coverage and functionality). The potential communication needs of other government entities should also be considered in the analysis and design. Don't design a communications system for a highway section project that will be expected to serve as part of a larger network that has not been planned.
- Answer the questions. Take note that most of the answers are provided in the context of traffic and transportation terminology. This is recognition of the purpose of the system - to provide communications capabilities for a traffic/transportation system.
- Each of the six primary questions will lead to secondary questions.
- Follow the process through to a logical conclusion.

**ASK THE QUESTIONS**

**What** is the purpose of the proposed traffic/transportation system? Look at the original project statement of purpose for this answer. Relate the communication requirements to the reason for the project's existence. Most projects require bi-directional

information flow. Many require bandwidth to support video from CCTV cameras.

- Will the communications network need to support multiple functions? Each function (traffic volume, traveler information, toll collection, congestion management) will have its own set of communication requirements.
- What is the impact of the "Market Packages" as expressed in the National Architecture to the overall project?
- What National Architecture Standards are envisioned for the system?
- What is the role of communications in the overall traffic/transportation system?

**Where** will it be located? Location of the project has an impact on overall design of the physical infrastructure and the cost of construction of a communication network. If the project is to be constructed in a narrow mountain pass, it will create challenges that won't be encountered on a local city street. Where is the TMC to be located in relation to the field equipment?

- If the TMC is located on the western edge of a city and the field equipment is located on the eastern edge, how will a communication link be created? Which will be more cost effective - lease, or construct the communications link?
- Location may also impact on the type of communication media. During the "Gee Whiz" discussions, the project team may assume that Free Space Optics (see technology description in chapter 2) would be a good system, but this may be negated by the actual location of the intended system.

**When** (over what period of time) will it be deployed? This is a question that is directed to the communication network. Does the project plan call for implementation over a relatively short period - one to two years - or a long period - five to eight years?

- During a relatively short deployment time frame, project planners can assume that communication technology will remain stable. The communication system design team can propose a system without concern that communication technology and process will change.

- Taking into consideration the total duration of traffic/transportation projects, one could expect that proposed equipment and actually delivered equipment will have changed. Example: a system was specified that required a DS-1 Multiplexer and a separate CSU/DSU. By the time the system was deployed (1.5 years later), most manufacturers were offering a combined DS-1 Mux and CSU/DSU. This lowered overall cost, saved space, and reduced power requirements. The end user - a DOT - required three months of meetings, and substantial paperwork before allowing the change - including the saving of money.
- Given the pace of change and innovation of communication technology and process, managers of long term projects should anticipate changes to equipment specifications. Under these circumstances, it might be wise to allow for a second look at communications technology before the final specifications are published. However, don't make changes that will require a total re-write of the specifications. Look for improvements (or enhancements) that create an overall cost/benefit for the project.

**Who** will operate and maintain the system? Consider whether the communication system will require that operational personnel activate various functions of the communication equipment. All of the following may have an impact on the overall design of the communication system:

- Will they need to know how to trouble-shoot for communication problems?
- Will they need to be able to effect minor repairs?
- Will they need to configure the operational functions of the communication system?
- Do I have internal staff capable of maintaining the communication system?
- What type of experience and educational qualifications are desirable?

Answering the question of who will operate and maintain the system will lead to operator and maintenance staff qualification requirements. DOTs have personnel regulations and guidelines that have to be met in order to provide staffing. Private

contractors supplying operational and maintenance personnel may have to meet other criteria. Outsourcing might be a reasonable consideration.

**Why** is the traffic system being deployed? This may seem redundant to the question of "what" is being deployed, but at this point the project team will focus on the specific type of traffic system. "Why" might be answered with a look at the research that was used to justify the deployment of the traffic/transportation system. The communication engineers responsible for analyzing and designing the communications system need to be provided with a good understanding of how various types of traffic/transportation systems work. This will lead to a design of the communication system based on the functions of the traffic/transportation equipment. Examples of various systems that should be explained:

- Enforcement controls (Traffic Signal, Speed, etc.)
- Toll Collection
- Traveler Information
- Incident Management
- Traffic Signals
- Ramp Management
- General Traffic Information Collection
- Regional Integration

There are a number of "**How**" questions to be answered and most are interrelated.

- How many devices will be deployed? A simple question that will have a tremendous impact on the overall design. A large number of devices will increase the bandwidth requirements and may strategically alter the initial communication system concept.
- How many operators at the control center? Another very simple question that may have a significant impact on the design. Related to this is a question that deals with diverse operator (or system control) locations. The number of operators will impact on the communications network within the TCC. Diverse operator locations (different buildings)

will have an impact on the entire communication network - in terms of both complexity and cost.

- How much redundancy is required? Redundancy can be viewed from several aspects. Redundant and diverse communication paths will add significantly to the overall cost of the project. It is probable that the total cost will increase by more than double. Redundant communication hardware will impact on the total by the factors of the hardware and installation costs.
- How will regional requirements be met?
- How much will it cost?
- How will it be funded? The reader might wonder - "what's the difference!" Each potential funding source will make payments under specific circumstances. Some may only pay for capital expenditures, while others may pay for capital and operational costs. The communications engineers will want to consider these aspects when making recommendations for the communication system architecture. If 50 percent of the communication system cost is for leased telephone line services, and the primary funding source will only provide for the capital expenditures, the project will lose 50% of its potential funding for communications systems. A public/private resource agreement may only provide for certain types of communication systems and equipment. Joint system development with a portion of the funding being provided by one, or more, additional agencies may add some requirements for the type of system or equipment used. The communication engineer will need to know if the funding arrangements will have an impact on the system design. In later stages of the requirements and design process, the engineer will need a good understanding of the amount of funding allocated for communications systems.

### ***Creating The Requirements Document***

Once the basic questions have been asked and answered the communications engineer will present a preliminary communication systems requirements document. The project design team should review the proposed requirements document, and consider the following:

#### ***Chapter 4***

1. **Merging Expectations with Reality** - At this point, it is time to look at the requirements for the communications system and reconcile original expectations with the realities of what is possible. Compare expectations with the preliminary communication systems design. Ask the communication engineer to fully explain how technical and financial barriers impact on expectations. Challenge the requirements document.
2. **What Type of Communications System Should I Build?** Now that the requirements document has been presented, the project team needs to determine if it should follow all of the suggestions made in the requirements document. There may be new information that was not available when the communications design team started to work on the requirements document.

#### **THREE BASIC SYSTEMS TYPES:**

- **Private System** - the DOT builds its own system and is totally responsible for the construction, operation and maintenance.
- **Public Network Based** - the entire system is leased from local telecommunication carriers or other types of communication service providers.
- **Hybrid - Public/Private** - a combination of the above systems types. In most instances, the DOT will take responsibility for field communication devices and circuits and use leased telecommunication facilities for transport back to the TCC.

#### **DEVELOPING A BUDGET**

Once the requirements have been reviewed against expectations, it's time to develop a "real" communication system budget.

- **Price out the "ideal" system** - have the communications engineers do a comparison between the system described by the requirements document, and the expected system.
- **Determine if there are alternatives** that will help the project get closer to the expected system without degrading performance criteria suggested in the requirements document.

- Are there viable alternatives that can help to lower the overall cost? The Utah DOT system described in chapter 7 provides a good alternatives example.
- Can you obtain better functionality? What's the marginal cost adjustment for a significant increase in additional functions? Will the additional functions increase the overall cost of maintenance and operation?
- Can the system provide for future growth? Not just amount of capacity, but the ability to handle (accept) technology changes.

### ***Conclusion***

#### ***A FEW SIMPLE GUIDELINES TO FOLLOW:***

- There's no magic formula
- Make certain that the communications engineering team is part of the overall project team.
- Don't let the communications engineering team act as an independent agent without direction.
- Assure that they receive significant input from the overall project team.
- Don't let the "techno-speak" (language of the communications engineers) be a creative engineering barrier.
- Investigate, and make certain that you have selected the right communication engineering team partner.
- Don't be afraid to ask questions and seek explanations. It's your system, you have a right to know!

## 5. CHAPTER FIVE – TELECOMMUNICATIONS FOR FIELD DEVICES

Previous chapters provided a look at the terminology, technology and history of telecommunications as well as the need to create a viable requirements document. This theme is continued with a look at the primary building block of telecommunications systems - the communication circuit. Telecommunication technology, its use and deployment, is an iterative process with new building upon the old. This is the industry's (telecommunication) way of assuring backward compatibility, and the continuing deployment

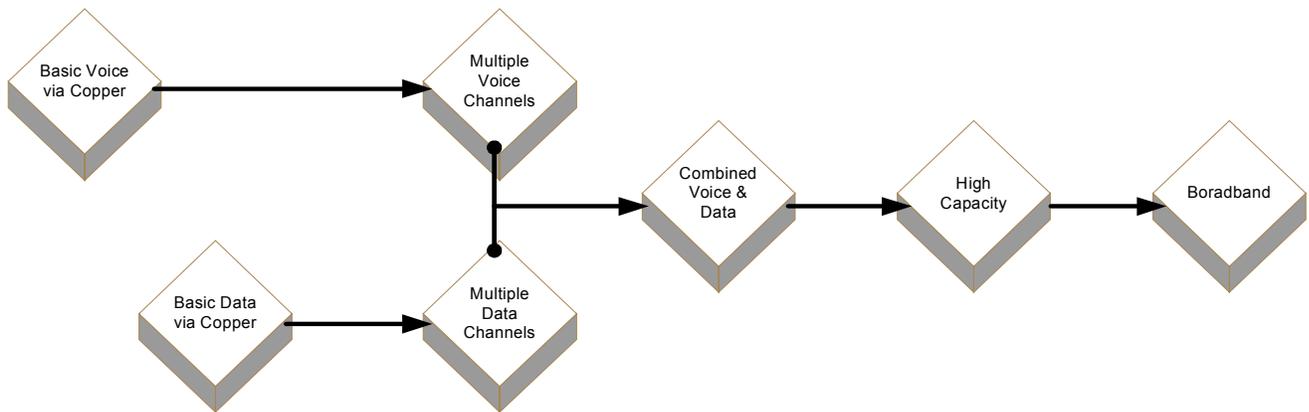


Figure 5-1: Diagram - Technology Flow

of available new technology. The diagram is a representation of the merging of voice and data over copper. Analog voice communications evolved to digital voice communications. One voice channel carried over a pair of copper wires evolved to hundreds of conversations over the same pair of wires. The use of copper as a communication medium evolved into the use of fiber. The change of technology was revolutionary, but the implementation of the change was evolutionary. No sudden and dramatic change from one technology or process to the next.

In the 1980s, that process changed. The convergence of events, technology developments, and action by the U.S. Department of Justice and the Courts precipitated a change in the corporate structure of the monopoly afforded to AT&T. The "telephone company" agreed to divide into several competing businesses. This created a competitive and open environment for the development of communications services and hardware that exists today. The basic developments and events:

- The "Carterphone" Decision of 1968 allowed end users to purchase and install telephone equipment from companies other than AT&T
- The microprocessor was invented in 1971
- Field trials by AT&T in 1977 proved that fiber could be used with transmission loss factors no greater than copper.
- The ARPANET - precursor to the Internet - was activated in 1969
- AT&T implemented a plan to break into 7 regional and independent telephone companies, plus a manufacturing company - in 1983.

These events, plus an overwhelming pent-up corporate and individual demand, converged to forge a new direction in telecommunications services and technology. However, corporate change and inventions did not minimize the desire to provide full backward compatibility with existing systems.

Telecommunication technology is a major element of the application of traffic signal and freeway management and Advanced Transportation Management Systems. The use of telecommunication technology as a part of traffic management systems has followed an evolutionary process. Early traffic signal systems - deployed 50 years ago - used available telecommunication technology. Systems being deployed today take advantage of new technologies while accommodating existing - or legacy - systems.

This chapter is devoted to a look at the specific communication circuit designs for traffic signal and freeway management systems. Much of the communication equipment used for both types of systems is very similar. There are application differences, but most of it is hierarchal and building block in nature. A common theme for all of the circuits is that they involve the use of a media or protocol converter. The flow is essentially from simple modem based systems using twisted pair, to fiber optics, and wireless, from analog transmission to digital transmission systems. From voice based communication protocols to Ethernet and Wireless Application (WAP) protocols. The examples provided in this chapter are the application of the technologies discussed in chapter Two.

Before discussing actual communication circuit types it is necessary to look at some of the basic elements of circuits, and then understand their use as part of a traffic signal or freeway management system.

### ***Basic Communication Circuits for Field Devices***

We start with basic twisted pair copper and progress through fiber optics and wireless communication technologies.

**NTCIP is actually a suite of protocols providing support for many different aspects of transportation communication system requirements.**

A key factor in the deployment of traffic and transportation control devices is the use of NTCIP (National Transportation Communication Interface Protocol) communication protocols. The use of NTCIP protocols does have an impact on the overall design of a communication network. Two rules that must always be followed in the design of a communication network:

- All communication elements cost money
- All communication protocols cost bandwidth

Every item attached to a communication circuit has a monetary value. Therefore, complex is inherently more expensive. Always attempt to keep circuit designs simple. Recognize the total cost is not just for the initial hardware. There is an added cost of installation, optimization, maintenance and operation. Avoid using complex telecommunication technologies simply because they are the newest. The "latest and greatest" won't always provide a solution to the communication challenges presented by a new traffic system. Let a properly developed communication system requirements document be your guide.

### ***BASIC CIRCUIT TYPES***

This section provides a definition of the basic communication circuit types and a concept of where communication engineers start the process of system design. Chapter Two, presented a reference to directly connected and switched communication circuits. In fact, whether direct or switched, all communication circuits fall into one of three categories:

- Point-to-Point (see diagram) - the communication connection between two devices, or a device and a controller.
- Point-to-Multipoint (see diagram) - a communication circuit connecting multiple devices to a controller. This can also be referred to as Multipoint-to-Point - depending on your starting point.
- Multipoint-to-Multipoint (see diagram) - a communication circuit allowing many devices to connect to many devices;

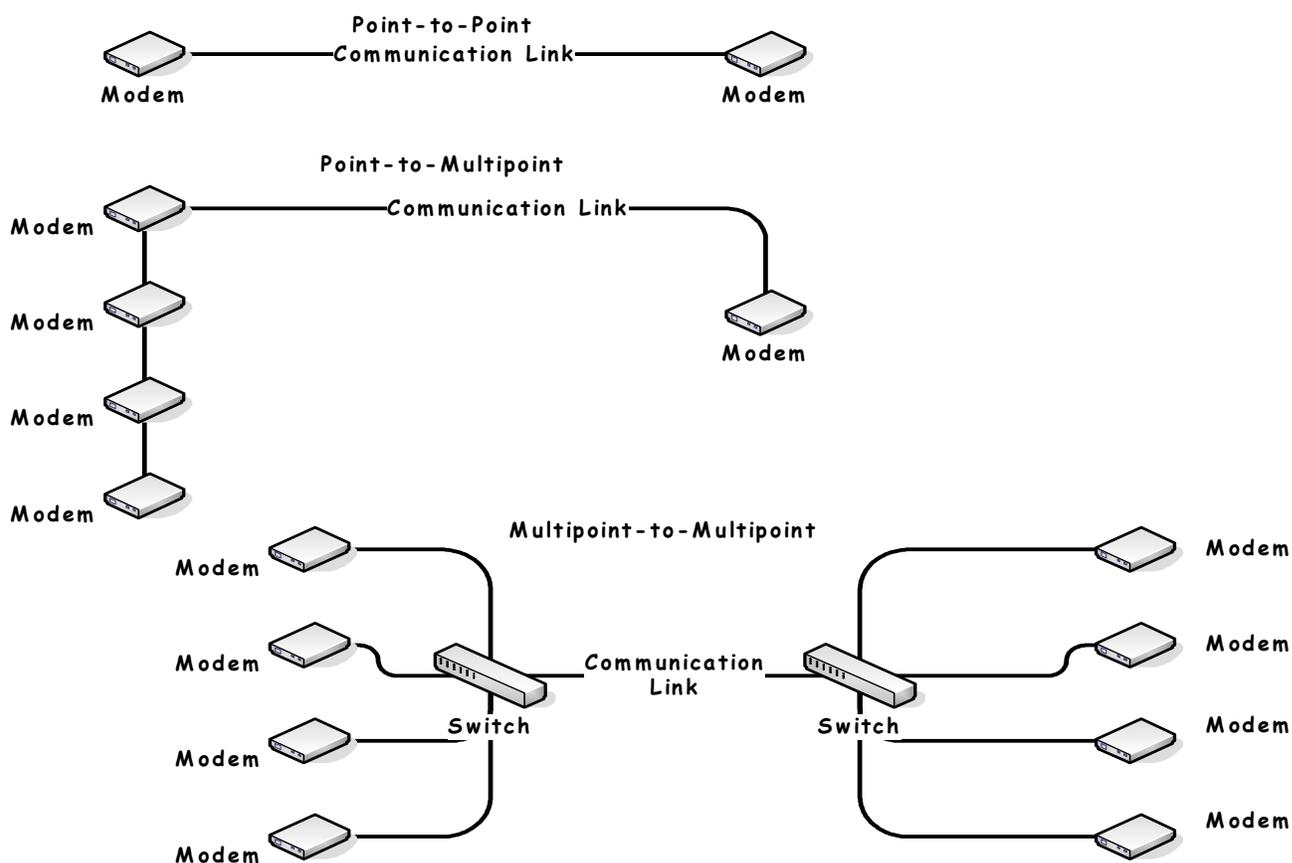


Figure 5-2: Diagram - 3 Types of Communication Circuits

this type of system always involves a switch or router.

Figure 5-2, represents the three basic circuit types using modems as the end devices connected to private line communication links. There are many variations, especially when using dial-up networks, or intelligent switches and routers. For example, the internet is an example of a Multipoint-to-Multipoint circuit. Many individual home computers can connect to one, or many web sites via the PSTN. The same type of service is also

provided via Cable TV networks using a combination of routers and broadband multiplexers.

### *The Design Process*

The development of a communication system design is very simple and not very complex - especially if a good requirements document is available. Let's take a look at the process and the steps to creating the design. Assume that a requirements document has been created for a signalized intersection project. The document lists the following communication system requirements:

- Seven 2070 controllers placed as indicated in table
- Traffic signals at intersections automatically adjusted for timing parameters by host computer
- Traffic Signals receive commands via field controllers
- Host computer will poll 2070 controllers once every second with query for data & time hack.
- 2070 controllers will store data from signalized intersections until requested by host computer
- 2070 controllers must respond to host query within 20 milliseconds
- Notice that there is no discussion of the type of technology to be used.

This allows the communication engineer to make hardware recommendations based on the requirements.

Communication engineers will generally visualize the basic communication circuit design as a block diagram rather than a mechanical design. This helps to simplify the overall design process. During the initial meeting to review the project concept, communications engineers will usually create a "back-of-the-envelope", or "table napkin", sketch. This helps to facilitate the discussion and provide the system designer and "client" (the DOT) with general points of agreement.

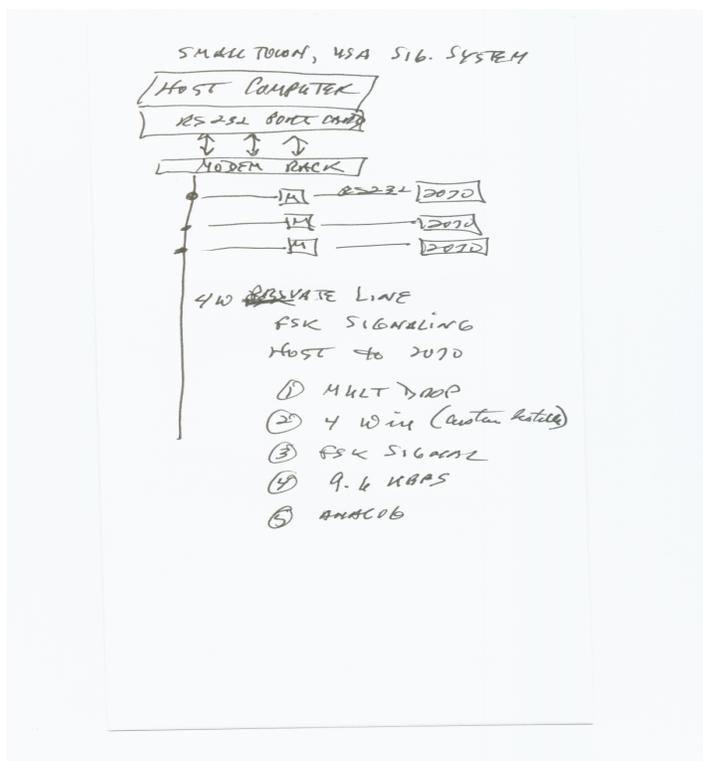


Figure 5-3: Napkin Sketch of Communication System

Communications systems are designed from the ground up. First step is to lay out the points of communication - generally identified by location. Street addresses are preferred, however traffic management systems are deployed at intersections or points on a highway. Exact locations will be determined during a site walk through. A device location table for a traffic signal system may appear as follows:

Table 5-1: Location of Field Controllers

Host Computer	Field Controller
7th & East Napa	East 2nd & East Spain
	East Napa & East Spain
	East 2nd & Patten

	East 4th & Dovall
	East 4th & East Napa
	East 4th & France
	East 4th & Patten
	East 4th & East MacArthur

The table is then laid out on a map to help identify exact locations and to provide distance measurements. The distance measurements between devices are required in order to determine "link loss". The communication engineer must know if the communication signal will need to be amplified to overcome excessive link loss. Distance measurements will also assist in the development of the construction budget.

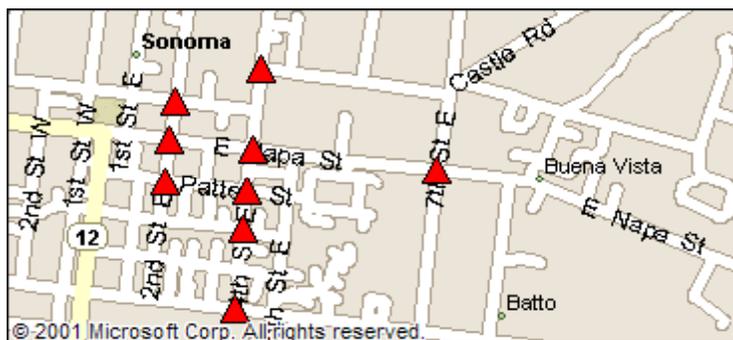


Figure 5-4: Location Map

Next, a device and bandwidth table is created. The table shows the amount of data per transmission by site. For this type of system, the host computer normally sends a "time hack" and requests that the field units send available data. The table becomes a database for the system configuration. The communication engineer needs to determine the maximum amount of data traveling in any single direction. Based on the information in the table, the maximum amount of data flows from the field units to the host computer. The total is 6400 bits.

Note: This is a "fictitious" example of a traffic signal control system for the purpose of demonstrating how to calculate data communication circuit requirements.

Therefore, a 9600 Bps (9.6kbps) communication circuit can be used successfully.

Table 5-2: Location & Data Requirements Table

Item	Host Computer	Field Controller	Maximum Data Per Transmission
1	7 <sup>th</sup> & East Napa		200 bits
2		East 2 <sup>nd</sup> & East Spain	800 bits
3		East Napa & East Spain	800 bits
4		East 2 <sup>nd</sup> & Patten	800 bits
5		East 4 <sup>th</sup> & Dovall	800 bits
6		East 4 <sup>th</sup> & East Napa	800 bits
7		East 4 <sup>th</sup> & France	800 bits
8		East 4 <sup>th</sup> & Patten	800 bits
9		East 4 <sup>th</sup> & East MacArthur	800 bits

From this information, a schematic diagram is created. The schematic helps the communication engineer visualize the relationship of all points of communication. Overall design of a communication network includes all devices and communication cable routes. Figure 5-5, might be considered as a cover page for a set of schematics showing greater detail. One of the drawings that should be included is a cable detail with a chart showing the

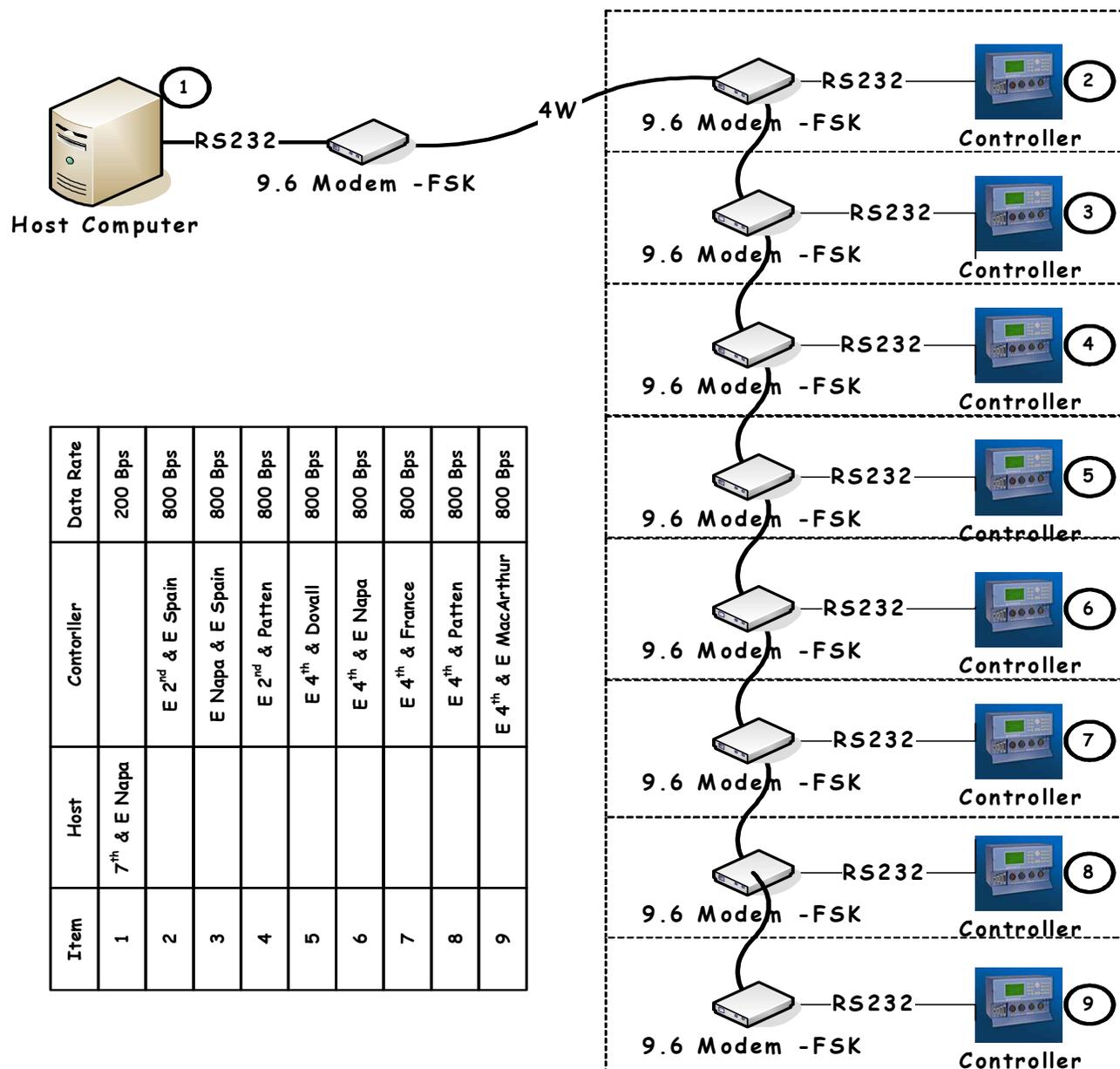


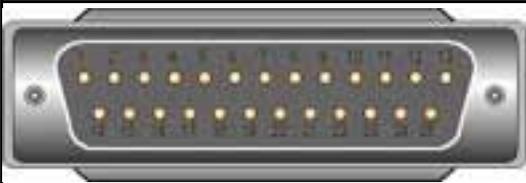
Figure 5-5: System Schematic

connector pins. Very often manufacturers make their devices with

a variety of cable connectors. Most computers use DB-9 connectors and modems tend to have either DB-25, or RJ45 connectors. If custom cables are needed, the cable connector and "pin-out" chart will save time and reduce confusion. If the Signal controller uses a DB-25 connector, and the modem has a DB-9 connector you should include a table that provides the following detail:

Table 5-3: DB-25 Connector Cable

DB-9 to DB-25 Modem to Controller Cable		
Controller 25 Pin Connector	Modem 9 Pin Connector	RS232 Signal
Pin #	Pin #	Function
1	n/a	Frame Ground
2	3	TX
3	2	RX
4	7	RTS
5	8	CTS
6	6	DSR
7	5	Signal Ground
8	1	DCD
9	n/a	+ TX
11	n/a	- TX
18	n/a	+ RX
20	4	DTR
22	9	RI
23	n/a	DSRD

25	n/a	- RX
 <p>Figure 5-6: DB-25 Connector</p>	 <p>Figure 5-7: DB-9 Connector</p>	

This chart is based on EIA/TIA standards for RS232 serial cables. Double check the standards for final reference and ask the device manufacturers to supply pin-out diagrams. Standards change, but a manufacturer may not have incorporated the changes.

This is a starting point in the overall design. As the process continues, the communication engineer will continue to refine the design until a reasonable conclusion is reached about solutions that will best support overall goals of the main project. A series of schematics are developed, and the design rules established in chapter Four are used to create a final design.

### **TRAFFIC CONTROL DEVICE CIRCUITS**

Following is a description of communications circuits commonly used in traffic and transportation systems. At the conclusion of chapter Five we will provide an example of a complex communication system that incorporates a number of varying traffic and transportation system devices. Chapter Seven will present examples of actual systems that have been deployed (or are in the process of being deployed).

Earlier, communication circuits were described as having three (3) basic elements - transmitter, receiver, and transmission medium. That description was given to provide a basic understanding of communication circuits. Communication circuits have another element in common - protocol conversion. The most elementary system - two (2) tin cans and a string - has this element. The tin cans convert sound to a vibration which is transferred to the string. A basic telephone converts the human voice (sound) to an electrical signal (protocol conversion). The electrical signal is transmitted via copper wire (media). The

electrical signal is received by another telephone and converted to sound. A modem converts the data protocol from a computer to a protocol that can be carried over a media<sup>11</sup>. Modem is a contraction of the phrase modulator/demodulator. The modem converts the binary one/zero data protocol of a computer (or other data device) to a protocol that can be carried via a specific medium. Modems have been developed for twisted pair, radio, and fiber optic.

### **TRAFFIC CONTROL SYSTEM**

Traffic controllers require a reasonably simple communication system. They are generally arrayed in a point-to-point, or point-to-multipoint serial network using low bandwidth, analog modems and twisted pair copper voice grade circuits. The greatest problem faced by a communication engineer in the design of these circuits is the polling requirements. Traffic signal systems are traditionally designed with system wide device polling every second. That is, every controller is polled once every second for information, and supplied with a clocking signal.

Remember - software and data protocols are stated in bytes, but communication transmission is stated in bits. 1200 bits of data is 150 bytes. One byte is equal to one character. Some traffic signal systems use a bit oriented message. The host computer is reading individual bits within a single byte to look for device status indications.

Consider a traffic signal system that uses a 9600 bps data transfer speed. If each device transmits 1200 bits of data per poll, then - theoretically - a maximum of eight devices can be connected on a single multipoint communication circuit. Allowing for round-trip delay or potential line problems, a communication engineer would only connect seven devices to each circuit. In theory, a signal system with 50 controllers would require eight individual multi-drop communication circuits.

If the traffic signal system uses a 10 bit message to provide all necessary information, a 9600 bps communication link could support a theoretical maximum of 960 field devices. The following formula is used: 9600 bits divided by 10 bits (each

---

<sup>11</sup> The plural term media is used because a modem can be used with many different types of media. It is the generic functionality of a modem that is being discussed in this section.

message) = 960. However, this figure is further reduced by the total time (round trip communication time) it takes to poll each device, signal attenuation based on distance, type and makeup of communication media, and the signal-to-noise ratio of the communication link. Additionally, there is the latency induced by a device to properly format and send a response.

If the system were using a byte oriented message, the maximum number of devices would be substantially less. A system that uses a message of 150 bytes would be limited to a maximum of 8 devices on a 9600 bps link - 9600 bits divided by 8 (one byte) divided by 150 bytes (each message) = 8. Make certain that the communication engineer and the software manufacturer coordinate these details. This will save time when the system is being optimized.

### *Basic Data Circuit Types*

The following diagram illustrates the basic elements of a modem. In fact, DSU/CSUs, Network Interface Cards (NIC), Video CODECs, and many other transmission devices have these same elements. Key differences are based on the type of data interface and the transmission medium.

All communication circuits use some type of media - protocol converter so that device input/output can be transported via a specific media, or through a communication network. Examples are:

- Traffic Signal Control

*Basic Modem Block Diagram*

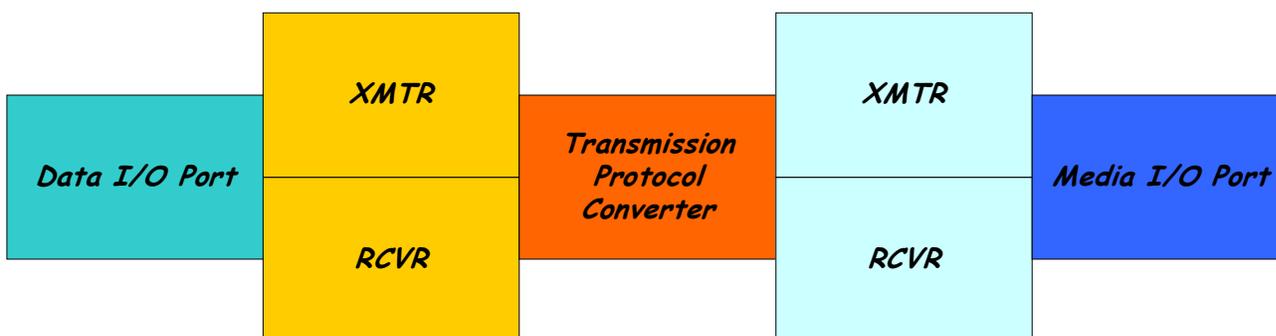


Figure 5-8: Modem Block Diagram

- Communication Cabinet for Traffic Devices
- Variable Message Sign
- CCTV Camera
- PTZ Control
- RWIS Station
- High Water Monitor

When an engineer uses a modem they consider the device as an intermediary between the data equipment and the communication network. The computer (or other data device) is called the data termination equipment (DTE) and the modem is considered the data communication equipment (DCE). DTE and DCE are terms which help a communication engineer visualize a communication system in a technology neutral manner. The DCE device has two sides - DTE and Network. Using these terms, an engineer is able to visualize the orientation of the equipment to the network.

The terms are also used in maintenance and installation manuals. Technicians are able to easily identify which side of the device is connected to the data equipment and which is connected to the network.

A CCTV camera is considered as a DTE device because it provides data in the form of an image. The camera is actually converting the image to an electrical signal which must be transported via a

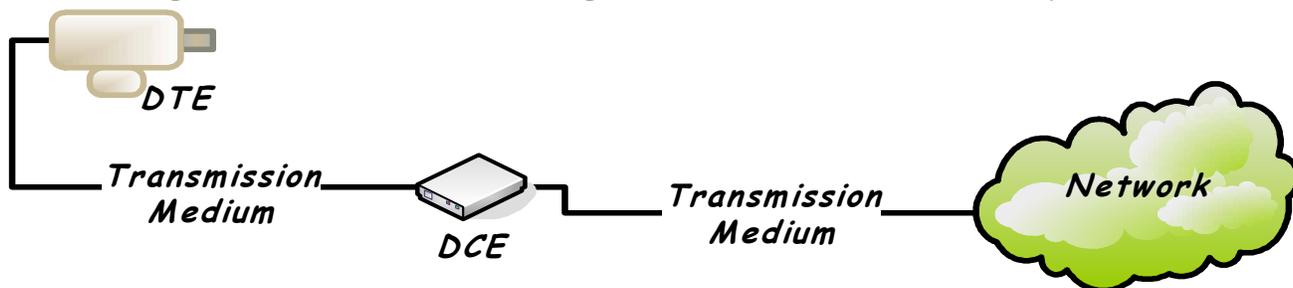


Figure 5-9: CCTV Circuit Diagram

DCE device. The DCE device could be a modem that converts the video electrical signal to a T-1 signal for transmission via twisted pair copper wire. In this case, the DCE modem device is called a CODEC.

The communication system designer may prefer to create a system layout that is very generic. The designer can choose the technologies later in the process, but still has a working idea of how the system will be developed.

When finalized, the above circuit may appear as follows:

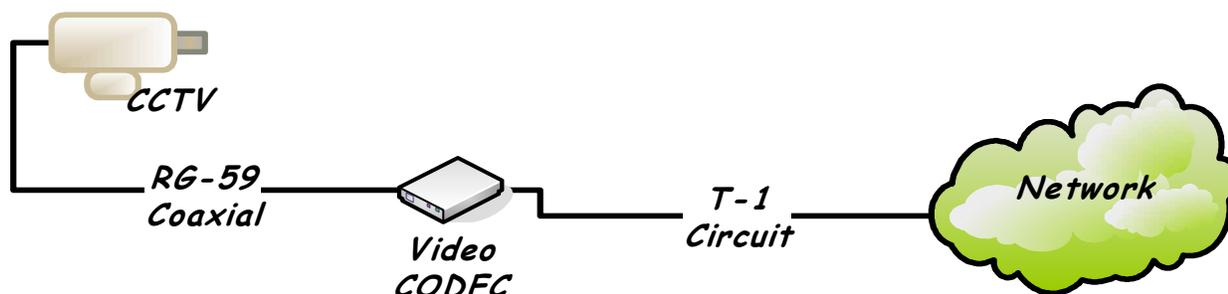


Figure 5-10: CCTV Circuit Diagram

### BASIC TRAFFIC DEVICE TYPE COMMUNICATION CIRCUITS

Communication links for Type 170/2070 and NEMA controllers are fairly simple. Under normal operation, a 1200 bit per second two-wire half duplex circuit is used. Most systems are connected using an FSK communication protocol between the field controller modem and the master controller modem. A basic direct link between a single 170/2070 and a Master Control Computer would look as figure 5-11. Note that the private twisted pair cable installed by

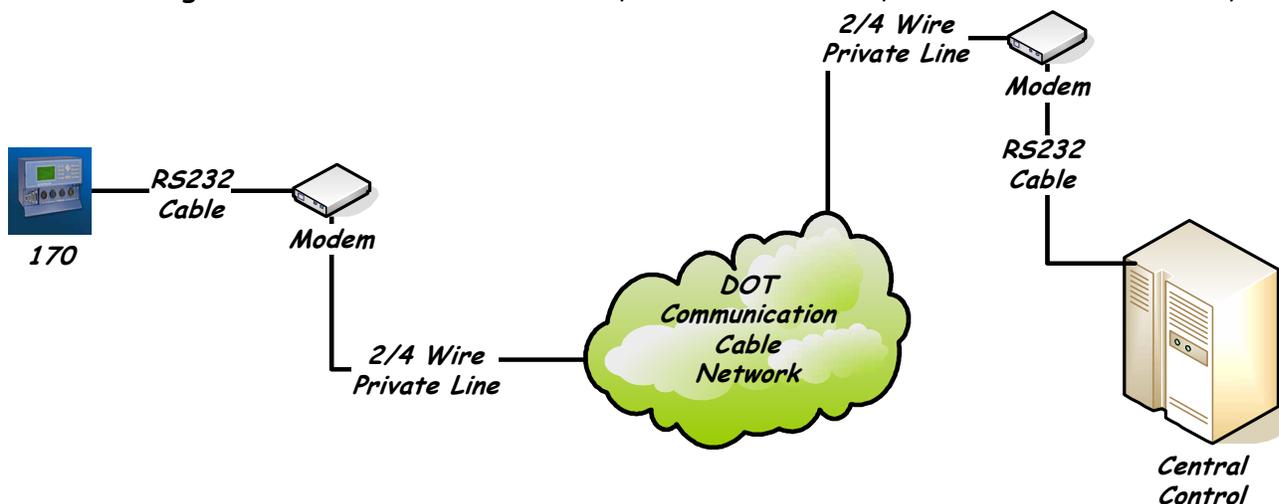


Figure 5-11: Diagram Field Controller to Host Computer

the DOT is described as a network.

Modems use a specific modulation protocol to convert the digital output of a computer (or traffic signal controller) to analog for transport via a telephone line or twisted pair. The protocol used by modems for connecting traffic signal controllers to central control computers is FSK (frequency shift keying). Frequency shift keying accommodates low speed (below 9.6 Kbps) data transfer. For higher data rates, other Modem protocols are used - PSK (Phase Shift Keying) and QAM (Quadrature Amplitude Modulation). If you want to learn more about these transmission protocols, consult any good telecommunications text book - there are several listed in the reference section of this handbook.

Frequency-shift keying (FSK) is a method of transmitting digital signals. The two binary states, "0" (Low) and "1" (high), are each represented by an analog waveform. "0" is represented by a specific frequency, and "1" is represented by a different frequency. A modem converts the binary data from a computer to FSK for transmission over telephone lines, cables, optical fiber, or wireless media. The modem also converts incoming FSK signals to digital low and high states, which the computer can "understand."

This basic communication system could be applied to almost any

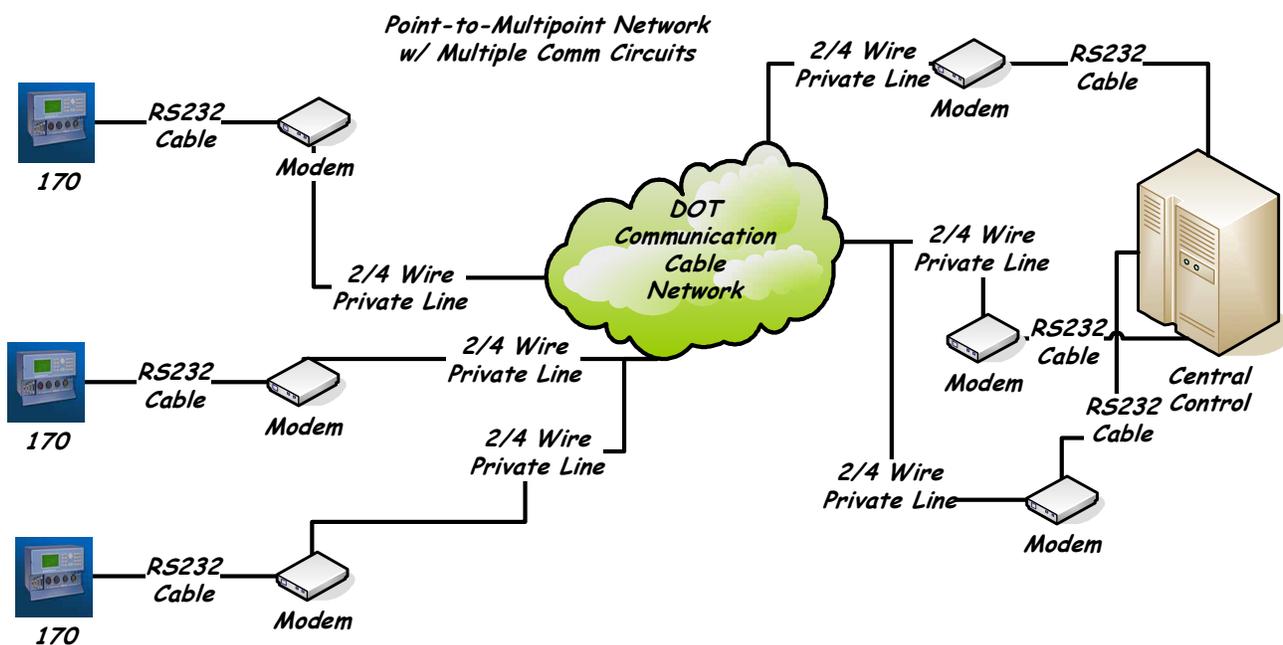


Figure 5-12: Diagram - Point-to-Multipoint

configuration. Substitute the 2/4 wire private line twisted pair with fiber and the basic network configuration does not change. The RS232 communication protocol used by the 170 controller would have to be converted to a light wave signal for transmission for transmission via the fiber. Decided to change to a newer 2070 type controller, but want to keep the existing twisted pair communication links? Just replace the controller, because the modems and transmission line remain the same. Note: *This is assuming that there are no changes to the software protocols in the overall traffic signal system.*

This arrangement (figure 5-13) can be used for multiple locations that require multiple point-to-point communication circuits. Each controller would have a direct link to the central computer and a

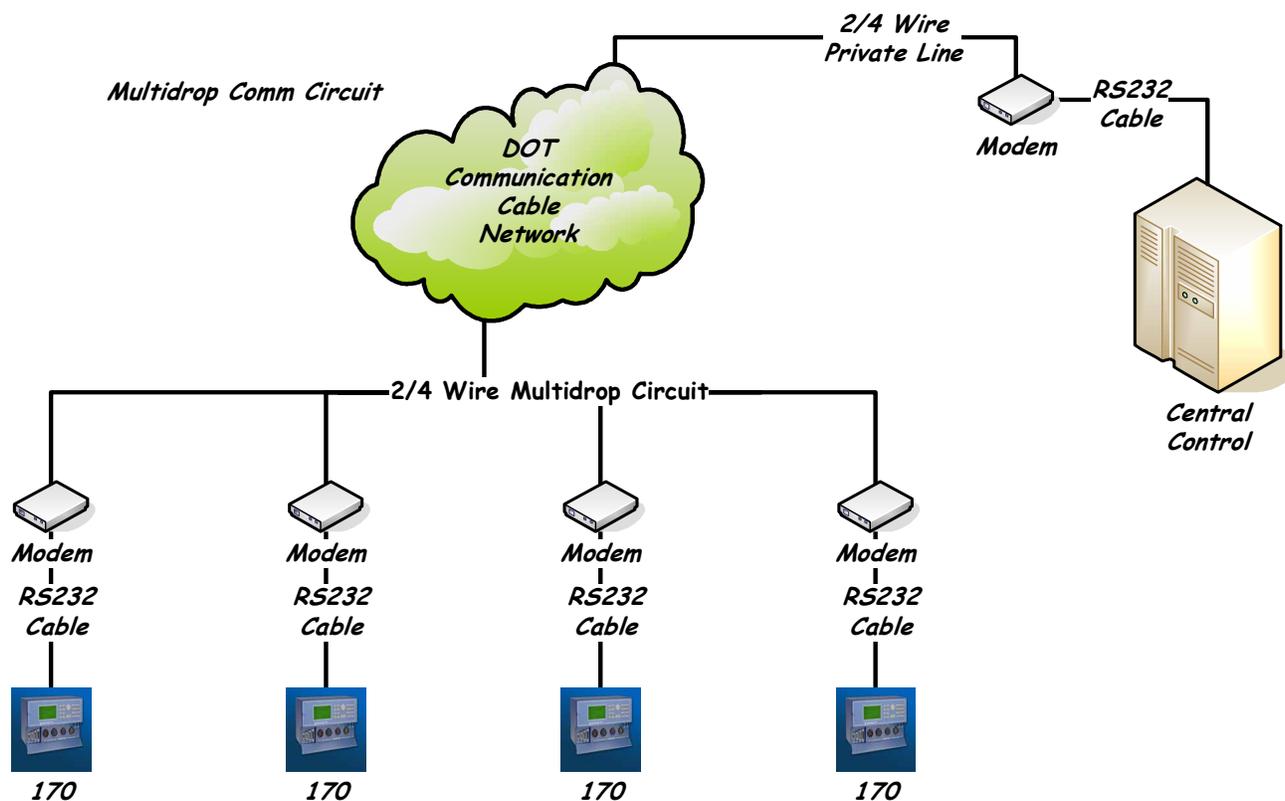


Figure 5-13: Diagram - Multidrop System

dedicated communication port. Engineers would refer to this as a point-to-multipoint communication network. The use of many communication circuits, modems, and communication ports on a central computer can be expensive. Traffic signal systems tend to use a variant of the point-to-multipoint. This arrangement is

called a multi-drop communication circuit. One modem at the central computer site serves many field modems. This scheme is especially cost efficient when leasing private line circuits from a carrier. The DOT pays for one communication circuit not the eight or more that it replaces.

The central computer is controlling all of the communications process. It polls the field controllers for information, using a point-to-multipoint arrangement that allows all field units to respond individually. They have a virtual communication circuit to the central computer. Using the multidrop configuration allows the central computer to poll all of the field units attached to a single circuit, but each field unit must respond in sequence and cannot use the circuit while another unit is transmitting. Use of a multidrop arrangement

requires close coordination between the communication system and the central computer software system. Make certain the communication engineer is fully aware of software

"Delay" - for this purpose - is defined as the amount of time elapsed from central computer request for information until it receives information from a field unit.

communication delay requirements. If a field unit modem is sufficiently distant from the central computer, the software may have to be instructed to wait an additional one or two milliseconds for a response.

The DB-25 to DB-9 diagram table - shown earlier in this chapter - indicates a pin labeled "CTS". These initials stand for "Clear-to-Send". The field unit modem will wait for a Clear-to-Send indication before transmitting information to the central computer. If too much time has elapsed the central computer will complete another poll sequence. If there is too much delay, or the central has sent out too many requests for information, the central may assume that one or more field controllers have malfunctioned and issue an error report.

### **BASIC VIDEO COMMUNICATION CIRCUITS**

Most FMS and a few traffic signal control systems use CCTV cameras to support incident detection. The communications systems used for video transport are very similar to the basic communication links discussed previously. That is, they use a communication transmission device to convert the video signal to one that is compatible with the selected media. There are several different methods used to prepare a video signal for transmission over a communication link. The most common is to convert it to an analog electrical signal and transmit via coaxial cable. Most video originating from the type of cameras used in an FMS can travel about 100 to 300 feet without degradation (depending upon the specifications of the cable). To travel longer distances the system must include amplifiers. Triaxial cable can usually provide distances of up to 1000 feet without an amplifier. All CCTV cameras used in North America provide an electrical video signal that meets standards developed by the National Television System Committee (NTSC). This standard is used by many other countries, including Japan, South Korea and Mexico. The NTSC standard is in part based on the 60 Hz AC electrical power provided in the United States, and was developed to provide a standard for broadcast television. The standard was adopted for use in CCTV systems. Two other standards exist - PAL and SECAM - based on the electrical standards in other parts of the world.

NTSC stands for National Television System Committee, which devised the NTSC television broadcast system in 1953. NTSC is also commonly used to refer to one type of television signal that can be recorded on various tape formats such as VHS, 3/4" U-matic and Betacam.

The NTSC standard has a fixed vertical resolution of 525 horizontal lines stacked on top of each other, with varying amounts of "lines" making up the horizontal resolution, depending on the electronics and formats involved. There are 60 fields displayed per second. A field is a set of even lines, or odd lines. The odd and even fields are displayed sequentially, thus interlacing the full frame. One full frame, therefore, is made of two interlaced fields, and is displayed every 1/30 of a second (30 frames per second).

### **Analog Video**

NTSC video can be transmitted via twisted pair, but not very far (a few feet). A standard telephone voice call (including low speed analog data used by traffic control devices) can be transmitted almost 20,000 feet. The difference

Note: "Hertz" is a unit of time to describe the frequency of occurrence. "Bit" and "Byte" are units of data.

is the amount of bandwidth used by the two signals. NTSC video requires between 3 MHz and 6 MHz, and a voice call requires less than 4 KHz of bandwidth. The following table provides a comparison of voice, video and text transmission requirements:

Table 5-4: Voice, Video & Text Transmission Requirements

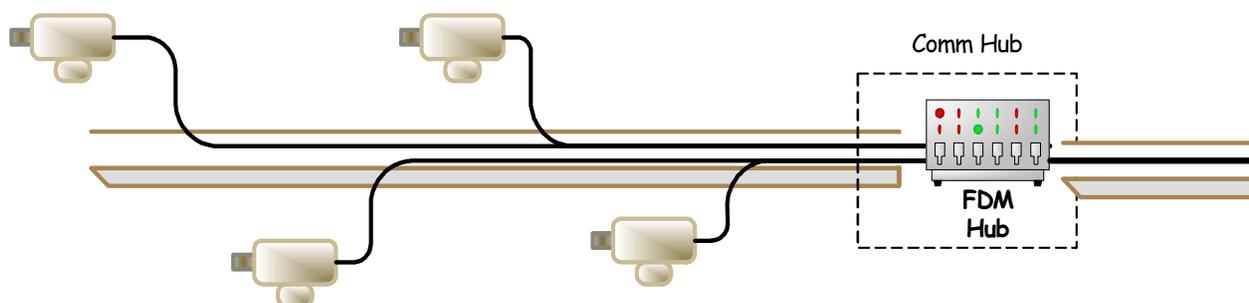
Comparison of Voice, Video and Text Transmission Requirements			
Transmission	Analog	Digital	Compressed
NTSC Video	6.3 MHz	100 Mbit/s	1.5 - 10 Mbit/s
HDTV	100 MHz	1.2 Gbit/s	20 Mbit/s
Voice Telephone	4 KHz	56 Kbit/s	4 Kbit/s
One Video Frame		3.3 Mbit/s	
One HDTV Video Frame		20 Mbits	
1000 Spoken Words		20 Mbits	
1000 Word Text File		60 Kbits	

CCTV cameras used for security and traffic incident detection do not output full broadcast quality signals and therefore do not require as much bandwidth. However, it is still greater than 4 MHz.

Most of the CCTV camera systems deployed in the 1990s used analog transmission systems with either coaxial cable or fiber optic cable. They were generally deployed in a configuration that used one communication link for each camera. As system operators gained knowledge of the video systems, they recognized that video signals could be multiplexed, allowing four (4) to sixteen (16) cameras to share a common communication link. Each camera could send a full video signal using a common coaxial cable (or fiber optic cable), and each could be displayed on individual monitors at the TMC. One of the drawbacks to this arrangement was that each video signal had to be brought to a

communications hub for multiplexing. However, there was a significant savings for the total cost of the communications infrastructure. Figure 5-14, is a block diagram representing the basic elements of a frequency division multiplexing system.

Video signals can also be converted to a digital signal in the same manner as voice is converted. A voice signal is digitized into a 64 Kbit/s signal and can easily be transmitted via two twisted pair for up to 6,000 feet. However, a full NTSC video signal requires a 100 Mbit/s signal and will not travel more than a few feet over



*Four cameras deployed at 3000 foot intervals are hubed at a convenient location. Their video signals are multiplexed onto a single coaxial cable for transmission to the TMC.*

Figure 5-14: Diagram - FDM Hub Circuit

the same two twisted pair cable. In fact twisted pair is not used for DS-3; carriers use coaxial cable, or fiber. Full bandwidth video signals don't travel very far (100 to 1000 feet) over coaxial cable. Transmitting video for any significant distance requires the use of a Video CODEC (coder/decoder). This type of CODEC is designed to use a DS-3 communication circuit. The DS-3 circuit is the equivalent of almost 45 Mbit/s. The reduction of the bandwidth to less than half of what is normally required is barely noticeable and in fact is used by broadcasters to send programming between television stations. DOTs have traditionally not used DS-3 CODECs because the cost of deployment was significantly greater than using the FDM type systems described above. DS-3 video CODECs have been in use for many years for "Distance Learning" programs and video conferencing. Many DOTs have deployed video systems using T-1/DS-1 communication links. Figure 5-15 is an example of a typical Video CODEC system using a T-1.

### Digital Video CODECS

In the 1990s, DOTs began to deploy video CODECs that could use DS-1 communication circuits (see figure 5-15). Telephone companies provided lower cost (than DS-3) services and the DOT

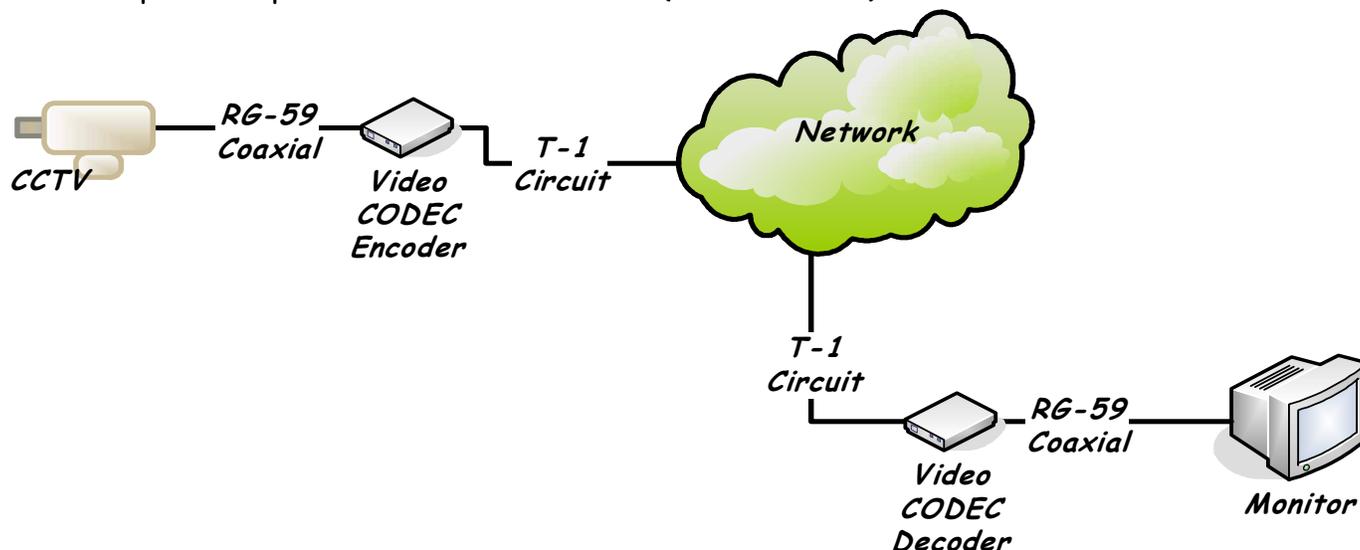


Figure 5-15: Diagram - CCTV with CODEC

could install twisted pair infrastructure within their own rights-of-way.

Several different types of video CODECs are available to serve a wide variety of communication needs. The CODEC provides two functions. First, it converts the analog video to a digital code. Second, it "compresses" the digital information to reduce the amount of bandwidth required for transmission. In the process of converting from analog to digital and back to analog, the video image loses some quality. The compression process also adds a small loss of video quality. Each of the following CODECs are used in DS-1 systems and has its own set of video image quality loss characteristics.

- H.261 CODECs are used primarily for PSTN based video conferencing. The A to D process sacrifices motion for video and audio quality. They typically use POTS (or DDS) services to reduce total cost of operation and are designed to provide simultaneous multiple connections for group conferencing. However, they can use DS-1 and "fractional DS-1" circuits for better image quality.

- JPEG (Joint Photographic Experts Group) and Motion JPEG are some of the most widely used CODECs for video surveillance purposes. However, they were primarily developed for the purpose of storing images electronically. Each still image is converted to an electronic data image and transmitted. The still images are assembled at a receive decoder and displayed at a rapid rate to provide motion. They can be used with POTS communication circuits, fixed low speed data circuits, or broadband copper and fiber optic communication links. They are also used in wireless applications such as spread spectrum radio.
- MPEG (Moving Picture Experts Group) CODECs were developed to provide a better quality motion image compression. There is less image quality lost in the conversion and compression processes. However, the primary purpose of MPEG CODECs is to provide "real-time like" motion pictures via the internet (also called Streaming Video). The overall process creates a storage buffer so that there is always a slight delay between the request to view and the start of the motion picture. For the average user of the internet, this is not a problem. CODEC manufacturers using the MPEG-2 standard for traffic surveillance purposes have adapted this standard to create a real-time video transmission. However, this does have a minimal impact on final image quality. The MPEG-4 standard was developed for internet streaming video, but is also being adapted for "real-time" surveillance purposes.

### ***Pan-Tilt-Zoom Issues***

The use of pan-tilt-zoom (PTZ) created another problem. These devices use either a direct electrical signal with variable voltages, or special coding to activate one of the functions. The manufacturers of the PTZ devices developed special modems that convert the PTZ signal to an RS232 data stream so that it can be transmitted via standard communication circuits. This requires a separate communication path. Incident management systems built during the 1990s generally required separate communications equipment for both the video and the PTZ control. Originally, CCTV camera manufacturers offered an external converter. One was required at the camera end and the other with the video switcher at the TMC. Today, manufacturers offer products that

combine both in one system using a single communication path. Most video CODECs and Fiber Video modems have a PTZ data port as part of the package, and cameras and switchers have the control signal conversions devices embedded. The video signal and the PTZ signal travel in opposite directions allowing full bandwidth to be provided for the video signal.

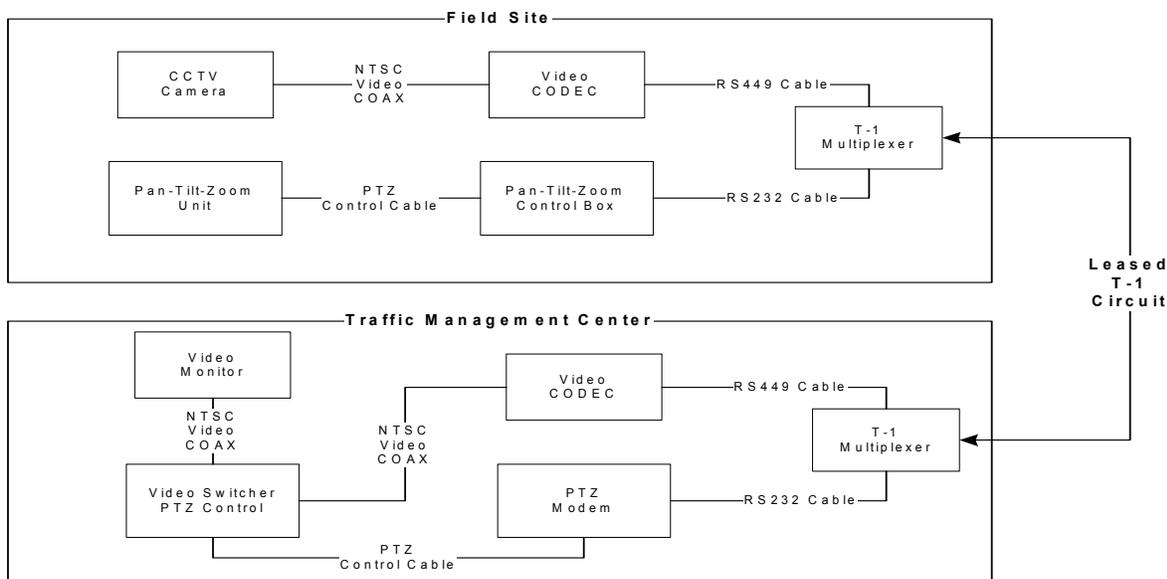


Figure 5-16: Diagram - Typical CODEC Communication Circuit - 1990's Deployment

### VIDEO-OVER-IP (VIP)

The video systems described previously were developed to work over communication networks that existed to process voice communications. All data and video transmissions have to be adapted for transport over large point-to-point communication networks. This requires a significant investment in transmission hardware and software systems and media infrastructure. Ethernet and VIP help to reduce the overall complexity of the communications networks and significantly lower the cost of hardware and infrastructure required to support the system. One of the major benefits is the relative ease with which video can be distributed to desktop computer workstations. Before discussing VIP, a quick look at how TV cameras function.

Distributed computing and the explosion of the Internet have driven the use of internetworking for over 30 years. Practically

every network in place today was engineered based on standards and technology optimized for handling the single data type, character data, that was prevalent as recently as 10 years ago. Today's sophisticated applications often require networks to handle video, storage and IP/Telephony. The speed and bandwidth requirements for applications using these data types are so high that most network technology is simply not up to the task. DOTs implementing new Advanced Transportation Management Systems (ATMS) are looking to new data communication technologies to help simplify their networks, and reduce the overall costs of deployment and maintenance. Ethernet for general data communication and video-over-IP are logical choices. The next few pages will look at the deployment of Video-over-IP.

TV cameras were first designed using an image pick-up tube. The face of the tube was coated with a light sensitive film that captured the image. The film created an electrical charge which was captured as an analog electrical signal. The electrical representation of the image was transmitted to a monitor. The output of the camera was an analog video signal. All of the equipment described above was needed to convert the video image to something that could be transported via the existing network infrastructure.

In the early 1990s, the "Charged Coupled Device" (CCD) was perfected. A CCD is an electrical device that is used to create images of objects, store information (analogous to the way a computer stores information), or transfer electrical charge (as part of larger device). It receives as input light from an object. The CCD takes this optical input and converts it into an electronic signal - the output. The electronic signal is then processed by some other equipment and/or software to produce an image. The camera must convert the digital image to an analog TV signal.

Initially, video transmitted via the Internet, was required to be converted from analog to digital, and then compressed for efficient transmission. VIP was created as a protocol for the efficient transmission of video via the internet (more about video over the internet and streaming video in Chapter 9). Some enterprising engineer recognized that cameras with CCDs were already capable of providing a digital image signal that was compatible with the digital display output of a typical desktop computer. CCTV cameras are manufactured today with a direct IP

output. They can be directly connected to a communication circuit capable of carrying IP traffic. The image data from the camera can be directly routed to a desktop computer.

Two types of basic VIP circuits can be used for video surveillance and incident detection in an FMS or traffic signal control system:

- Direct VIP CCTV camera to Desktop Work Station
- Analog CCTV camera to Desktop Work Station.

The first is very simple (as shown in figure 5-17), and the second does not have a high degree of difficulty. The direct system uses a camera that is designed to provide a direct output to an

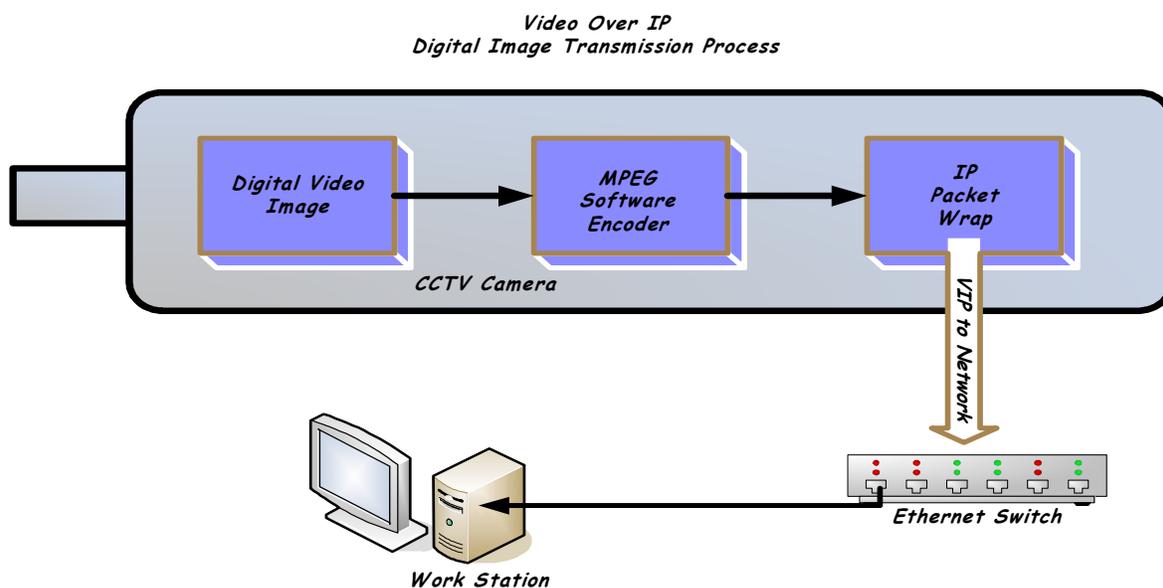


Figure 5-17: VIP Basic Camera System

Ethernet. The digital video signal is compressed using an MPEG software encoder, and then wrapped in an IP packet for transmission. The second system (as shown in figure 5-18) requires a video CODEC that is designed to take the analog output of an existing CCTV camera, convert it to digital, encode the signal, and wrap it in an IP packet for transmission. There is no need to convert the video signal back to analog. Just use any media viewer application with a compatible MPEG software decoder.

Converting an existing system to VIP is relatively simple. Replace existing Video CODECs (or FDM modems) with a VIP CODEC. In most cases (note: replacement of an FDM system requires additional consideration of communication equipment), the existing communications cable infrastructure can be kept in place. Chapter Seven provides a description of the process used by Utah DOT to update its ATMS system to VIP. In the process, they were able to eliminate an expensive analog video switcher,

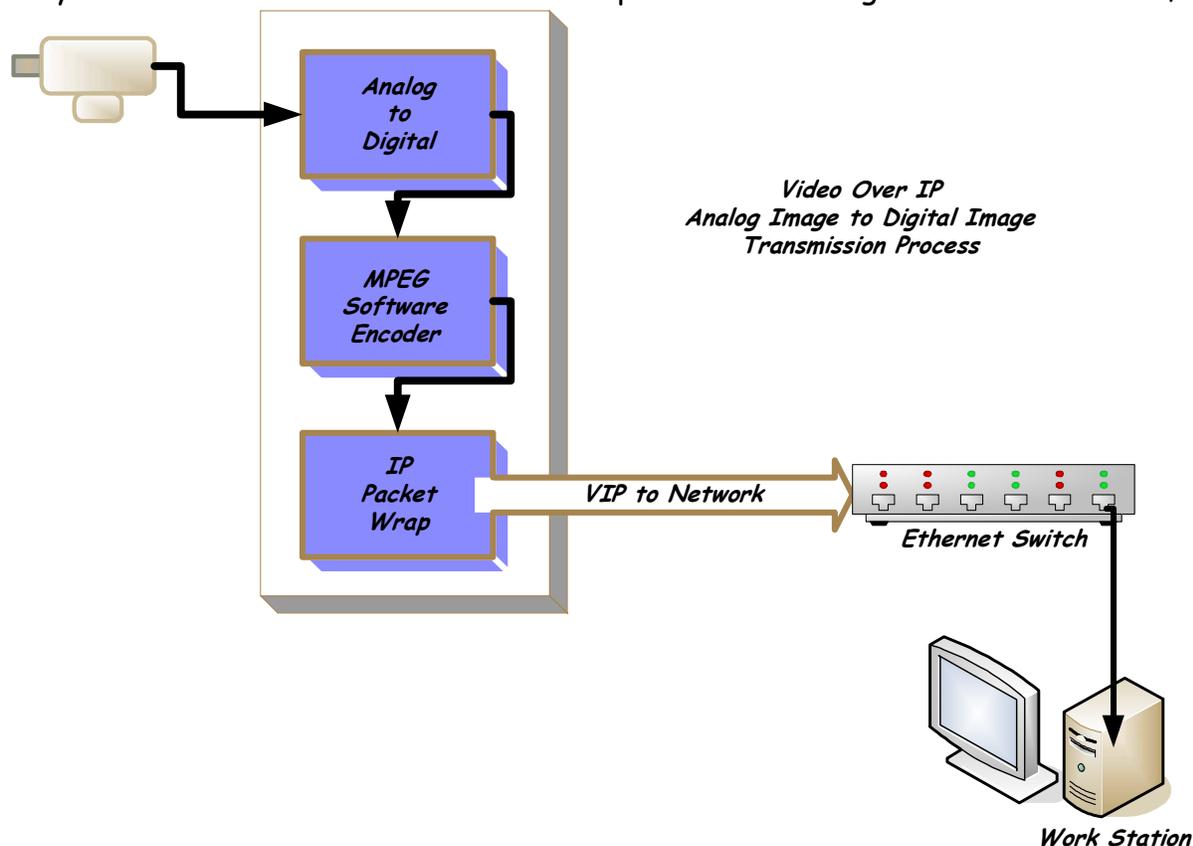


Figure 5-18: Diagram - Add-on Conversion to VIP

and conveniently distribute video to multiple traffic, transportation and public safety agencies.

## Basic Traffic and Freeway Management Networks

### BASIC DEVICE NETWORKS

The following systems all require the same type of communication circuit - low speed (9600 Bps or less). Some devices are connected via dial-up and others via private leased-line. RWIS systems normally communicate via a wide area radio link - a typical communication circuit diagram is provided below.

- Dynamic Message Signs
- Loop detectors
- Radar detectors
- Video detectors
- Remote Weather Information Systems (RWIS)
- Ramp Metering
- Pavement Condition Sensors

Note: Figure 5-19, is a basic network diagram for the listed devices. However, each device is unique and requires a specific set-up.

These devices all send or receive short (a few bytes) messages

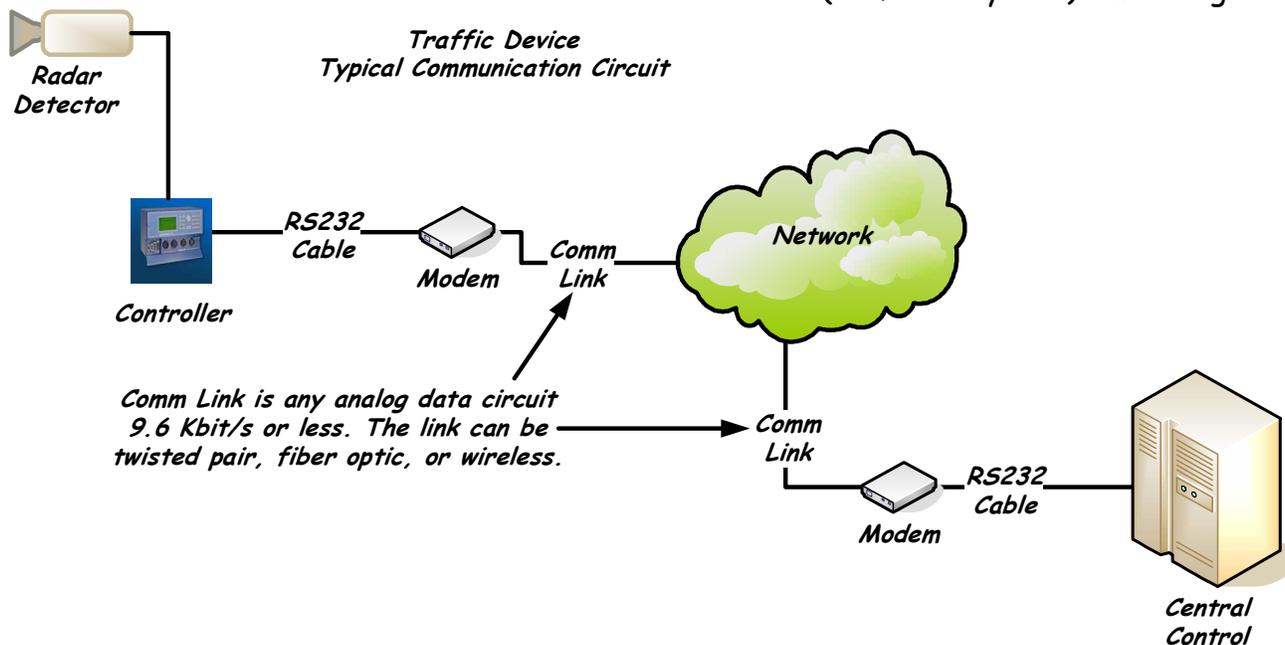


Figure 5-19: Diagram - Basic Traffic Device Communication Circuit

(e.g.: status, condition measurements, temperature, volume and speed, etc.). Most communication links are similar to those used by traffic signal controllers. One significant note is that RWIS sensors, very often, are located in remote areas without easy access to power and communication utilities. The preferred communication link is wide area radio. Wide area radio uses frequencies in the same range as Police, Fire, or Highway Maintenance vehicles. The systems use a fixed low power radio with a very directional antenna. The FCC has specific rules for using these types of radio systems on a secondary and non-interfering basis. The radio frequency availability and the rules for use are listed under "Title 47 CFR 90.20".

A communication engineer must be aware of all of the devices that will be deployed in the system. Each type of device has a set of communication requirements. The key differences are the frequency of communication, and the amount of data to be transferred. These factors are multiplied by the total number of devices to help determine the amount of required bandwidth.

This section dealt with basic communication circuits for traffic signal control, video incident detection, and generic traffic devices. The next section will provide a look at how all of the circuits are integrated into a single communication network. The principles of multiplexing described in Chapter 2 will be applicable.

### ***Complex Communication Networks***

Let's take a look at communication networks that support a complex traffic management system (an ATMS) combining traffic signals, CCTV cameras, dynamic message signs and radar detectors used for traffic volume and speed monitoring. A series of basic system design criteria and block diagrams will be created. Each will eventually become part of the requirements and specification documentation that is presented to potential engineering services, systems integrators and construction services vendors. Following is a typical scenario:

*The basic system is planned for a major arterial that connects a suburban community to a major urban center. The overall route is 10 miles with a traffic signal system at both ends of the arterial,*

*some low points that flood during frequent heavy rain storms and a total of six travel lanes throughout the arterial system.*

*The local DOT wants to optimize the traffic signal operation in both the suburban and urban areas adjacent to the arterial. They will utilize information collected from the arterial traffic flow radar speed and volume detectors at various points along the arterial. Additionally, the DOT will monitor for traffic incidents using radar detectors and CCTV cameras, and be notified of flooding conditions during rain storms via RWIS sensors.*

*The DOT has specified that it does not want to construct a private communication network. There is easy access to communication facilities adjacent to the arterial that can be leased from "LocalTel".*

The engineer developing the communication network will create several diagrams to assist in overall system design. One of those diagrams should be a private system alternative to provide cost comparisons.

First, the engineer will create an overview block diagram to help visualize the relationship of the primary connection points. The communications engineer will also draft a narrative of the overall system - actually a statement of understanding, or concept of operations (from a communication perspective):

*"The proposed network will provide communication links to connect four (4) primary elements: existing suburban traffic*

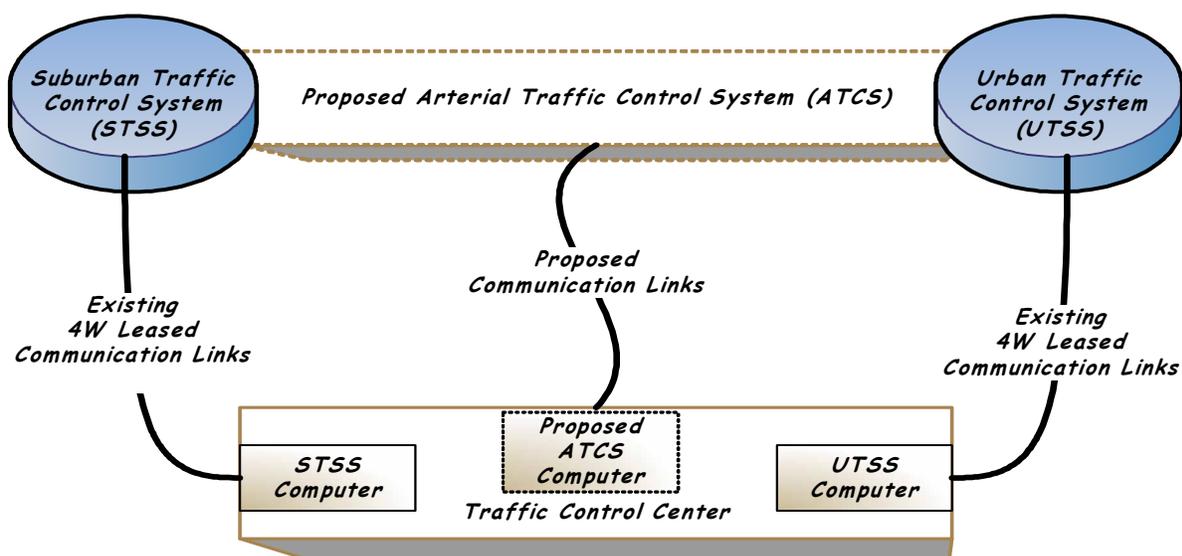


Figure 5-20: Diagram of Proposed System

*signal system; existing urban traffic signal system; proposed arterial traffic control system; proposed central traffic control center. In addition to existing 170 type traffic signal controllers, the D.O.T. is proposing to add CCTV, changeable message signs, speed and volume detection equipment, deer crossing sensors, RWIS sensors, connectivity to the internet, and communication links to a regional traffic advisory network. The proposed system will replace existing copper communication links with fiber and make use of spread spectrum radio to link remote devices. New traffic signal control computers will be placed in the proposed TCC. The existing traffic signal control computers will remain in place as backup servers."*

This paragraph is reviewed by the project team for concurrence or changes. A block diagram representing the statement is created as a visual aid.

Next in the process is the creation of an overview of the major systems. The overviews include simple block diagrams and a brief written description of the system.

*Suburban Traffic Signal System (figure 5-21): "The town of Nowheresville has an existing traffic signal system with a total*

**STSS Comm Diagram**

**Notes:**

- ⊗ 2 Comm Links @9.6
- ⊗ 4W Private Lined Leased from Local Telephone Company
- ⊗ No circuit problems
- ⊗ Circuit #1 = 12 Drops
- ⊗ Circuit #2 = 9 Drops

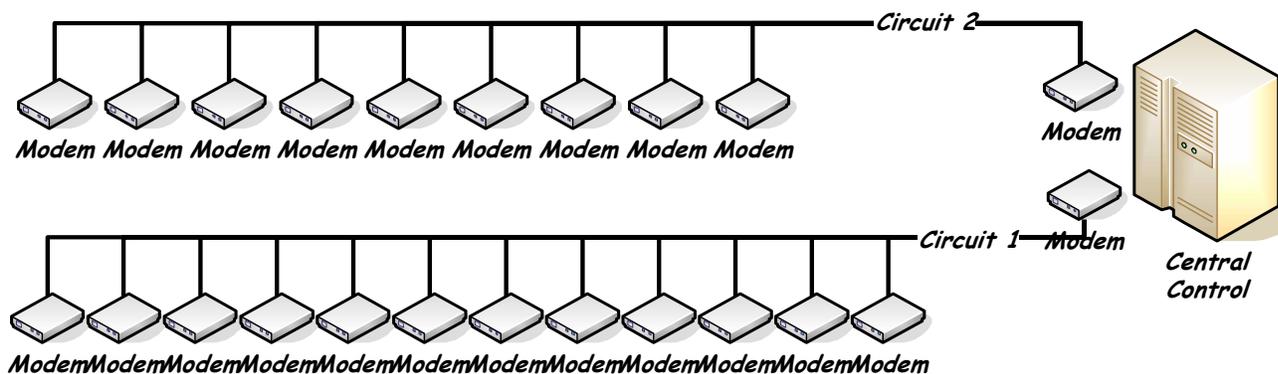


Figure 5-21: Diagram STSS Communication System

*of twenty-one 170 Type signal controllers. " The system is deployed using two 4-wire 9.6 Kb/s multi-drop circuits leased from the Nowheresville Community Telephone Company. Modems*

used in the systems operate in a half-duplex mode. The traffic signal controllers are deployed in a 10 square block area of the community with the controlling computer located at 5th & Arch Streets.

Urban Traffic Signal System (figure 5-22): "The city of Wearegreat has an existing traffic signal system with a total of

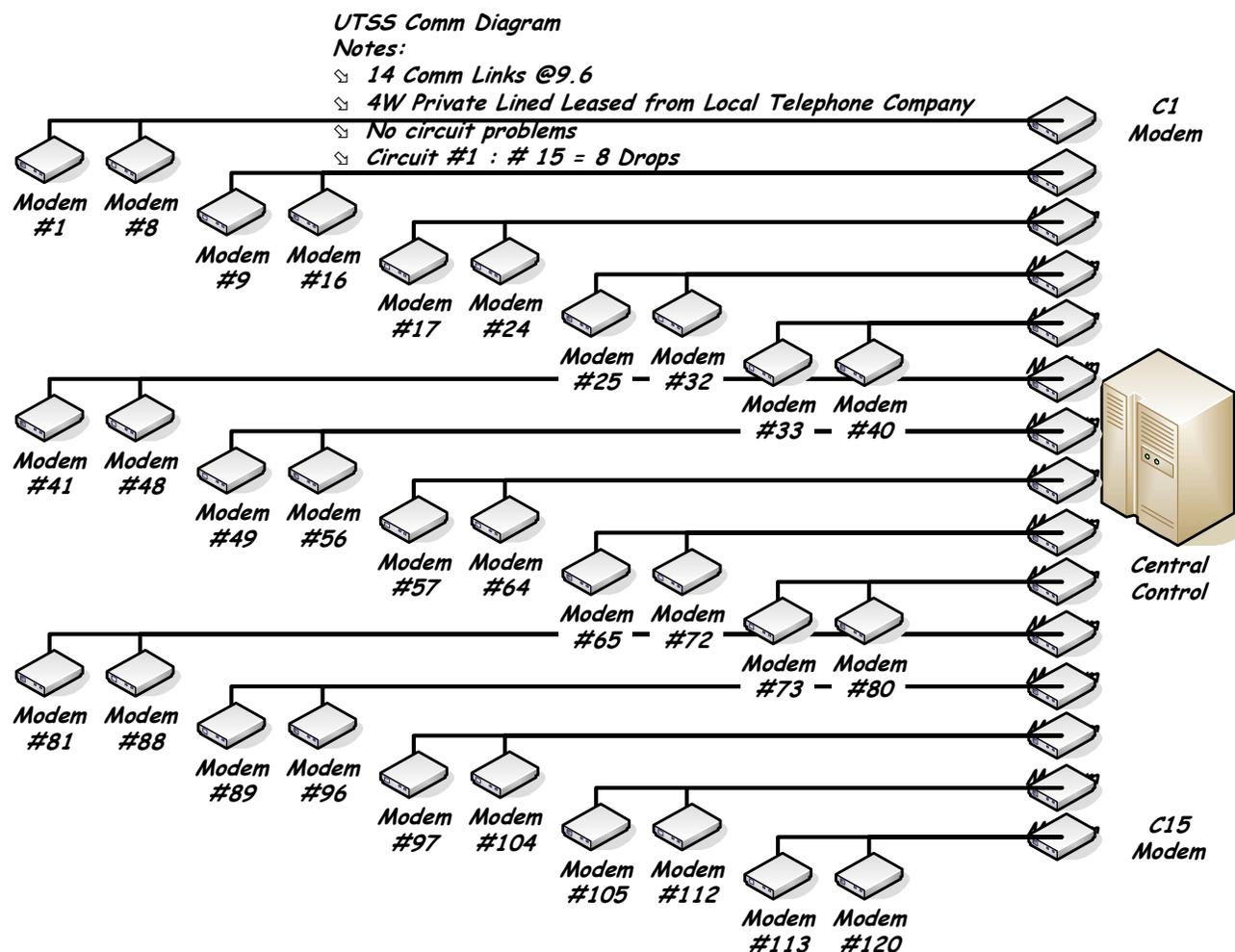


Figure 5-22: Diagram UTSS Communication System

one hundred twenty (120) 170 Type signal controllers. The system is deployed using fifteen (15) 4-wire 9.6 multi-drop circuits leased from the Verybig Telephone Company. Modems used in the systems operate in a half-duplex mode. The traffic signal controllers are deployed in throughout the city with the controlling computer located at Broad & Main Streets."

The next set of schematics is for proposed systems. There is less detail because the systems that are represented do not exist. The engineer may put in some information about the communication circuits, but realizes that they will change as the development process continues. The following schematic (figure 5-23) shows the proposed connecting arterial management system. The objective in the "first pass" at the system design should be generic making very few assumptions about the technologies that will be deployed. A database is developed using mile marker indicators as a reference for where equipment will be located. The requirements document should indicate the type of devices that will be deployed with approximate distances. The project team (including the communications engineer) should complete a field survey to pinpoint device locations. This will be critical for

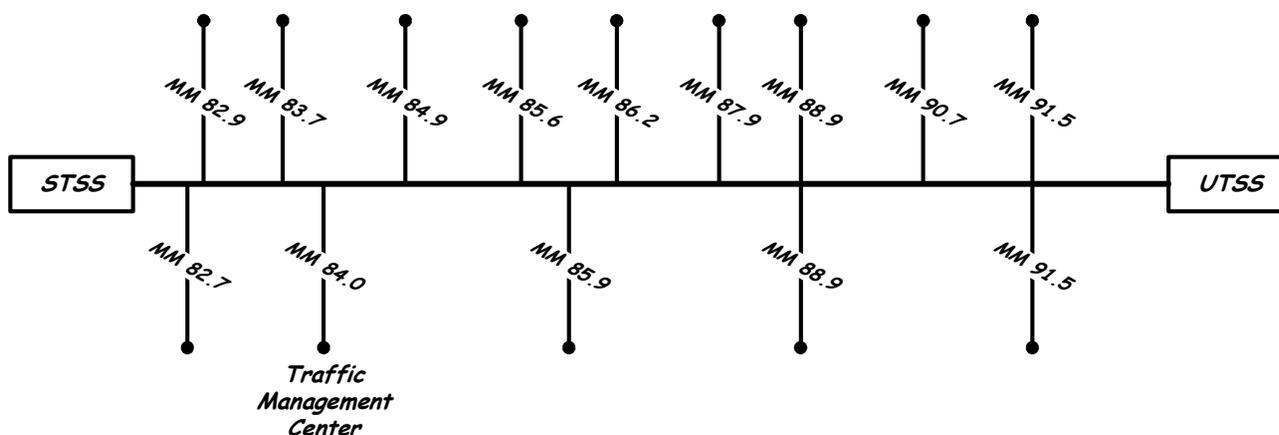


Figure 5-23: Straight Line Diagram

the communications system. The communication system designer will have to assure that there is enough signal strength. In addition to the device location, the table should also list approximate data bandwidth requirements.

Field Devices		
Device	Field Unit Location	Max Data Transaction/Sec
CCTV - PTZ Control	MM 82.9	1.536 Mbit/s
	MM 83.7	1.536 Mbit/s
	MM 84.9	1.536 Mbit/s
	MM 85.6	1.536 Mbit/s
	MM 86.2	1.536 Mbit/s
	MM 87.9	1.536 Mbit/s
	MM 88.9	1.536 Mbit/s
	MM 90.7	1.536 Mbit/s
	MM 91.5	1.536 Mbit/s
RWIS	MM 85.6	2400 Bit/s
	MM 86.2	2400 Bit/s
Radar Detector	MM 82.9	1200 Bit/s
	MM 85.6	1200 Bit/s
	MM 86.2	1200 Bit/s
	MM 87.9	1200 Bit/s
	MM 88.9	1200 Bit/s
Dynamic Message Sign	MM 82.7	2400 Bit/s
	MM 85.9	2400 Bit/s
	MM 88.5	2400 Bit/s
	MM 91.5	2400 Bit/s
Traffic Management Center	MM 84.0	TBD

Table 5-5: Field Device Location

A straight line communication diagram (figure 5-23) is created from this information. The table and the straight line diagram help to provide the communication engineer with a better understanding of where devices will be placed.

The communication system engineer creates a block diagram for each site to show how each device will be connected to the TMC. The diagram contains all necessary information and details the communication links and the type of connections for each device. A written description of the site details is also provided. Here's an example based on MM 85.6:

*"The site at MM 85.6 will contain one CCTV Camera with PTZ side mounted at the 20 foot level of a 30 foot pole, an RWIS system will be placed on the top of the pole, and a radar detector will be side mounted at the 15 foot level. All of the communications equipment will be placed in a cabinet at the base of the pole. The communications cabinet will contain a Video CODEC which will have an RS 232 port for the PTZ. The cabinet will house a CSU/DSU multiplexer with four data ports. The primary communication link to the TMC will be a leased DS-1. A utility demarcation point will be placed within 50 feet of the site. The DOT will run necessary communication cable and power cable from the site to the utility demarcation."*

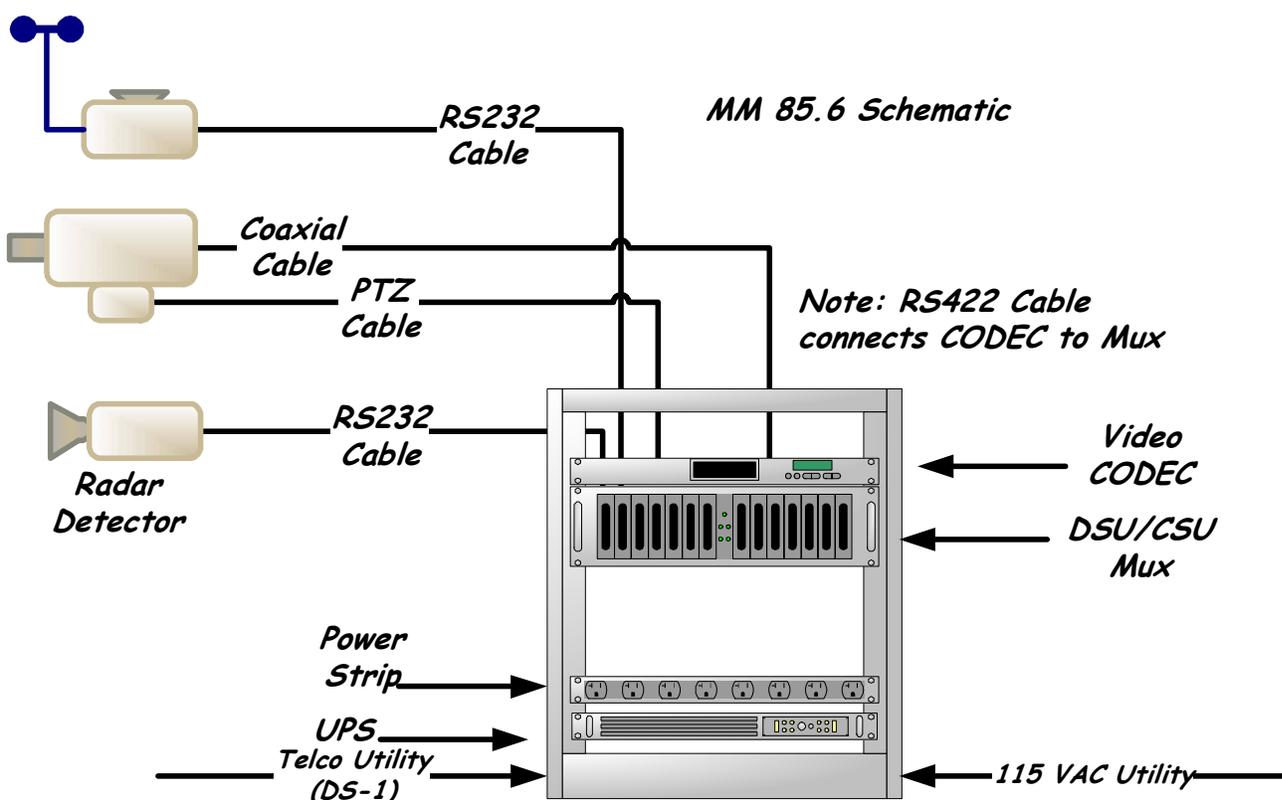


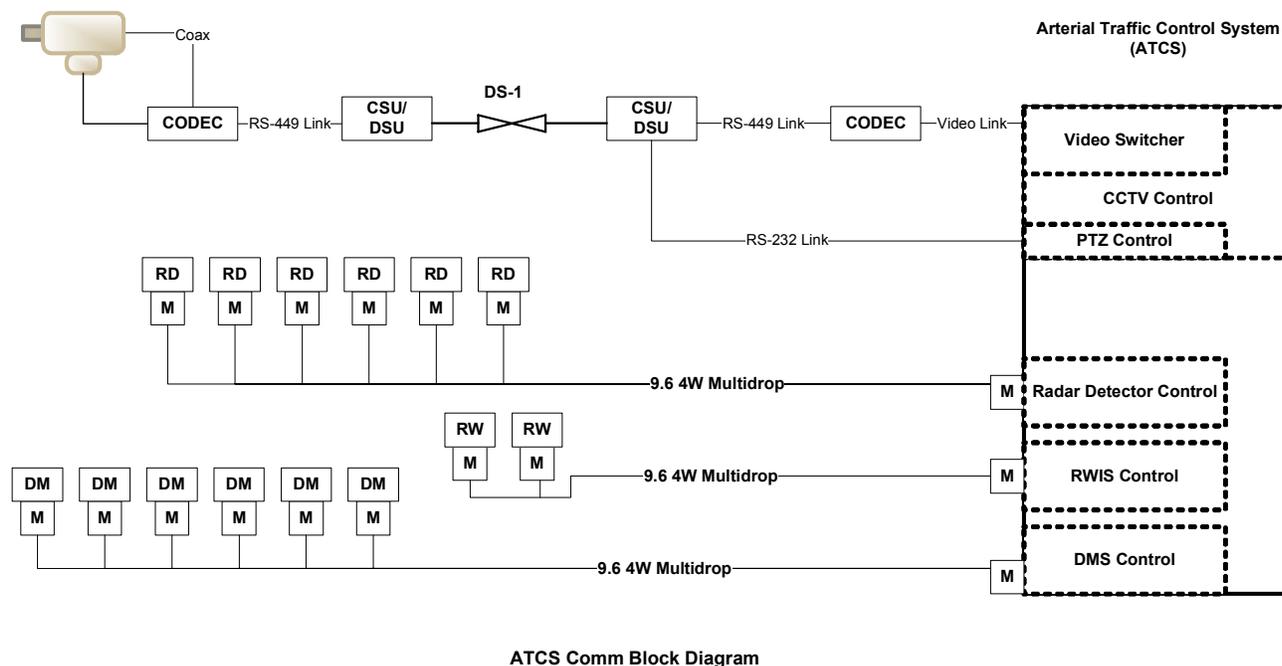
Figure 5-24: Diagram - Site Equipment

The written description of the site helps to clarify what is needed, and prevents a misinterpretation of the schematic diagram.

Notice that the site at 85.6 has multiple devices and takes advantage of hardware that can provide multiple communication ports via the single DS-1. Also, a 170/2070 controller is not included. Some traffic control software may require the use of a controller. This system is however, incident based. That is, the radar detector provides data that indicates the speed of traffic at a specific point. The central computer reads the data and alerts operators to take action. For locations with a single device, a specific type of circuit can be leased. Another alternative can be used. Multidrop circuits for each type of device can be run to each site, and DS-1 circuits can be run to the CCTV sites. This will add equipment and complicate some of the communication systems. However, if one type of communication circuit has a problem, the others keep functioning.

Following is a block diagram (figure 5-25) for an entire system using device based communication circuits:

**SUMMARY**



- Notes:**
- ⇄ All Comm links leased from Localtel
  - ⇄ Video use DS-1 Links
  - ⇄ RD use 9.6 4W circuits with max. 5 drops ea.
  - ⇄ RWIS use 9.6 4W circuits

Figure 5-25: System Block Diagram

Traditionally, transportation and construction engineering documentation is a series of technical drawings with material and construction specifications incorporated as part of the PS&E information. A plan set for a lighting pole (for example) will contain all of the information required for the contractor to provide and install. The dimensions, weight, wind-loading and mounting information can be specifically quantified and shown in the plan set. Minor deviations from standards can also be shown. Actual written instructions and other requirements are kept to a minimum. There's no instruction manual provided by the manufacturer that explains how to install and maintain the lighting pole.

Telecommunications systems have the same type of requirements for documentation. However, remembering that telecommunications equipment is primarily designed for Carriers, there is additional documentation that is supplied, and necessary for installation and optimization. Hardware manufacturers provide a complete installation and maintenance manual with every device (or every 10 devices if ordered in large quantities). Make certain that the documentation manuals are kept, and that there is a set (in a weatherproof pouch) at every equipment cabinet, plus a master set at the TMC.

A typical modem can be set to run at a fixed data rate, or allowed to adjust the data rate based on communication link conditions. If you don't specify this in writing, there's a fifty percent chance that the installer will be wrong. This will delay the overall project and cost money to correct.

SONET multiplexers, Ethernet routers, spread spectrum radios, modems, etc. are manufactured to fulfill a number of different requirements. Make certain that your communication engineer provides enough information for installation personnel to properly setup and optimize the equipment in your freeway management and traffic signal control systems.

### *Network Topology*

A network can be defined as a link between any two points (or more) that mutually relies on the presence of the other. Communication points are normally referred to as nodes or hubs. Simple networks are developed to establish a temporary communication path, such as a basic telephone call. Complex networks are designed to provide a permanent communication link and have alternate links to protect the viability of the network. Freeway management systems typically use a complex communications network.

Many types of networks can be defined for telecommunications, each with a different purpose. Understanding the different types of networks is important. Each type of network has advantages and drawbacks. There is no "ideal" network solution that fits all situations. Consideration should be given to the ultimate requirements of the system that a communication network will support.

A "mesh" network may provide the ultimate solution for assuring that communication links will always be available. However, it is the most expensive network topology that can be established. Not assuring that communication links will be available when needed can also be expensive. Networks that support financial transactions require a high degree of reliability. The operators of financial networks will tend to require a highly redundant communication system. The telephone companies and long distance carriers have developed highly redundant networks to make certain that communication links are always available.

Four basic network topologies with many variations can be described to meet requirements.

- Point-to-Point
- Star
- Ring
- Mesh

### ***POINT-TO-POINT NETWORKS***

Point-to-point is the simplest. Start at node 1 and connect to

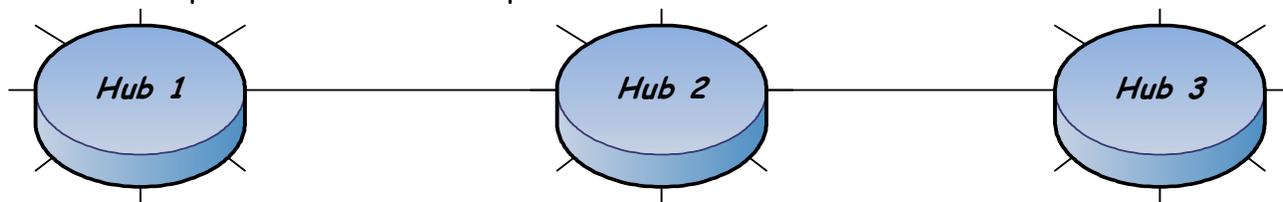


Figure 5-26: Diagram - Point-to-Point Network

node 2, then 3, and continue. Communication is serial and passes through each node. Lose any one node or link, and communication can be disrupted.

### ***STAR NETWORKS***

A Star network is simply a multipoint communication system that allows one node to communicate with many nodes (or many to one). This is also referred to as a "one-to-many" system. 10Base-T Ethernet is an example of star network. The LAN in your office has a router hub that connects all desktop computers to file servers and printers.

The star network allows any point to communicate with any other point in the network. However, if the central hub is taken out of service, then the entire network is out of service.

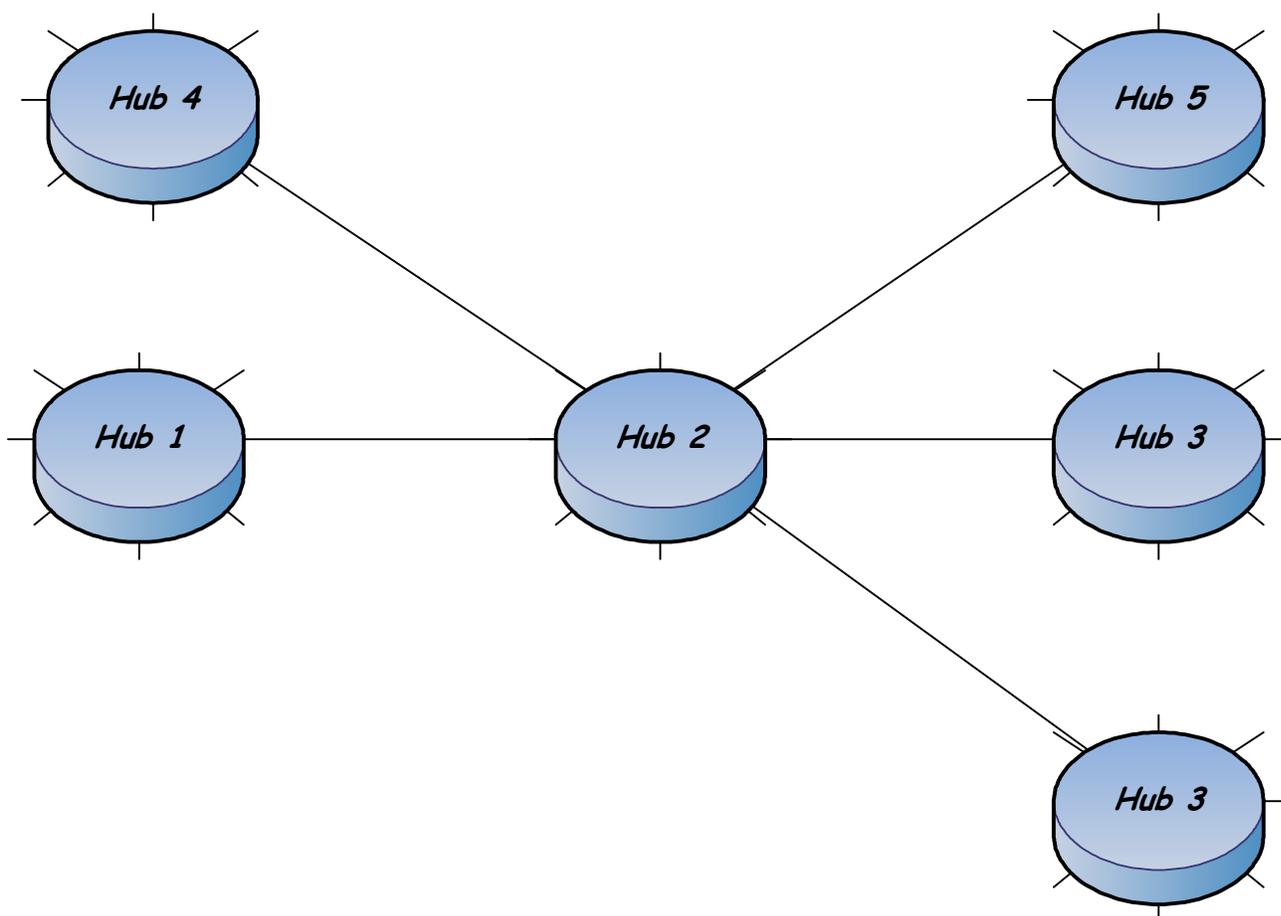


Figure 5-27: Diagram - Star Network

### **RING NETWORKS**

Ring networks are designed to overcome the weakness of the point-to-point system. Placing the nodes so that they can always communicate with an adjacent node helps to assure an available communication path. Fiber Optic systems are generally deployed using a ring network topology. SONET multiplexer hardware is designed to facilitate various types of ring networks. Two basic ring architectures are available with many variations and combinations that can be developed.

Uni-directional - the communication signal always travels in one direction around the ring. If any single node or path link is disrupted, communication between the other nodes continues in a serial path around the ring. A single strand of fiber can be used to for this type of network.

Bi-directional - the communication signal can travel in either

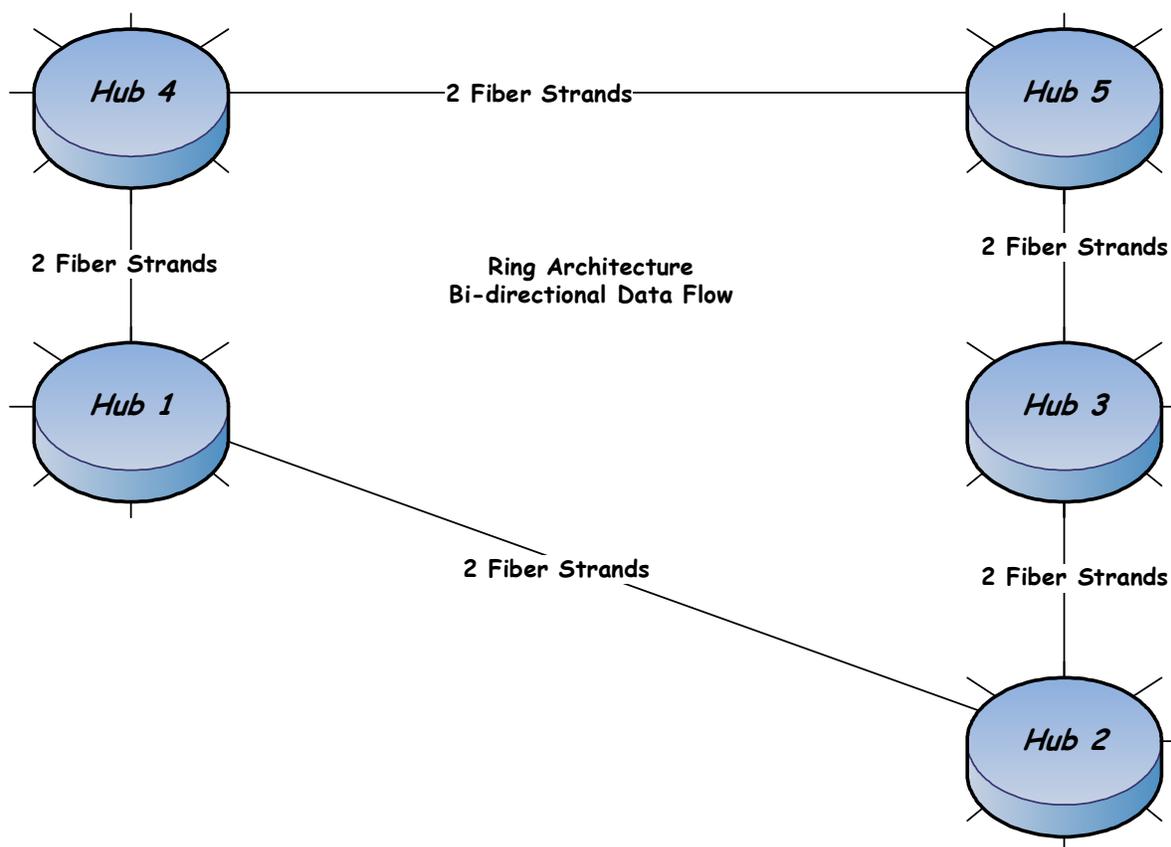


Figure 5-28: Diagram - Ring Network

direction. This allows the system to manage signal flow and determine the most efficient path. Two strands of fiber are used. One strand is the transmit, and the other is used for receive. Add more pairs of fiber strands, and the system will support dedicated hub-to-hub data flows.

### **MESH NETWORKS**

Mesh networks are a combination of the star and ring topologies. They can provide multiple communication paths for all nodes in the system. A ring network basically provides for one or two communication paths for each node. A mesh network can be designed to provide three, four, five, or more communication links for each node. How many is dependent upon the amount of money available and the willingness to manage and maintain a very

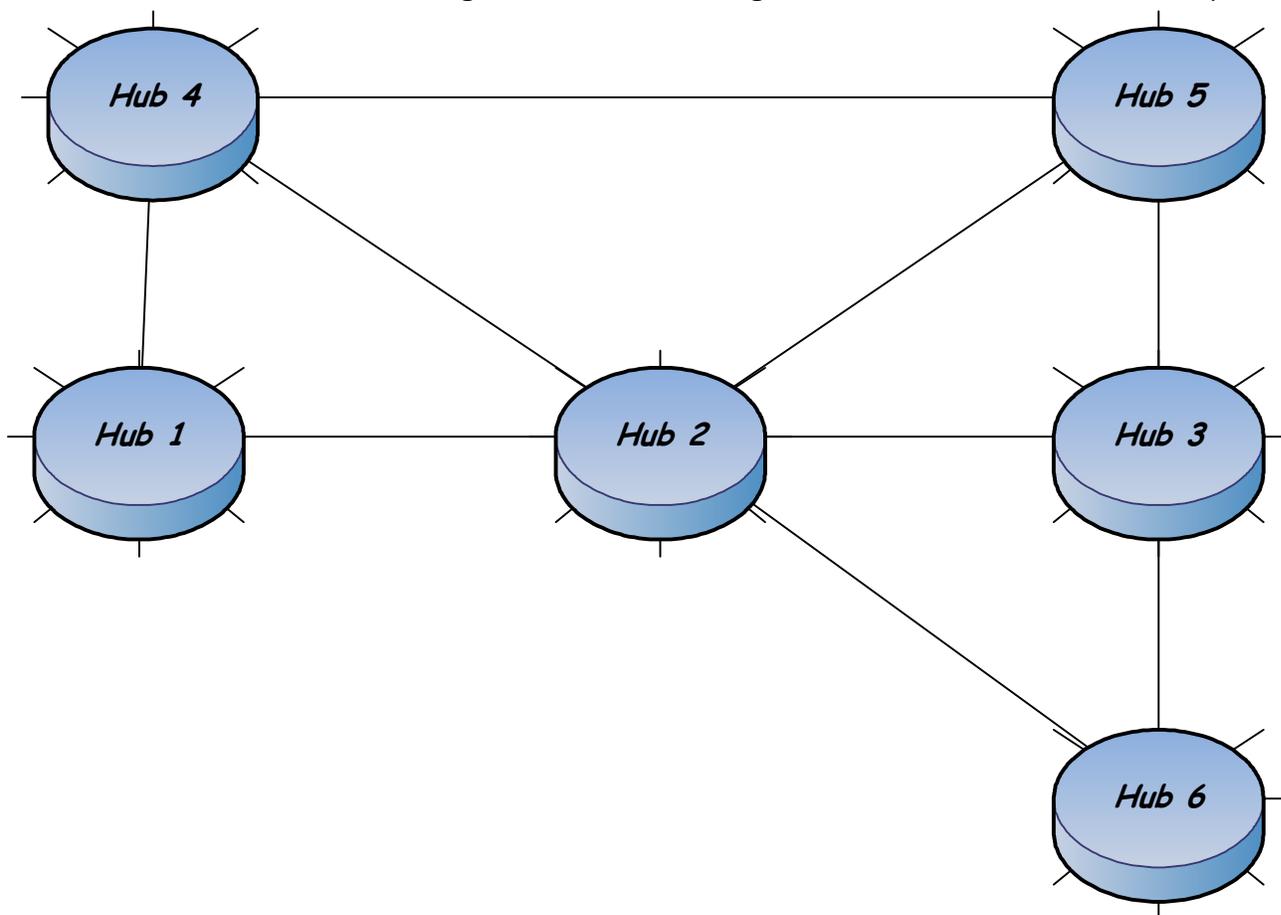


Figure 5-29: Diagram - Mesh Network

complex communication system.

Note that these network topologies are independent of the media being used for transmission. Most of the more complex network topologies are used with fiber. However, microwave systems are also arrayed in star, and ring topologies, and basic Ethernet local area networks use a star configuration. New generations of wireless networks are being developed using a mesh topology in order to assure connectivity. That is, wireless customers will be able to access a network via more than one wireless base site.

### ***NETWORK REDUNDANCY***

How much redundancy is needed in a communications network? There is no simple answer or magic formula. One answer may be to ask how long your system can be down before operations are affected. Another answer might hinge on whether parts of your system can be out of service and not effect operations.

The mesh network shown above has multiple communication paths to each hub. If full redundancy is required one set of communications hardware for each communication link at each hub is required, and don't forget to add redundant power supplies. This arrangement can be very expensive especially when you consider that mesh networks weren't developed to provide communication path redundancy. Mesh networks were developed to support the needs of the internet. Communication paths have bandwidth limitations and communications hardware has functional limitations. To assure that most users of the internet will have a high availability of service, mesh networks are used. Mesh networks help to share communication path loading. This assures that no single communication path will become a bottle-neck.

Using Mesh Networks for communication path redundancy also requires a very complicated "alternate routes table". You have to provide each Hub with the routes to use if the primary is out of service. This can create problems with data intensive applications.

Ring Networks were created to provide communication path redundancy. They are simple (compared to Mesh) to set up. There are no complicated routing tables. The hardware operating system is told to switch to the alternate path if communication is lost on the primary. The amount of hardware required to implement a Ring Network is less than a Mesh Network.

### ***Conclusion***

Development and design of a telecommunications system is an iterative processes. Each element is built upon a very specific set of standards and requirements. The use of any type of communications circuit to support a traffic or freeway management system should be based on a clear understanding of the requirements for such a system. The creation of a thorough set of system requirements is key to the design and construction of an efficient communications system.

### ***Chapter 5***

## 6. CHAPTER SIX – MAINTENANCE & WARRANTIES

### *Introduction*

A basic truth of nature is that all things change. Until this point, the Telecommunication Handbook for Transportation Professionals, has looked at the planning and development of the communication system. Chapter 6 will discuss maintenance of telecommunication systems and look at issues that should be addressed by the operator of a system. The chapter provides information on the reasons for maintenance, technician qualifications, explanation of warranties, and typical cost of maintenance agreements.

Communication systems are made of physical things that wear out (or change) over time. It is difficult to see the change, because

there are very few moving parts. However, the components (transistors, capacitors, microprocessors, etc.) that make up devices that are part of a communication system do change, and lose their performance tolerances. When enough components operate at less than specification, the overall system (or device) will not perform as required. Operationally speaking, there is not a huge difference between a freeway system and a communication network. Both wear out from use and require maintenance and revitalization.

Communication networks should be treated as any other element of a modern transportation system. DOTs need to provide an adequate budget for maintenance, and training for personnel to become familiar with the elements of the communication equipment. The DOT technicians don't have to be capable of repairing the communications equipment. They simply have to be able to determine when the communication hardware is not functioning, and in many cases replace the device with a spare.

Most manufacturers provide a detailed manual of installation, testing and maintenance recommendations. Many provide on-site

**Chapter 6**

Note: This chapter provides a focus on telecommunications equipment. The reader is referred to FHWA Handbook: "Guidelines for Transportation Management Systems Maintenance Concepts and Plans" for more information about the development of equipment maintenance programs. See: <http://www.ops.fhwa.dot.gov/Docs/TMSMaintCptandPlans/index.htm>

and factory depot service plans. The use of these plans may be a critical part of your overall maintenance program.

This chapter will:

- Review the need to create a budget for operations, maintenance and system upgrades.
- Review the differences between product warranties, guarantees of performance, and service and maintenance plans.
- Consider the relationship between D.O.T. product specifications and manufacturer warranties.
- Provide recommendations to assist in setting a budget and creating a staff function to support maintenance.

Systems maintenance and upgrade is crucial to efficient operations. All communication equipment does eventually wear out, or reach the end of useful operational life. The communication system is the glue that unites the elements of a traffic signal, FMS, or ITS system, keep it operating with an efficient maintenance and upgrade program.

### ***Why create a Maintenance Budget?***

Fifty years ago, communication equipment needed constant attention. The "state-of-the-art" used components that were highly sensitive to environmental variables (heat, cold, moisture, dust, etc.). Communication systems required significant adjustments by operations and maintenance personnel. All equipment was manufactured with external controls that were used to adjust the device back to specified parameters. Current equipment is less affected by its environment, and most manufacturers have eliminated the external adjustment controls.

The use of fixed value components minimizes the need for adjustments. Communication devices either perform as specified, or must be replaced. Manufacturers have created "board level" systems with all necessary components placed on a single card.

Some manufacturers will make significant claims about the reliability of their products. Many will claim MTBFs (mean-time-between-failures) that make it seem as though failures occur once in a million years. But, nothing lasts forever.

Communication hardware normally fails either during, or just after, installation. These failures are the direct result of manufacturing "birth defects" - that is, the manufacturing testing process fails to identify a manufacturing error, or substandard component. However, the leading cause of near term failures is the result of improper installation or operation. Hardware manufacturers have standard component testing procedures to help assure that virtually all equipment leaving the production facility meets specifications (more on this subject later in the chapter).

Most communication system component hardware is constructed on a single printed circuit board that can easily be replaced by a qualified technician. The components are so small that they can't be repaired, or replaced. Simply replacing the board with the failing component saves time and money.

Don't confuse the "feature option" switches, or option setting software for maintenance controls. The feature setting switches and software are only provided to allow users to optimize a device for a specific operational requirement.

Installation failures are caused when technicians fail to familiarize themselves with the manufacturer's recommendations. Many technicians will try to use shortcuts to reduce the installation time, or because they have installed similar equipment



Figure 6-1: Photograph of a Fiber Optic Modem - Courtesy GDI Communications, LLC

and believe that there are no differences between devices manufactured by different companies. Another common error is to assume that there won't be differences between old and new versions of the same device.

On a long term basis, most failures are the result of electronic component aging (through constant heating and cooling components will fail to meet original specifications). Systems will either fail, or develop substandard functional characteristics.

Don't forget that equipment also fails because of lightning strikes, electrical power surges, and connection of electrical power to a communications port.

Most communications equipment is built with internal monitoring capabilities. Diagnostics are displayed in one of two general ways: external display on the equipment, or via diagnostics terminal (or as a program on a PC). Most modems have L.E.D. indicator lamps to show that the device is functioning in a proper manner. A multiplexer or router will provide diagnostics via directly connected terminal, or through a device setup and management program on a PC.

Keeping track of all communication devices is part of any maintenance program. A simple equipment list table is best. The following is an example:

Table 6-1: Example Communication Device Inventory List

Communication Device Inventory				
Item I.D.	Serial #	Date Installed	Warranty Term	Device Location

An individual should be assigned to keep track of all equipment, and maintain relationships with manufacturers, installation companies, and system integrators. This person should have experience (or training) for completing simple repair and installation of communications equipment. If there is not enough equipment to require a full-time staff maintenance specialist, the agency should consider part-time personnel, or an outsource contractor. A field verification inventory should be conducted at

least once per year. Whenever a new system is installed, an information table should be completed and added to the database.

If communication systems are very reliable and don't require constant attention, why budget for maintenance?

- Communication systems are generally composed of items from many different manufacturers.
- Most hardware and firmware (the hardware internal operation instructions) is revised on a regular basis to account for field use problems and changes in performance standards.
- On rare occasion, the equipment does break down
- External forces cause equipment failure
  1. Power fluctuations
  2. Cable cuts
  3. HVAC failure
- Need for qualified personnel (or services) to provide for repair and restoration
- Need to provide funding for emergency repair and restoration. When a problem does occur, there's no rush to pull money away from some other budget.

### ***Creating the Maintenance Budget***

Creating a budget to provide for maintenance requires that several factors be considered:

- Level of experience and training of communications equipment maintenance personnel?
- Complexity of the communication equipment in the system.
- Number of individual communication equipment devices.
- The type of network being used - leased or owned.
- Potential for emergency repairs.

One of the first items to consider when creating a maintenance budget is "who" will do the maintenance work, and what type of services will they be required to provide? This is in some way a "chicken or the egg" question. If full maintenance services are provided (testing, using diagnostic equipment, and full repairs),

you will need highly qualified and trained technicians. If maintenance is viewed as a matter of blowing the dust out of the cabinet, and making a call to an out-sourced repair and maintenance service, a semi-skilled individual with minimal experience and training will suffice.

Most DOTs have been using some type of communications system to support traffic management and department operations for many years. A few have created an internal staff function to support maintenance and upgrade functions, others outsource the required services. Following is a suggested maintenance technician experience level table:

Table 6-2: Technician Experience Classification

<b>Technician Experience &amp; Qualification Levels</b>			
<b>Level</b>	<b>Yrs Experience</b>	<b>Type of Experience</b>	<b>Amount of Training</b>
Entry	0 - 2 years	PC Skills, Technical Ability	Vocational education from an accredited High School, or Technical School.
Mid	2 - 6 years	Military Experience with communication systems, or, Above + Working Knowledge of the Communication equipment in the system + Ability to replace module boards.	Military Training, or above + Communication Theory Courses + Manufacturer Equipment Courses
High	6-10 years	Above + Additional Knowledge of communication systems + provide presentations at professional meetings + ability to trouble-shoot, and resolve system problems.	Above + advanced communication theory courses

Senior	10+ years	Above + participation in communication standards efforts + review of technical papers	Above + additional technical training as required + extensive reading of technical books on communication process and theory.
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These levels of experience should be applied to both department personnel and/or outsourced personnel responsible for the maintenance of telecommunication equipment. These levels are directly related to experience with telecommunication and other technology based systems, not general work experience. An individual with 10 years of experience as a project manager would not be considered as having the qualifications to be a maintenance technician for telecommunication equipment. There are a number of good High School Vocational education programs, and Technical School programs that provide individuals with the proper knowledge and skills for an entry level maintenance technician position. The U.S. military provides well grounded maintenance technician training and experience for at least a mid-level position.

The type of equipment will often help determine the experience level of personnel required to support a maintenance function. If everything is leased from a communication carrier, entry level personnel can be used. Their primary job description will be to manage the services supplied by the communication carrier, and call for support when necessary.

A system comprised of a large number of communication devices with a mix of new (less than 2 years old) and legacy (more than 5 years old) equipment will require support from more experienced personnel. With this type of system, the maintenance personnel will need to know when to call in outside support to effect repairs.

If the system consists of a few CCTV cameras, several changeable message signs and traffic flow detectors, with required communication equipment, it's probably best to arrange for outsourced services. Consider that special tools and test equipment may be needed to help troubleshoot communication

problems, with highly compensated experienced maintenance technicians.

A communication equipment maintenance contract will typically cost between 10 and 20 percent (per year) of the original equipment cost. If the total system cost was \$300,000, maintenance will average no more than \$15,000 per year - significantly less than the cost of hiring a qualified individual.

A system with several thousand devices spread over a large area that cost \$20,000,000 to deploy will require a significant investment in maintenance and upgrade services. Outsourcing the needed services will most likely cost \$4,000,000 per year (using the 10% to 20% rule). The cost of hiring five qualified personnel and supporting them with necessary tools, transportation, spare parts and training might be about \$2,000,000 per year. Make certain that at least one of the technicians has a significant background for maintaining telecommunication systems.

The components of a \$4 million maintenance budget would include:

- Personnel
- Maintenance Shop Facilities
- Test Equipment
- Spare parts inventory & consumable repair supplies.
- Tools
- Technician Training
- Service Vehicles
- Etc.

A simple single function system (traffic signal control) will require personnel with fewer skill sets. Training will be limited to knowledge of upgrades to cover new equipment. Systems will have minimum complexity. Complex systems supporting multiple types of communications equipment and systems will require a larger staff with more skill sets and continuous training for changes in systems and upgrades.

One important aspect of the budget development process is completion of a risk assessment. This should have been done for the overall system design during consideration of redundancy, and will have a direct impact on the maintenance budget. The communication system is, in most respects, the least failure prone element of an overall system,

Basic traffic signal systems use modems and wireline transmission media. Technicians will only have to be able to do general troubleshooting and item replacement. Traffic signal repair personnel can be trained to this level of repair.

but potentially has a high risk of being disrupted by outside forces.

The risk assessment is not done to create the maintenance budget. Elements of the assessment will provide an indication of how much money will be required to accomplish repairs in the event of a problem. In this case, risk does not refer to intentional disruption - although, that certainly is a factor - but the potential for power failures, "Backhoe Fade" (cable cuts from construction), lightning strikes, HVAC failures, etc. The risk assessment should consider the following:

- Assess which portions of the communications network are crucial to overall operations.
- Which communication resources are needed to keep the operation functioning at a reasonable level?
- What elements can you live without?
- How long can you function without critical elements?
- How much system degradation is acceptable?
- Make an assessment that recognizes which elements must be kept in service and which can be removed from service during the repair and restoration cycle.

Knowing which elements of your communication system can be out of service and awaiting repairs will help provide effective management of resources. The cost to effect repairs during a holiday period will always be more than repairs completed during normal business hours. Even during holiday periods there are portions of the system that can be out of service without effecting operations.

Communication devices will require some type of upgrade during their life cycle. Most communication equipment will operate for 10, or more, years without a problem. Equipment manufacturers will offer firmware updates, and occasionally revise the physical design of the equipment. Very often, these updates are not critical to existing operations and systems. However, you should budget for occasional updates, especially if the manufacturer offers a major firmware update.

The firmware updates are normally free (some vendors do charge), but the end-user is required to cover the cost of installation. Installation of most firmware is usually only a

matter of uploading the update via the system manager program and can be accomplished by the operation staff. Occasionally the operation is more complex and will require the services of a qualified technician for a few days. Legacy systems may require significant replacements of components to accomplish the update. Consider the overall cost of updating older equipment and compare with replacement by new equipment.

Upgrades to existing equipment, due to addition of new sections, can be accomplished via a budget provided by the contractor adding the new section - however, there may be unforeseen consequences as a result of the additions which were not considered as part of the new section budget. Consider availability of older equipment. The contractor may not be able to purchase exact duplicates of equipment used in older sections of highway. Make certain that the contractor gets new price estimates for the desired equipment. Older equipment becomes difficult to find and may cost more than the original.

### *Warranties, Extended Warranties & Service Plans*

This section takes a look at various aspects of product warranties and their relationship to maintenance programs. There is a tendency to assume that a warranty will take the place of a maintenance program. Often, as consumers, we have become accustomed to relying on product warranties to help protect us against failure of a product. These warranties are very specific about the coverage, the rights of the company, and the rights of the consumer. "Note: The author suggests that you read a complete product warranty for any consumer electronics item you may have recently purchased. All of the examples considered for publication here had an express prohibition of reproducing without written permission". All warranties reviewed had one thing in common - the very last sentence: **"Specifications and availability subject to change without notice"**.

This last sentence is important, because manufacturers do change specifications on a regular basis. A key reason for changes is product updates. Products are updated based on feature demands from customers, or product problems discovered during warranty repairs. Standards also cause changes in product specifications. Often, manufacturers will release a product using a preliminary standard, and make changes when a standard is finalized.

Consumer based telecommunication products have a life cycle of 18 to 24 months with new variants being released every 4 months. Wireless handsets are a good example. Commercial products have a longer life cycle, usually based on market demand. If the demand is strong, a manufacturer will keep producing a product for 5 to 10 years. However, that doesn't keep the product from changing. Manufacturers do make changes for the reasons stated above.

Some telecommunication products are manufactured to serve both consumer and commercial demand. Wireless routers based on the 802.11 series of standards are an example. Their life cycle and new product introduction cycle follow the consumer market. If you are using these types of products in your system (most likely within a TMC) be prepared to have several different versions, and possibly units from different manufacturers.

### **WARRANTIES**

Following are a few key facts about warranties:

- Most hardware manufacturers provide a warranty for their products.
- There are no state or federal laws requiring that a warranty be provided. Several states have special regulations that may govern provisions of warranties, but those are primarily directed at protection for individual consumers, not commercial (or government) enterprise.
- Warranties are offered as part of a marketing program.
- Equipment manufacturers create a budget line item to provide for fulfillment of warranty programs.
- Warranties normally provide for the repair, or replacement, of a product due to manufacturing defects.
- Warranties are actually one of the cost components of a product.
- **Warranties are not maintenance programs!**

Warranties for commercial products are essentially the same as consumer products with one general exception. Consumer product warranties tend to be very short term - 30 days to one year. Commercial product warranties tend to be offered for longer periods - 90 days to 5 years.

Some manufacturers will provide full replacement, while others will only provide parts and require payment for labor charges. Most commercial product warranty periods start on date of manufacture, others on date of shipment, and others on the date of installation. There are no government or industry standards for warranties. The terms of the warranty are set by the manufacturer. Commercial law and court decisions help to mold the wording of warranty terms.

### ***EXTENDED WARRANTIES***

Many manufacturers offer factory service and repair programs. For a small one-time fee (paid in advance) products can be returned to the factory (or authorized repair center) for "out-of-warranty" service. Instead of providing the standard warranty, the manufacturer offers an extension (typically one to three years) beyond the basic time period. Coverage is the same as the basic warranty. Damages due to abuse, or lightning strikes, or power surges, floods, fire, etc., are not covered. Factory service can provide overall savings for a maintenance program when used for "commodity" type products. Commodity products are low cost and mass produced. These would include modems used for traffic signal controllers, or fiber optic modems used in FMS, or handheld 2-way radios used by roadway maintenance personnel. The products can be easily replaced with spares by a technician with minimal experience and returned to the factory for repair. Extended warranty programs help reduce the maintenance cost associated with component degradation and failure. Under the warranty, the factory will replace components that no longer meet specification, and upgrade the product to the latest version. Extended warranties do not provide for on-site service and trouble shooting of external system problems affecting the warranted device.

The following is a typical hardware warranty from a manufacturer of modems/fiber optic modems used in traffic signal and freeway management systems:

XXX COMMUNICATIONS, LLC

## **XXX Communications LLC**

Traffic Electronics Manufacturer    Specializing in Communications

### LIMITED WARRANTY

XXX Communications LLC (XXX) warrants to the Buyer that all XXX goods (equipment and component parts) when sold are free from defects in materials and workmanship under normal use and service for a period of one year from the date of shipment, as evidenced by XXX 's or its agent's packing list or transportation receipt. XXX 's obligation under this warranty shall be limited to the repair or replacement of goods, at XXX 's option, which XXX 's examination shall disclose to its satisfaction to be defective. In no event shall XXX 's liability for any breach of warranty exceed the net selling price of the defective goods. No person, including any dealer, agent or representative of XXX, is authorized to assume for XXX any other liability on its behalf.

XXX has no obligation or responsibility for goods which have been repaired or altered by other than XXX 's employees.

This warranty is the only warranty made by seller and is expressly in lieu of all other warranties express or implied, and warranties of merchantability and fitness for any particular purpose are specifically excluded.

### WARRANTY CLAIM PROCEDURES

Defective goods must be returned, transportation charges prepaid, to XXX for correction. XXX will pay return transportation charges for warranty repair. Upon redelivery of goods corrected under this warranty, the repaired or replaced portions shall be subject to this warranty for a period of 90 days or until expiration of the original warranty, whichever is later. All claims of failed or defective goods must be in writing and received by XXX within the specified warranty period. XXX will provide Buyer a return authorization number as authority to return the goods and for use in monitoring repair status.

Repair or replacement of defective goods will be at XXX's discretion and for the Buyer's account when the cause of failure is determined by XXX 's examination to be misuse, mishandling or abnormal conditions of operation. In such event a firm price quotation for correction of the goods may be submitted to the buyer. No repair or replacement work will be initiated prior to receipt of the buyers written authorization to proceed and approval of price, except as may be necessary to complete XXX's examination of the goods. If returned goods are determined not to be defective or if the Buyer elects not to authorize correction at its expense of goods not covered by this warranty, XXX may charge a reasonable amount for such evaluation. Any amounts due XXX under these conditions will be subject to the same payment terms as the original sale. The Buyer will not recover from XXX by offset, deduction or otherwise, the price of any goods returned to XXX under this warranty.

Note that there are statements which limit the liability of the manufacturer, and the fact that the warranty starts on the date of shipment. There is no agreement under the standard warranty with respect to acceptance of a system or other testing.

#### ***RELATIONSHIP OF WARRANTIES TO SYSTEM SPECIFICATIONS***

There is nothing in the terminology of a warranty that makes the manufacturer responsible for the functioning of their products in a system. Manufacturers of hardware generally do not take responsibility for system construction and system integration. Because they do not have total control over the situations in which their products are used, manufacturers will only take responsibility for the quality of their manufacturing process and the components used.

A number of specifications for freeway management and traffic signal systems will require that a system be installed, optimized and pass acceptance testing before a warranty period starts. This is contrary to the statements in manufacturer warranties. Many products are delivered three to six months before installation. Some manufacturers will take this into account and extend the warranty start date, if requested in advance. However, the terms of the warranty do not change.

Most systems are installed by a general contractor (GC) or systems integrator. The GC is ultimately responsible for meeting the D.O.T. specifications. If the end objective is to hold the general contractor responsible for the system until it passes final acceptance testing, then state this in the specifications. Don't confuse manufacturer warranty terms with contractual purchasing terms. Often, the general contractor asks a manufacturer if their product meets specification, but fails to ask if the manufacturer will agree to the purchase terms. The end result is that the general contractor does not account for the testing and acceptance period in their bid pricing. Ultimately, a low bid price translates into system optimization delays while the GC and the equipment vendors work to resolve contractual issues.

#### ***SERVICE PLANS***

A "do-it-yourself" systems maintenance and service policy doesn't always make sense when you're trying to manage time, people and budget. Maintenance service plans help to off-load some of the

cost of keeping a communication system running. Advantages of a service plan are:

- Provide a fixed cost to help control budgets
- Assurance that service personnel are available
- Routine system and hardware checks to help maximize "up-time"
- Can provide for technology and software updates on a regular basis
- Considered as an operational cost rather than a capital expenditure
- Provide for emergency repairs and system restoration without additional costs.
- Eliminate the need to support "specialty" technicians on staff focused on a small portion of your overall operation.

Service plans (or maintenance agreements) are a fixed fee contract with a hardware vendor, system integrator, or maintenance services company for the routine maintenance and repair of hardware and systems. Contracts are typically based on the following elements:

- Number of devices
- Number of different vendors products
- Types of devices
- Individual "Mean-Time-Between-Failure" (MTBF) factors
- Area of system deployment (state, region, local)
- Age of respective devices and system
- Services to be provided
- Other factors (based on a review by the services provider)

The largest factor in determining the fees for a service contract is the total number and types of devices. Service companies have statistics that indicate how often a product, or type of product, will need routine maintenance and general repairs. They use this as a baseline to determine pricing. Generally, the greater the number of devices, the lower the unit cost. One device may require two service incidents per year plus two routine maintenance calls per year, but 10 devices may still only require

two service incidents per year, plus routine maintenance. A service incident can be defined as the requirement for an actual repair due to failure. Therefore, a service company may charge \$500 per year to maintain a single device, and \$1,000 to service 10 devices. The cost of the service incidents is spread over 10 units.

Variety of devices (modems, video CODECS, CCTV cameras, etc.) and manufacturers will affect the total fees because of a need to maintain spare parts and devices, and technicians with different skill sets. A large system spread over an entire state will require more resources than the same system deployed in a small area.

Maintenance contracts can be limited to a few services, such as emergency repairs only. Or, they may include a whole suite of services including a requirement to replace devices that have been in the field for more than 3 years. The more services required, the greater the cost of the contract.

There are some things that most service plans do not cover. They won't cover repairs required because of acts of vandalism, faulty electrical service, power surges, damage due to "acts-of-god", outages of telecommunication lines, or faulty installation. However, you can make stipulations in a contract and pay extra to provide coverage because of those problems.

Before starting a service contract, make certain that your system is fully functional and that all problems created by faulty installation have been corrected. Don't expect the service contractor to make up for the short-comings of a poor installation, or faulty design.

To learn if a maintenance/service contract is a good option for your operation, complete a full equipment inventory, and ask qualified vendors to submit an estimate for their services using an RFI process. Don't be concerned about vendor qualifications at this point. The objective is to determine potential costs and the number of vendors interested in providing services. If you determine that a service/maintenance contract will help save money, or improve your overall operation, then use a formal bid process. Apply the technician qualifications listed at the beginning of this chapter. Also request a list of current clients and complete a user satisfaction survey (contact existing clients) before selecting a vendor. Don't forget to refer to the FHWA

Handbook "Guidelines for Transportation Management Systems Maintenance Concepts and Plans" for more information.

### ***Conclusions***

All communication systems require some form of maintenance. Current design and manufacturing techniques have eliminated a lot of the requirement to constantly check that equipment is running to specification. Most current communication hardware and systems, once properly installed and optimized, will run trouble-free for life. However, that does not eliminate the need for checking the system at least once every three to six months. The technicians can check for loose connections or moisture and dust, or other problems which may affect system performance. The technician can also verify equipment inventory. A good maintenance program will help to assure relatively trouble free system performance, and ultimately lower overall cost of operations.

## 7. CHAPTER SEVEN – SYSTEM EXAMPLES

### *Introduction*

Departments of Transportation have been learning how to develop telecommunications systems to support traffic and freeway management for many years. There has been a concerted attempt to create a standardized architecture that would support requirements for most deployments. However, one constant that has evolved is that no two systems can be configured in the same way. Many elements (i.e.; modems, video codecs, transmission media, etc.) of a communications system are consistent in their functionality (system to system), but, it is the unique arrangement of those elements that differentiates between systems. Each user has their own set of requirements which a unique (in overall design) telecommunications system is required to support.

This chapter will look at two very different approaches to using telecommunications technologies supporting freeway operations and traffic signal management:

- The Utah Department of Transportation Salt Lake Valley Regional Freeway Management and Traffic Signal System
- The City of Irving Texas Traffic Management System (As this handbook is being written, the system is in the process of being installed).

Both systems, unique in their approach to providing a telecommunications system, have several factors in common:

- Both are upgrades from a legacy system
- Both are the result of requirements to expand overall traffic management services
- Both have a requirement to merge with, and transition from, legacy systems
- Both will use latest generation telecommunications equipment supporting broadband video.
- Both will allow traffic data to be transported to multiple users
- Both will upgrade to take advantage of recently developed IEEE 802 series standards.

- Commonly used telecommunication devices (modems, routers, video CODECs, etc.) have the same functionality in both systems.

The primary differences are that one system was created to support a regional traffic control plan, the other created to cover a small urban/suburban city area. Each system is unique because each was designed to meet a specific set of end-user requirements. The UDOT system was originally designed to support multiple functions incorporating both traffic signal control for local streets, and freeway operations. The City of Irving system was originally designed to support traffic signal management for local streets.

### *Utah DOT System*

#### **BACKGROUND**

In the early 1990's, the Utah Department of Transportation (UDOT) began plans to develop **CommuterLink**, an Advanced Traffic Management System. This system, started as a regional coordination of signals across jurisdictional boundaries within the Salt Lake Valley, has grown to include over 600 traffic signals, 1400 detector stations, 250 closed circuit television cameras (CCTV), 70 VMS and a wide range of ancillary transportation management systems such as 511, a website, HAR, RWIS, etc. To support this system, UDOT has installed its own dedicated fiber optic communication network.

The communication network encompasses most of the valley, and reaches outwards to include the Cities of Ogden to the North, Spanish Fork to the South, and all other major cities in between such as Provo and Orem. With over 100 miles of fiber optic cable (as of the publication date of this handbook) installed, the system is expected to double by 2006. This network is dedicated exclusively to transportation and security related services and links the UDOT Traffic Operations Center (TOC), the Salt Lake City and County Traffic Control Centers (TCC's), the Utah Transit Authority (UTA) dispatch center, and various emergency management centers.

In response to the new expansion efforts, capacity limitations and some end of life hardware announcements - such as the video matrix switch - UDOT requested that an alternatives analysis, and future needs assessment, be performed to identify new and

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proven state-of-the-art video technologies and other communication technologies that could be used in an upgraded and expanded CommuterLink. The result of this analysis was a recommendation for full-scale replacement of the existing Javelin video matrix switch, and the conversion from the existing ATM and SONET network to an Ethernet over IP solution.

In the original concept, placement of multiple video matrix switches was envisioned within Regional centers to serve the local areas, with a fixed and limited number of ports being shared between centers (i.e., limiting the transfer between the TOC and Regional Hubs to any 8 video signals at any one time). Implementation of this concept was delayed until after the Olympics because the need was not there, and because new CommuterLink software was also required to control these multiple switches.

With the expansion of the number of CCTV cameras and the provisioning of video links to additional agencies, the analysis was expanded to include consideration of the communication requirements necessary to interface with these centers. The use of a video matrix switch with remote nodes is tightly intertwined with a communication infrastructure, and one cannot be analyzed without the other. The resulting analysis took into account all current and envisioned future CommuterLink requirements of the State, County, and municipal agencies within the state of Utah, while preserving to the greatest extent possible, legacy systems. Also considered are recurring and upgrade costs that are associated with a "do nothing" approach. This option is in reality a misnomer, because significant resources are still required to maintain and / or replace obsolescent equipment (i.e., Hub Ethernet switches, fiber modems, etc.).

Manufacture Discontinue - the manufacturer of a product decides to stop manufacturing a product (or product line), and provide minimal warranty and parts support.

*Note: The above background information was excerpted from an assessment study completed by a consultant for the Utah Department of Transportation. The study makes an important observation about communications technologies and planning - as technology advances, plans must change.*

The original plan was to deploy several matrix type video switches in various locations throughout the regional system. Unfortunately, matrix video switches require significant telecommunications infrastructure to support their ability to route video between several locations. Simply put, they are "bandwidth hogs". During the period of the initial deployment of the CommuterLink system communication technology, standards, and processes evolved to provide the ability to route video with significantly less bandwidth and telecommunications infrastructure support. The overriding factors were the continued development of the IEEE 802.3 series of standards, and MPEG video compression standards. Video can now be routed from its source to a desktop computer using "Video-over-IP". The UDOT system takes advantage of these new capabilities. During this same period, the matrix video switcher product line was sold to a new manufacturer. The new company decided to "manufacture discontinue" the product line.

UDOT asked the consultant to look at alternatives to replacing the video matrix switch. The resulting investigation concluded that replacement of the matrix switch with video over IP would provide a significant operational advantage, and provide significant cost savings via the use of lower cost communications infrastructure hardware. The actual recommendation was to migrate to a digital IP communication network with IP Multicast for switching and distribution of the video. However, the existing ATM/SONET telecommunications infrastructure would have to be replaced, or modified. There would be an initial capital outlay to effect this change, but the savings on future equipment purchases (and maintenance) would pay back the initial outlay. Most important, UDOT would gain the ability to route video without having to install and maintain expensive video matrix switchers.

**"IP Multicast" - A process that permits distribution of a CCTV camera image to many users. The image is sent to a multicast switch that allows users to view using a Web Browser application on their desktop computer.**

### ***THE SYSTEM - EXISTING***

The current system was evaluated for its ability to support video over IP with the objective of re-using as much of the current

telecommunication system as possible. Because the existing system was based on using a video matrix switch there was a single point-of-failure. A matrix switch is nothing more than a large input-output device. In this case, the switch had a capacity of 300 inputs and 200 outputs. The switch would allow any one of the inputs to be output on one, two, three, or more outputs. The mechanics of the switch are such that every one of the inputs and every one of the outputs must be directly connected to an analog video source, or monitor. This was a reasonably efficient design for television production studios of the 1980s and 1990s, and certainly, in the place of any other reasonable alternative, very useable for the CommuterLink system. Lower capacity (and lower cost) switches are used in the security industry.

Video Matrix switches were designed to take an analog video source and route it to a recording unit, or a video monitor within a television production studio, or within a large office building, or between several buildings in a campus environment. To use it in a transportation environment, the video from CCTV cameras must be transported from the field to the Traffic Control Center. This requires using a significant amount of fiber optic strands (or coaxial cables) to support a large number of CCTV cameras for direct camera to switch connections. Another option is to convert the video to a compressed digital signal, multiplex it with other video signals and transport to a TOC where the signal is de-multiplexed, un-compressed, and then connected to the switch. Either of these scenarios creates a situation that is hardware intensive, and costly to deploy and maintain.

Deployment of the CommuterLink systems occurred over a period of years and utilized three generations of communication distribution networks. The distribution networks progressed from a requirement to use one strand of fiber per CCTV camera, plus two strands of fiber for a multi-drop PTZ communication link, plus two strands of fiber for a multi-drop traffic controller/traffic device data link, to a single strand of fiber for all three systems. UDOT uses two primary fiber optic cable networks:

- Backbone - designed to provide service from communication hubs to the TOC
- Distribution - designed to provide service from field cabinets to the communication hubs.

The change in the design of the distribution network systems provided a significant savings in the amount of fiber strands and the amount of communication equipment required in the field cabinets. However, there was no change in the amount of fiber required between the hubs and the TOC.

Between the hubs and the TOC, UDOT used three separate communication networks:

- ATM to provide connectivity between various computer systems
- SONET to provide communication for low speed data channels that served camera PTZ, changeable message signs, traffic signal controllers, and other devices
- Video to provide transport of full motion video from

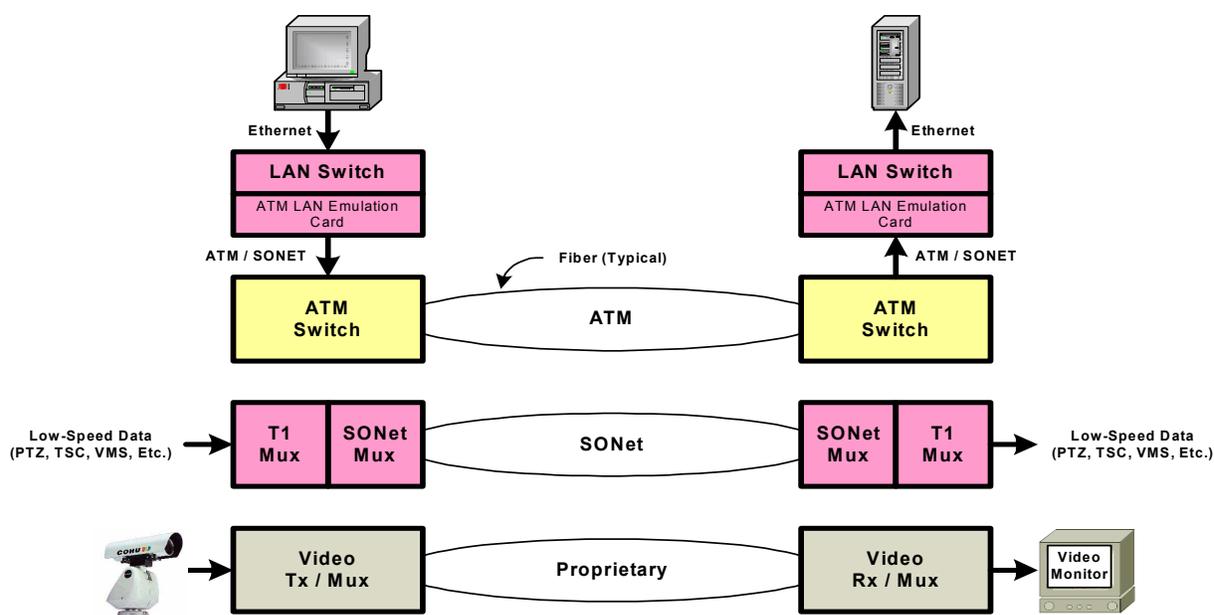


Figure 7-1: Diagram UDOT Current System

cameras.

The UDOT Network diagram provides a graphical representation of the three communication networks used for the overall system. The first generation system used separate fiber strands for each network in both the distribution and the backbone cables. Subsequent generations used fewer fibers in the distribution

cable, but continued to use separate fibers in the backbone cable.

**THE SYSTEM - NEW**

UDOT originally considered deploying additional analog video matrix switches to route video to other centers and user agencies. The existing fiber optic cable infrastructure would have to be expanded to support the additional switches. With the knowledge that the video matrix switch product was taken out of production and no longer supported by the manufacturer, UDOT looked at alternative video distribution strategies. This led to a complete review of existing systems and their communication requirements.

The decision was made to complete a phased replacement of the telecommunication system and the analog video matrix switch. This process would be facilitated by the fact the existing fiber optic cable infrastructure would not have to be replaced. A

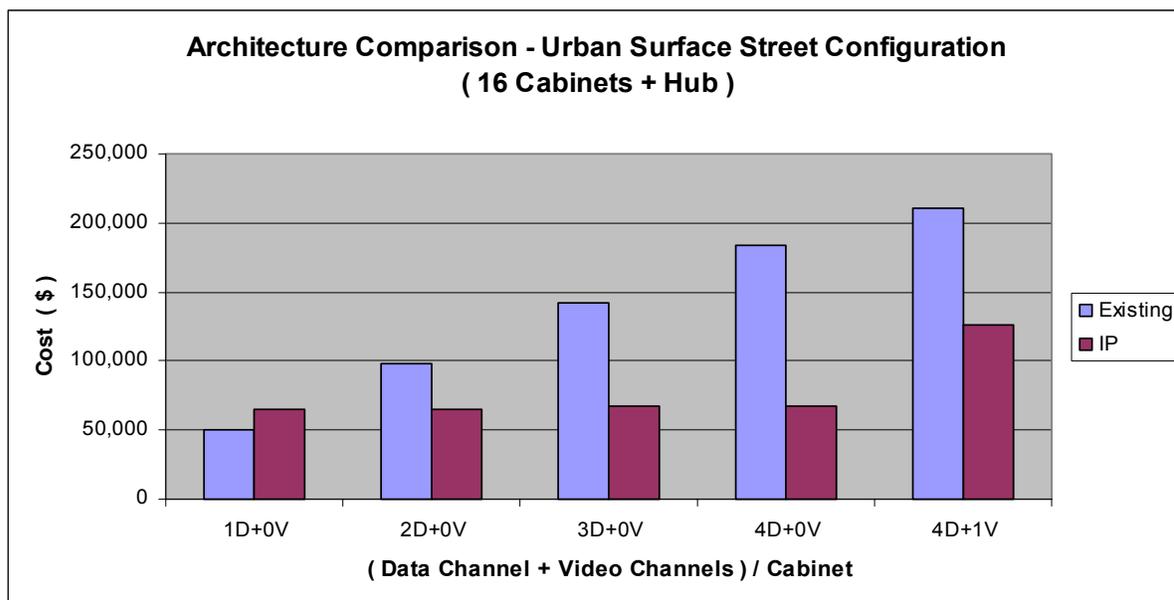


Figure 7-2: Graph - Comparison of Savings Realized by UDOT Converting to an IP Architecture

recommendation was made to convert the video signal to a digital IP format in the field cabinet.

The comparison shows that significant savings are gained by converting to an IP architecture. Table 7-1 provides a list of estimated costs and a proposed upgrade schedule:

Table 7-1: Deployment Cost Estimates

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Deployment	Cost Estimate	Proposed Schedule
TOC Ethernet LAN Switch Upgrades	\$250,000	FY04
Video Decoder Equipment at the TOC and all Existing Partner Agency Locations	\$750,000	FY04 - 06
Hub Ethernet LAN Switch Upgrades	\$650,000	FY04 - 06
Cabinet Ethernet LAN Switch Upgrades	\$520,000	FY04 - 06
Cabinet Serial Port Adapters	\$120,000	FY04 - 06
Video Encoder Equipment for 200 Field Cabinets	\$800,000	FY04 - 06
<b>Total</b>	<b>\$3,090,000</b>	

UDOT can continue to use the existing systems and provide upgrades over time to minimize overall budget impact. As shown in the above table, there are no expenses to modify the existing fiber optic cable infrastructure. Affiliated user agencies can be added at minimal cost because the video, and other data, can be

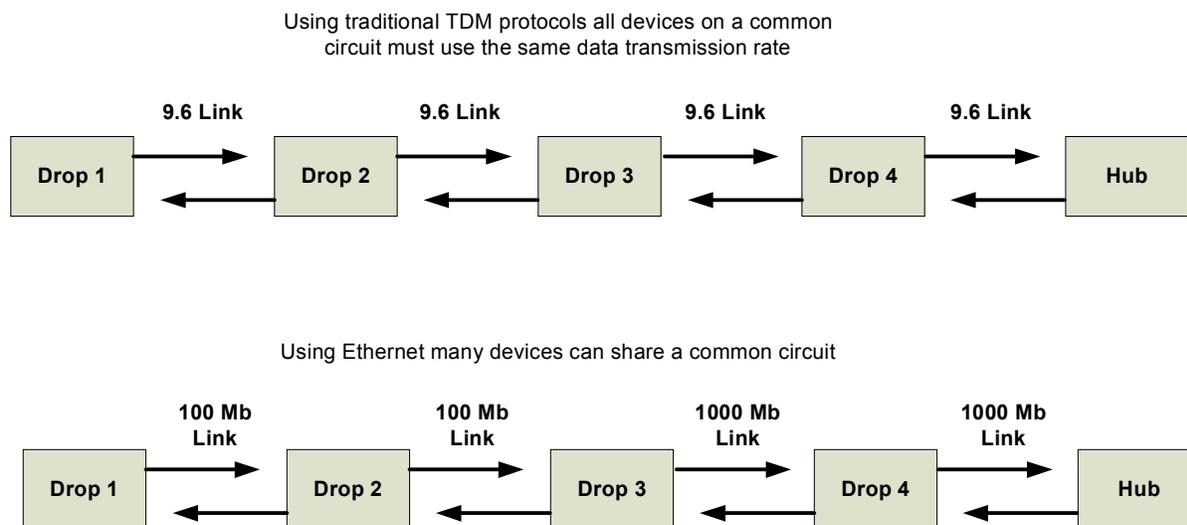


Figure 7-3: Diagram - Comparison Multi-Drop VS. Ethernet

routed using standard Ethernet architecture and lower cost off-the-shelf hardware.

A major advantage of using the Ethernet architecture is that it can support multiple devices requiring different data transmission speeds. Multi-drop communication circuits - such as those used with traffic signal controllers - require that all devices communicate at the same data rate. The compressed video signal from a CCTV camera cannot be added to a multi-drop circuit used for traffic signal controllers unless the video signal is transmitted at the same data rate. Most traffic signal controllers use a data rate of 9.6 Kbps and most compressed video signals are transmitted using a data rate of between 384 Kbps and 1 Mbps. Using Ethernet and IP protocols, each device can transmit at its own data rate. Therefore, many different devices can share a common data communication circuit. The end result is a simplification of the overall communication system, i.e., fewer strands of fiber, and less hardware.

The full report: *CommuterLink Communication System Analysis - Alternative Architecture Options* - is available on the USDOT Joint Program Office web site.

### *City of Irving Texas*

#### **BACKGROUND**

Irving, Texas, a community of about 200,000 residents, is part of the Dallas-Fort Worth Metro Area, and home to the Dallas Cowboys Football Stadium. The Traffic and Transportation department is responsible for the operation and maintenance of the traffic signal system- a system with 175 signalized intersections. Most operate on a "time-of-day" signal plan, and a few are closed-loop. The current system uses several versions of the NEMA traffic signal controller, and there is no centralized control. The department relies on telephone callers to report problems and dispatches technicians to investigate and effect repairs. The City of Irving is seeking to update its current traffic signal system to provide for centralized control and problem location. The traffic department is proposing to replace the variety of signal controllers with the 2070 type.

The update calls for the total replacement (over time) of the NEMA type controllers, addition of CCTV cameras, traveler information signs, and centralized control of all traffic signals.

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Central control would provide immediate notification of signal problems and allow for dynamic re-timing of signals to account for special events or significant traffic incidents. The use of CCTV cameras would provide real-time viewing of congestion problems and support temporary re-timing plans.

### ***PROPOSED UPDATE***

An overall development plan with the objectives of standardizing on one controller type, one software system, one cabinet type, and centralized signal control was created. The department recognized the need to provide a telecommunications infrastructure to support the plan, and the construction of a private fiber optic communications network was considered. TEA21 funding was requested, and granted. However, the level of funding was substantially less than needed. The ultimate objective of adding all signals to the communication network could not be realized if a fiber network was used. The estimated cost of the fiber optic network was \$10 million.

The City looked for alternate communication technologies to support their plan. Their first consideration was the use of leased telecommunication services from local carriers. This plan was rejected because:

- The overall cost exceeded funding levels
- Available bandwidth was insufficient to handle the individual (3 MB) video feeds required for the system
- The city did not want to incur a monthly recurring expense

The City investigated wireless systems and discovered that they could provide total coverage at a substantially reduced cost over the fiber optic and leased telecommunication networks. Requirements for the system included:

- Broadband capability to support video
- Point-to-multipoint to support centralized control
- Ability to add locations with minimal system disruption (scalable)
- Ability to add locations with easy to configure communications hardware
- Communication system reliability

- Overall initial system costs kept within budgeted levels

In addition to the centralized control of traffic signals, the Irving Traffic Department wanted to provide:

- CCTV cameras with pan-tilt-zoom
- Changeable message signs
- Dynamic lane assignment
- Video incident detection
- Additional advanced traffic management features
- Real-time traveler information

The city has made a significant investment in a wireless infrastructure to support operational agencies and services. They currently use 5.8 GHz microwave (Wi-Fi 802.11a), 24/23 GHz microwave, and 18 GHz microwave. A group of experienced, licensed radio technicians are on staff to maintain and operate the radio networks.

Considering several different wireless network topologies, the city sought a design that would provide the necessary bandwidth, secure transmission and high availability (99.999%). The typical point-to-point-to-point (multi-drop) design used for most traffic signal wireless communication systems did not prove to be adequate for a system that would ultimately be required to support more than 70 CCTV cameras, and almost 200 signalized intersections.

The city's Communication & Electronics Department investigated a wireless system designed to provide broadband internet access. They found a product that is compliant with the IEEE 802.16 and 802.16a standard. The 802.16a standard provides for a significant reduction in the potential for interference from other radio systems on the same or adjacent channels. The IEEE 802.16 was developed as the "Air Interface for Fixed Broadband Wireless Systems." This standard describes wide area wireless networks (WAN) and is designed to provide coverage in terms of miles. Compare this with the IEEE 802.11 wireless standard series developed for local area wireless network (LAN) coverage, with coverage distances measured in terms of feet.

### 5.8 GHz ATTRIBUTES

- Operates in 5.8 GHz U-NII/ISM frequency spectrum
- Scalable throughput from 20 Mbps to 60 Mbps
- Base station can provide up to 360 degree coverage in 60 degree segments
- Simplified installation using a self-enclosed radio/antenna module with Ethernet 10/100 baseT connections.
- Compliance with IEEE standards: 802.1d; 802.1q; 802.16; 802.16a.
- Additional field units can be installed without disrupting current operations.

### 4 Wireless Channels used to create 360 degree coverage

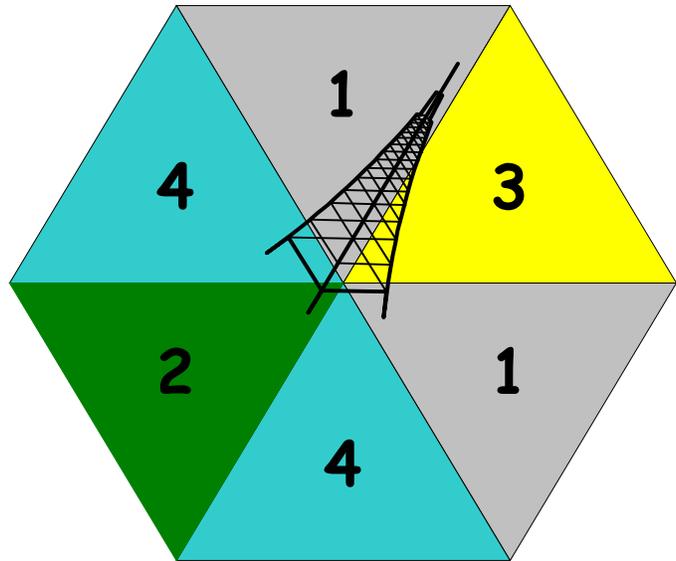


Figure 7-4: Diagram - Wireless Channel Alignment for 360 Degree Coverage

**THEORY OF OPERATION**

The FCC has designated four operational communication channels within the 5725 to 5825 MHz frequency range. Each channel occupies 25% of the available spectrum. Each of the four channels can be used to cover a 60 degree arc. Re-using two of

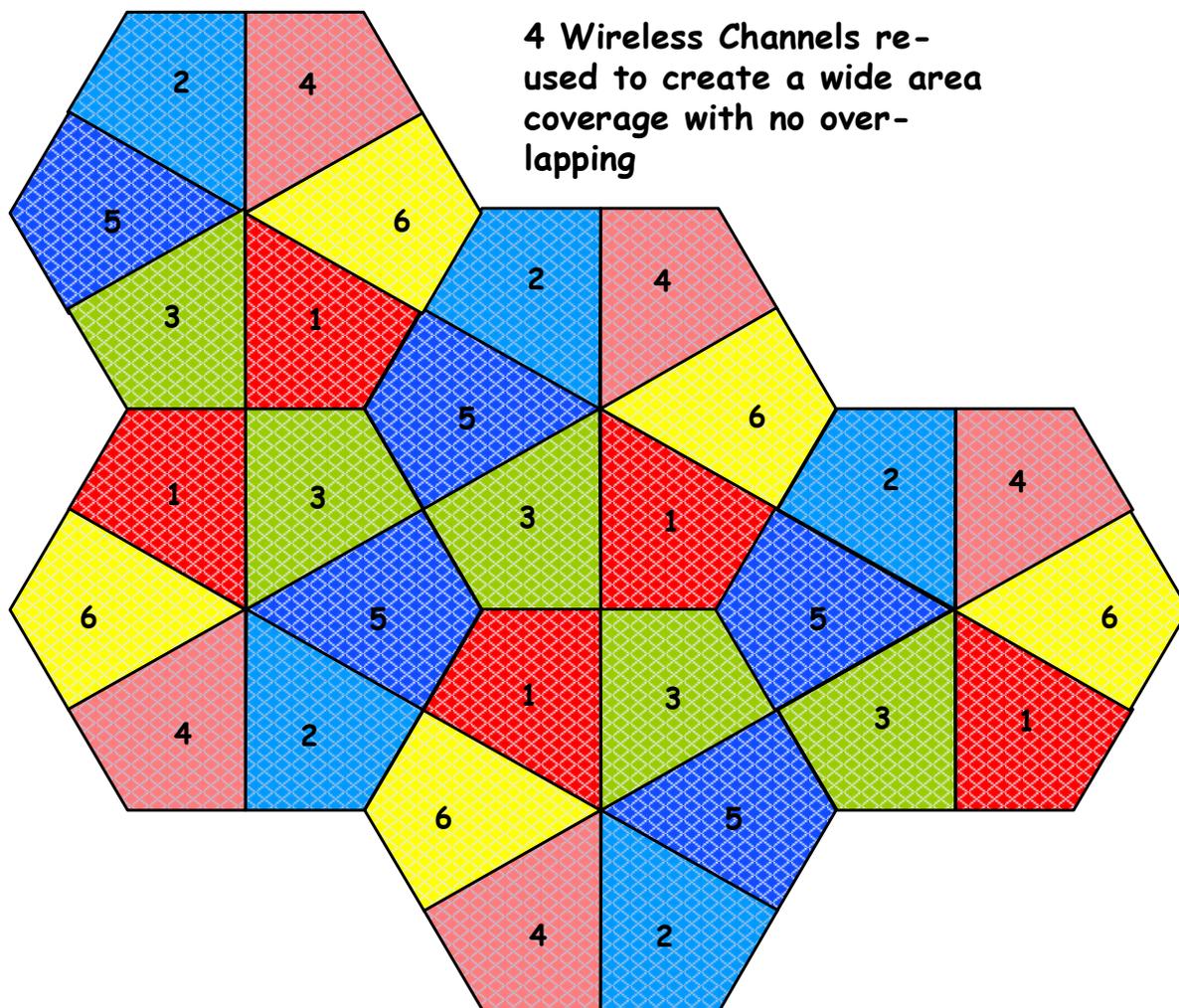


Figure 7-5: Diagram - Channel Re-use Plan for Wide Area Coverage

the four channels permits a six channel array for coverage of a 360 degree circle. Following are examples of how the four wireless channels can be re-used to provide total coverage without over-lap.

Each of the individual coverage hexagons has an array of six base stations at the center and referred to as a "Hub Site". The base stations are networked to provide for a 360 degree coverage

area. Field units, also called "Subscriber Units", have a highly directional antenna pointed toward the sector base station providing the best line-of-sight coverage. It is also possible to create communication path redundancy for a subscriber site.

### **THE IRVING PROPOSAL**

The initial plan calls for the development in two phases of six (6) coverage zones each. The first phase will use a single base site with six coverage zones. The second phase will use two base station sites with three coverage zones each. Future system upgrades will permit additional zones to be added as required.

Some of the coverage zones may overlap, but the subscriber units are set to a specific radio channel to prevent interference from other base stations. Also, the subscriber unit antennas are highly directional and aimed at a single base station.

**Possible coverage scenario using 4 radio channels to cover 12 communication zones.**

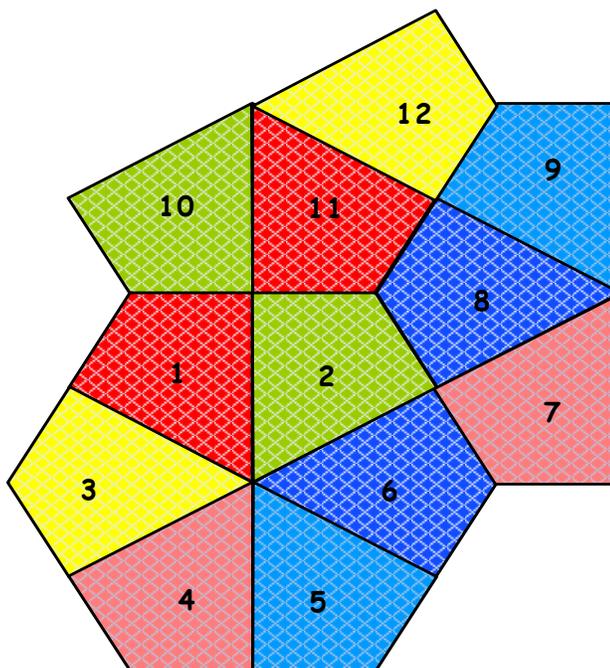


Figure 7-6: Diagram - Proposed Channel Re-use Plan

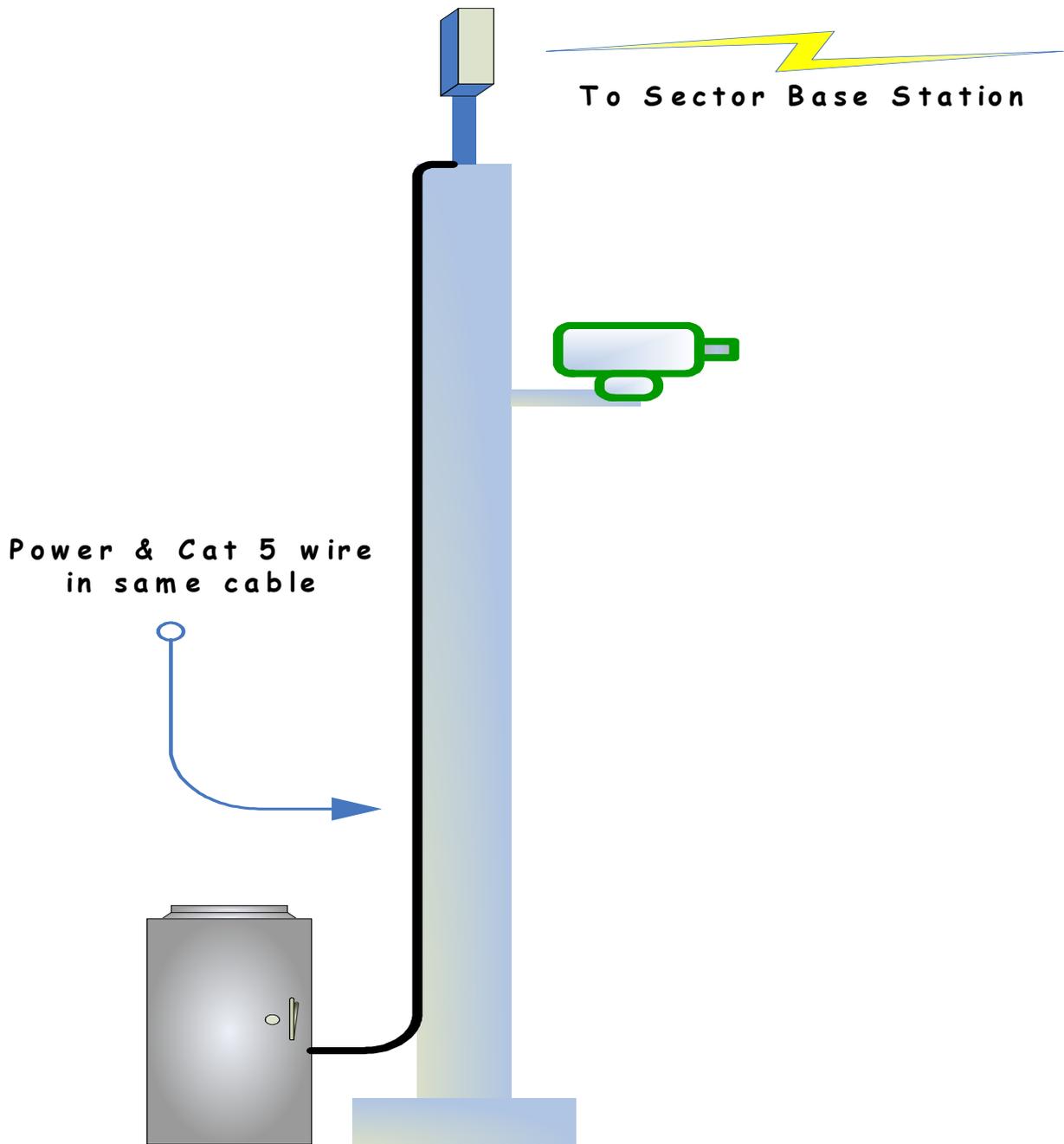


Figure 7-7: Drawing - Typical CCTV Site

Notice that a single cable runs from the antenna/radio system to the cabinet. Inside the cabinet is a communication module that provides power and Ethernet to the radio unit at the top of the pole. The VIP signal, and PTZ signal, from the camera are connected via the communication module to the CAT 5 pairs in the

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cable. The CCTV camera has a built-in<sup>12</sup> CODEC-VIP module that converts the video to IP.

Following (Figure 7-8) is a site schematic diagram:

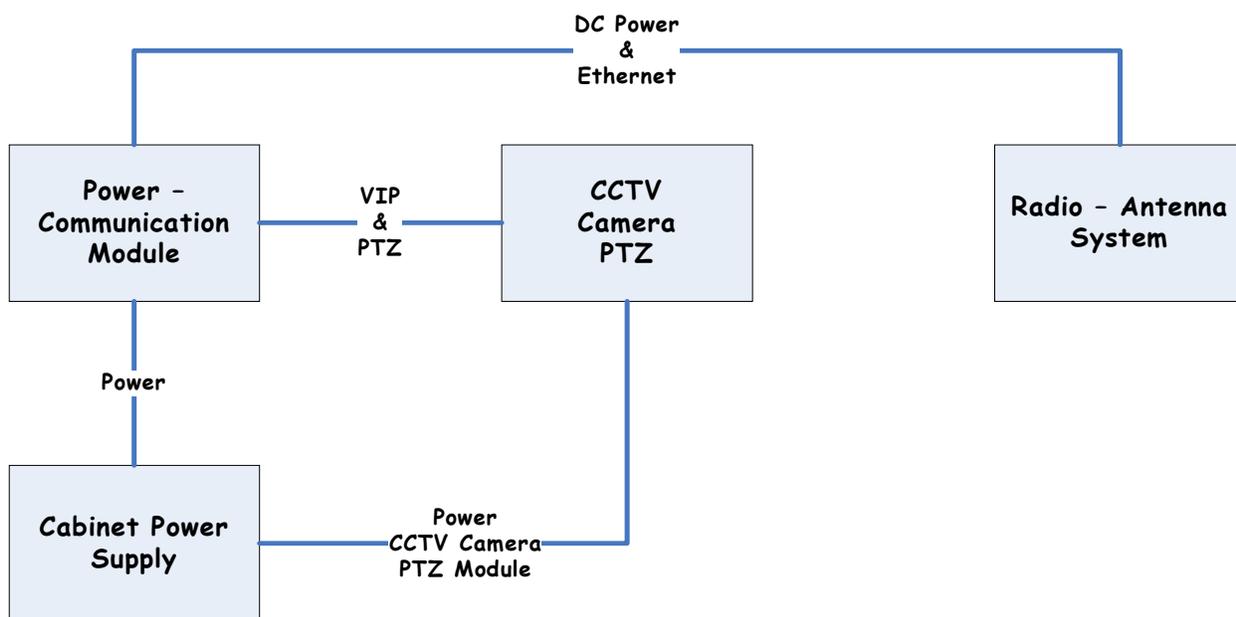


Figure 7-8: Typical CCTV Site Schematic

Individual site antennas are oriented toward a specific base station unit. The highly directional system prevents overlap and allows for optimization of communications traffic through any single system. Irving TTD has assigned each signal device a communication zone within the coverage grid. They have also proposed locations for CCTV cameras and other equipment. The following map shows the overlay of the coverage zones and where each device and signal controller is located:

<sup>12</sup> See chapter 5 section on video over IP.

The overall objective of the Irving Traffic & Transportation

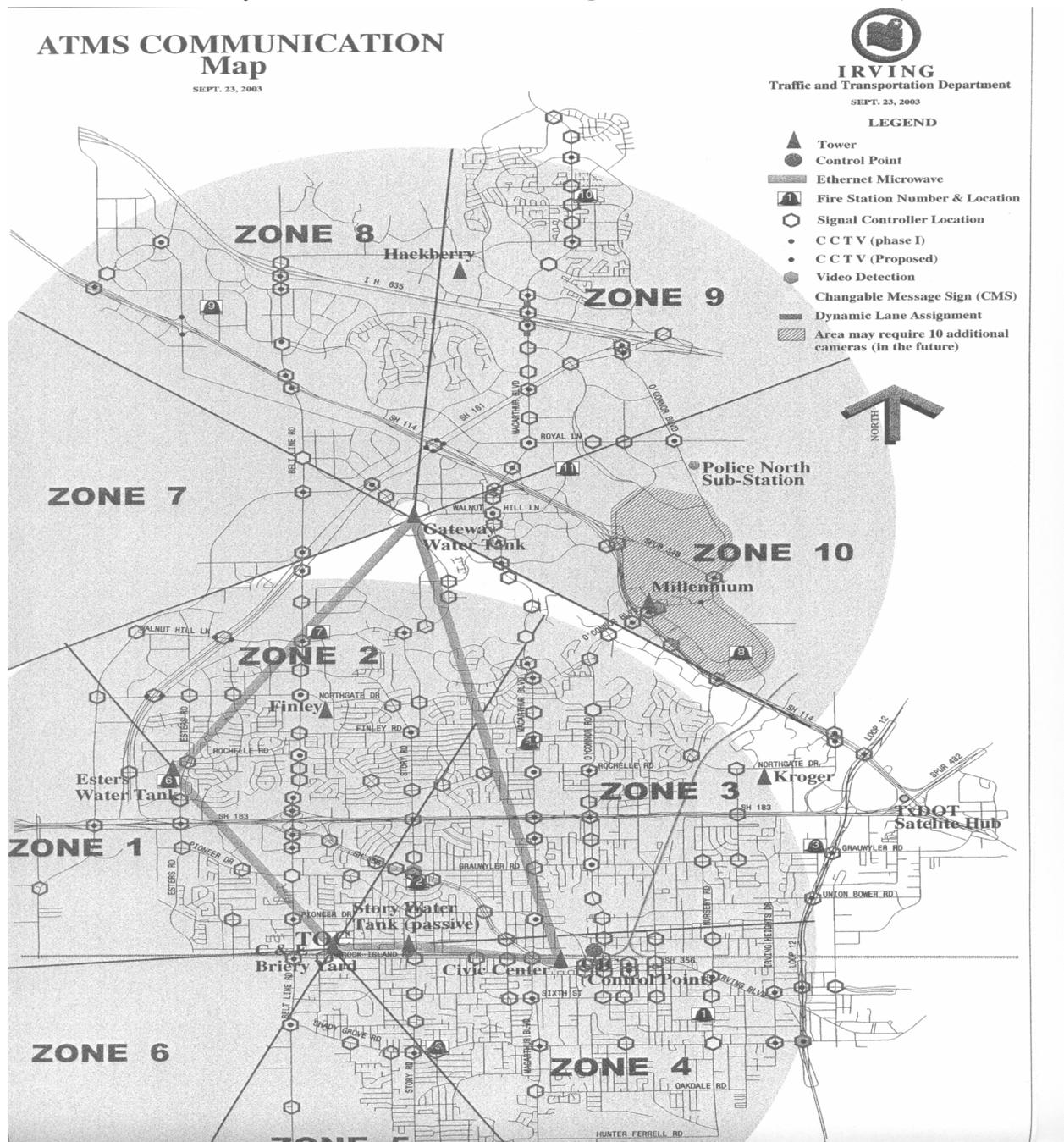


Figure 7-9: Map of Proposed Irving Texas System

department is to update the current system, standardize on the types of devices being deployed, and provide for greater efficiencies in the overall management of their system. The use of a technology initially developed to provide broadband internet service is a reasonable choice given the total cost of

implementation and operation. Fixed broadband wireless communications systems are also being applied for security, water and wastewater management, and agricultural operations systems.

**TIE-IN TO MAIN COMMUNICATION NETWORK**

The City has a microwave communication backbone that connects all major systems. The backbone system is a point-to-point microwave communication link. Five sites are set up in a loop configuration to allow for a self-healing ring and redundant paths to all sites. The paths are rated at 100 Mbps to carry maximum bandwidth in either direction of the loop and operate in the 18 to

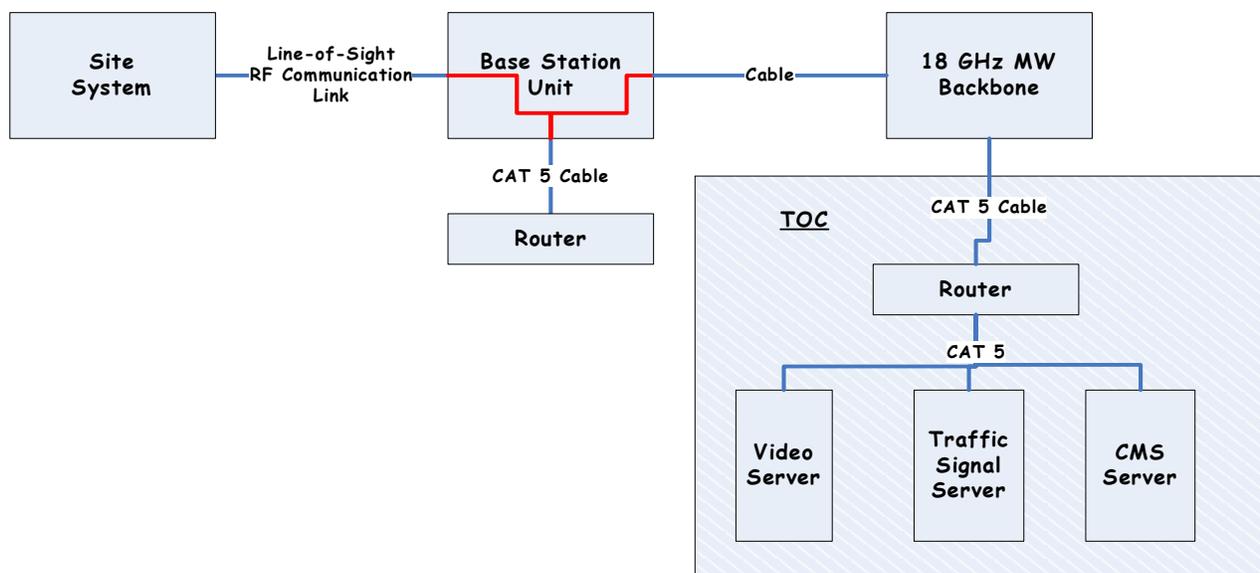


Figure 7-10: Schematic - Microwave Backbone Configuration

23GHz licensed microwave range. 100 Mbps is currently the maximum available, but several manufacturers are in the process of testing with 240 Mbps systems. The schematic shows how the Traffic system ties into the microwave communications backbone.

The broadband base stations are connected to a microwave radio backbone for transmission to the Traffic Operations Center.

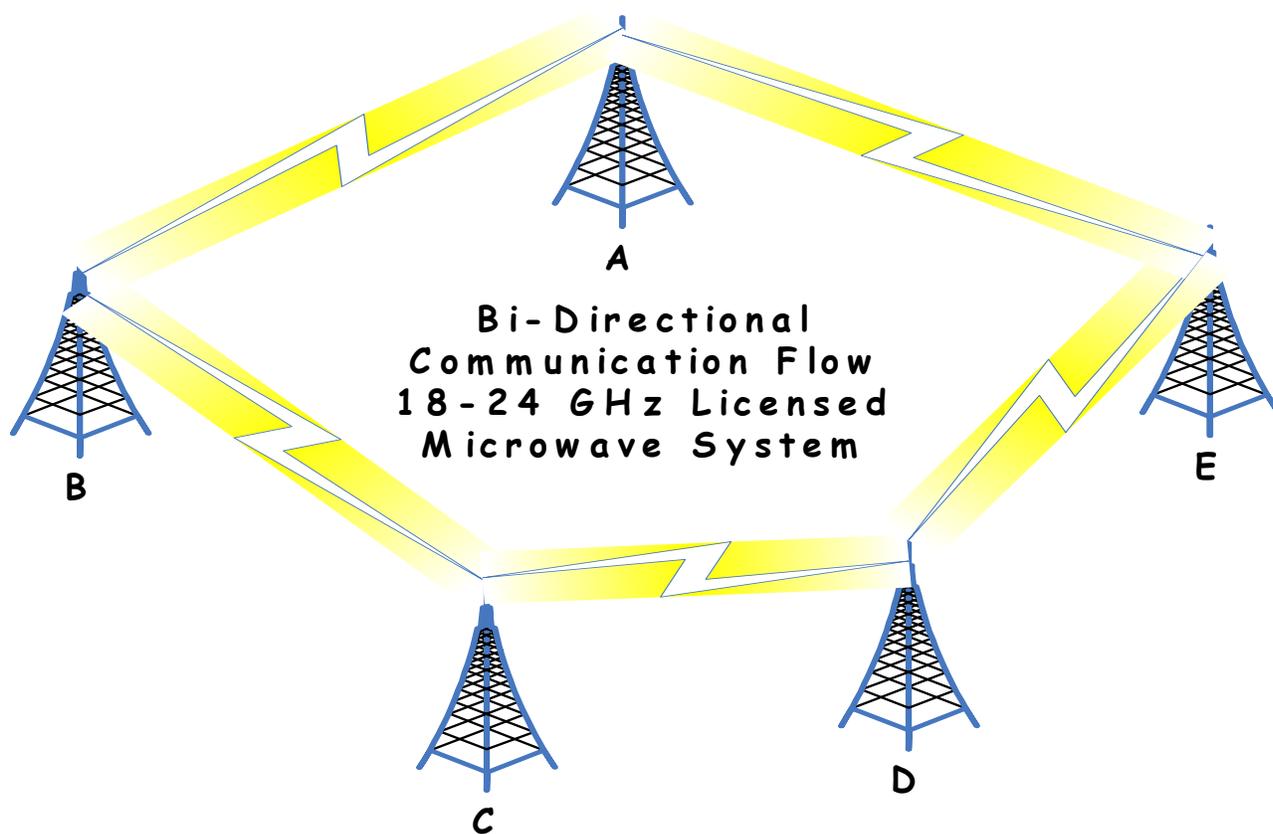


Figure 7-11: Diagram - Microwave Backbone

### *Conclusion*

This chapter has provided two very different solutions for a similar problem - updating an existing system with the incorporation of legacy devices and newer technology. Both user agencies evaluated their needs and options. Utah has an existing fiber optic communications network that it wanted to update. Irving, Texas has an existing traffic signal system that needed modernization. The same general requirement resulted in two very different approaches to the use of communication systems. The examples used point to the fact that there are many different telecommunication system designs that can be used to solve similar problems. Each design (solution) is unique to the needs of the end users. The lesson learned is to consider all possibilities and select the one that meets your needs.

## 8. CHAPTER EIGHT – CONSTRUCTION

### *Introduction*

Chapter Two presented the term media to describe the physical layer of a communication system that is used to convey information between two or more points. This chapter presents guidelines that should be used in the handling of the media during construction. The items described in this chapter are typically the responsibility of a general contractor, however, it is important for project managers and consultants to have a good knowledge of the construction process. General design and construction practices are the same as those associated with almost any civil works project. Conduit and direct-bury cable projects need to be designed using cable and conduit manufacturer recommendations for bending radii, and cover depth specifications. Towers and poles supporting radio antennas need to be designed using manufacturer recommended mounting and support guidelines.



Figure 8-1: Fiber Cable Route Construction – Photograph Courtesy Adesta, LLC

Many of the presented guidelines have been developed by manufacturers wanting to make certain that customers are satisfied with their products. Other guidelines have been developed based on observation of common mistakes made by construction contractors. The most important recommendation that can be made is to carefully monitor the construction process. Don't let contractors take "shortcuts". Make the manufacturer construction and media handling guidelines part of the project specifications. There may be good reason to not follow the recommendations (or the specification), and the contractors should be required to explain the need to deviate. Most requests

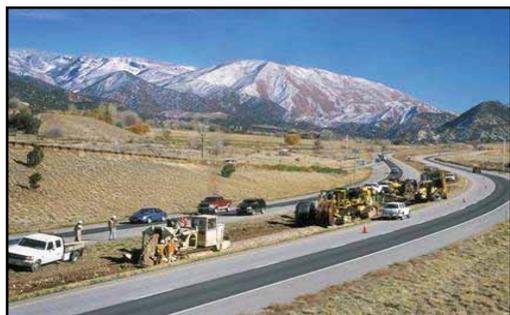


Figure 8-2: Fiber Cable Route Construction – Photograph Courtesy Adesta, LLC

for this type of action will be in the form of a "path" re-alignment. Treat the request as you would for any other highway construction project.

The physical design of the media path should conform to national and local construction design codes. Most municipalities issue construction permits. Many have specific codes relating to the locations of conduit or radio towers.

For very large projects, hire an independent construction management firm to observe the testing and construction process. Train in-house personnel to observe smaller projects. Require construction contractors to follow manufacturer recommendations for installation of their products.

Much of this chapter is devoted to the care and installation of fiber optic cable. Copper (twisted pair, coaxial, and antenna cable) transmission media cable require similar care and testing during installation.

### ***Handling and Installation of Fiber Optic (and Copper) Communications Cable***

Most ITS, Traffic, FMS systems use fiber optic, or copper cable as the primary communications transport medium. Use of the recommended procedures during installation can save a substantial amount of money. Most media problems occur because of a lack of care during installation. This section provides guidelines for the installation of "outside plant" communication cable. Each cable manufacturer will provide specific information related to the product they provide about care and handling during installation.

Following is a list of recommendations for the handling and installation of fiber optic communications cable. These same general procedures can also be followed when installing coaxial or twisted pair cable. The general procedures and requirements apply for all fiber optic communications cable whether installed aerially on communications utility poles, or in underground conduit, or structure attached conduit, or inner-duct placed in conduit, or direct burial.

- Receiving and inspecting the cable
- Unloading, moving and storing the cable
- Testing cable on reels

### ***Chapter 8***

- Documentation and record maintenance
- Cable Installation

### **RECEIVING AND INSPECTING FIBER OPTIC CABLE**

Let your cable manufacturer or distributor customer service representative know of any special packaging or delivery requirements (no shipping dock available, call before delivery, etc.). Put this information in the specifications so that contractors will be aware of these requirements. Make certain that personnel with test equipment are available. It is important to test damaged (or suspect) cable reels before accepting delivery - request 24 hours notice.

When the shipment arrives, make sure the cable types and quantities match the bill of lading. Inspect every reel and pallet of material for damage as it is unloaded. Suspect cable should be set aside for a more detailed inspection before the shipping documents are signed. The delivery persons may be on a tight schedule, but they aren't paying for the cable!

Notify the general contractor and the manufacturer/distributor that there are damaged cable reels before signing for the cable. Follow-up the telephone call with a written notice via e-mail or fax.

- Receipt of the cable does not imply acceptance!
- You may be pressured (by the distributor) to accept the cable by being told that you will have to wait 18 months for new cable.
- Remind the person applying the pressure that they won't get paid until the order is complete.
- Accept a 30 day delay in return for having a fully functional system. The delay will cost less than replacing damaged cable.

Some additional points to consider:

- Reels of optical fiber cables are shipped on their rolling edges not stacked flat on their sides. Make sure you note the orientation and condition of the reel in your inspection.
- If any cable damage is visible or suspected and if it is decided to accept the shipment, note the damage and the reel number on ALL copies of the bill of lading.

- If the damage is too extensive to accept the shipment, advise the carrier's driver that the shipment is being refused because of the damage. Immediately notify the cable manufacturer/distributor, Customer Service Department so that arrangements can be made for a replacement shipment.
- Cable performance test results taken at point of manufacture and reel loading are provided with each reel. Compare them to your own tests using the methods outlined in the cable testing section.

#### ***UNLOADING, MOVING AND STORING CABLE***

When unloading the cable reels from the delivery truck, exercising care is important. The reels may look like two wheels on an axle, but they should never be rolled off the back-end of the truck. The reels are heavy and may contain from 5,000 to 15,000 meters of cable. Following are guidelines for unloading, moving and storing of communication cable reels:

- Optical fiber cable reels are typically very heavy and, therefore, they must be loaded and unloaded using a crane, special lift truck or forklift.
- Forklifts must pick the reel up with the flat side of the reel facing the forklift operator.
- Extend the forks under the entire reel.
- Keep all reels upright on their rolling edges and never lay them flat or stack them. Optical fiber cable reels are always stored on the rolling edge
- All reels are marked with an arrow indicating the direction in which the reel must be rolled. Roll only in the indicated direction.
- **DO NOT drop reels off the back of the truck onto a stack of tires, onto the ground or any other surface.** The impact may injure personnel and will damage the cable.
- The reel is labeled with handling directions. Consult these directions if you have any doubt about handling the reel.
- To prevent reel deterioration during long term storage, store optical fiber cable in a manner that protects the reel from the weather.

### **TESTING THE CABLES**

- Manufacturers test the cable for continuity at the factory once it has been loaded onto the reel. This is your assurance that there are no breaks in any of the fiber (or copper) strands that make up the cable. The results are published and added to tags on the cable reel and to the paperwork that accompanies each cable reel. Do not accept any cable reels that lack the testing documentation. There are five phases associated with testing of fiber optic cable starting at the point of manufacture:
  1. Factory cable reel testing and documentation,
  2. Visual inspection at the delivery site for shipping damage, and possible reel test,
  3. Pre-installation testing, which occurs when the cable is delivered to the job site, and before it is installed,
  4. Installation testing, which occurs after the cable is pulled through the conduit (or mounted on poles) and at every splice point,
  5. Final acceptance testing, which occurs just prior to activation.

Why is testing so important, and why so many tests? Each test phase occurs at a responsibility hand-off.

- Factory to shipping company
- Shipping company to general contractor (or DOT)
- General Contractor to installation (path construction) company
- Installation Company to splicing contractor
- Splicing Contractor to end-user

Each entity will claim that the cable was in good condition when it made delivery of the product or service. Testing at each stage assures that liability for damage can be placed with the appropriate company. A significant portion of the cost of constructing the fiber optic cable system is in the final installation (cable pull, splicing and quality testing) of the cable. Imagine having to replace 15,000 feet of cable because of damage

sustained during the pulling. Knowing that the installation contractor is responsible will save a lot of time and finger pointing.

Following is a list of testing guidelines:

- Testing reels of optical fiber cables at delivery is not required (most manufacturers suggest that this be done to ensure that damage did not occur during shipping), however, testing prior to, and after construction is essential to identify any cable performance degradation caused during installation. Testing prior to installation provides a baseline of performance.
- Pre-installation Testing - This typically consists of an OTDR (Optical Time Domain Reflectometer) test performed at 1550 nm. All optical fiber cables must be bi-directionally OTDR-tested prior to shipment and the test report attached to the reel. Bi-directional testing is important to verify results and to make certain that no potential problems were missed. Remember, the data can flow in two directions on the fiber strand. Test to make certain that it will.
- A pre-installation test will verify the characteristics of the cable and check for any shipping damage. The tests must be jointly conducted by the system operator and the construction contractor in order to preclude future difficulties should a cable be damaged during construction.

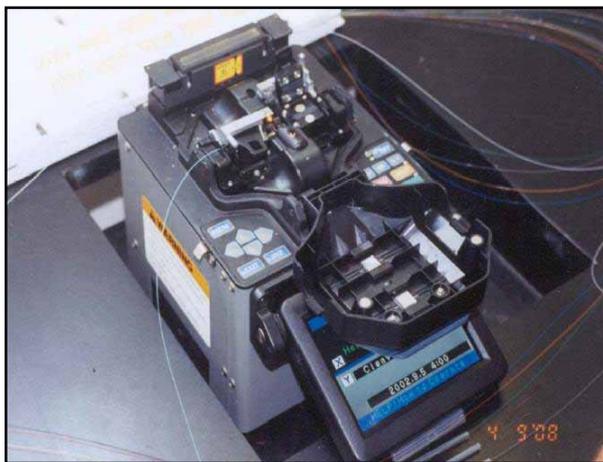


Figure 8-3: Fusion Splicing Fiber Strands -  
Photograph Courtesy Adesta, LLC

- Installation Testing - Cable should be tested once it has been placed in the conduit, or on the poles, and prior to splicing to make sure that there has been no installation damage. Installation testing is usually done with an OTDR.

- Splice testing is done after each splice to ensure that a clean, low-loss connection was made. OTDR, local injection

detection and profile alignment can be used alone or in combination for splice testing.

- Post Installation - Final Acceptance Testing - The usual post installation testing method is to perform end-to-end OTDR testing from both directions. The results should be compared to the pre-installation test. It is highly recommended that an ongoing testing program be established after the system is powered up.
- It is important that technicians testing the fiber use the same brand and model of test equipment and the same testing profile. Use of different test equipment and profiles will result in confusion and inconsistent test results.
- Make certain that someone on your staff (or the communication engineering consultant) is able to understand the test results to verify that all specifications have been met.

#### ***DOCUMENTATION AND RECORD MAINTENANCE***

"The best defense is a good offense", is a phrase that should be applied to the construction of a communication cable system. Optical fiber installation involves multiple fibers in a cable that may be very long and have many splices and connections. If cable is damaged during installation and not detected by on-going field testing, the replacement costs can be extremely high. It is recommended that the following records be maintained and kept current on a daily basis:

- schematic drawings - to include "as-built" information for street maps records
- splice loss data
- end-to-end optical loss measurements
- end-to-end OTDR signature traces
- end-to-end power meter tests

The documentation is needed to provide historical references for maintenance and, emergency restoration. By maintaining this data, the system operator is assured of a prompt repair response by the quick identification of the location of any problem that may occur within a cable. Data collection starts with the delivery of

the fiber cable, continues through construction and for the life of the system as new devices are added.

Following is a list of data that should be collected for the permanent record:

- Calculated data obtained from cable reel data sheets and splicing logs.
- Measured data, such as OTDR data, is obtained from end-to-end cable testing.
- Total amount of cable pulled between splice points - including slack coil loops
- Placement and use of pull boxes and cable splice boxes
- Accurate street maps showing the location of fiber cable and all accessory items
- Accurate location information of any repairs
- Maps that show where other utilities cross the fiber cable, or are in close (parallel) proximity to the cable
- A record of all communication devices connected to the fiber cable
- Where conduit (or the cable trench) is shared - list the other users
- Any other information that might be needed to support changes or emergency repairs.

### ***General Cable, Installation and Design Guidelines***

The following guidelines are presented to assist in the general design, construction and installation of fiber optic cable systems. Many of these guidelines can also be used for other types of communication cable.

#### ***CABLE PULL-BOX/SPLICE-BOX PLACEMENT***

- Every street (up to 50 feet wide) crossing - one (1) box located within 10 linear feet of the crossing, unless a traffic device (signal, DMS, video detector, etc.) is located near (within 50 linear feet) of the crossing.
- Every freeway, railroad, or bridge crossing - two (2) boxes located (one each) at the terminal points of the crossing.

- All mid-span splices must be placed in a splice box and secured in an appropriate cable tray.
- All splice boxes used for aerial cable installations should be mounted on a convenient utility pole. If no space exists on the pole, then a suitable in-ground splice/pull box must be installed near the utility pole. All cable leaving the aerial installation must be installed in conduit.
- All splice points must contain sufficient slack (50 foot minimum) to allow for future addition of communication devices, cable and splice repairs, or additional runs of "drop" cable. This would be especially true if the cable is located within a freeway right-of-way.
- All splice boxes must be properly grounded according to NEC, EIA/TIA and Bellcor (Telcordia) standards.



Figure 8-4: Aerial Fiber Optic Cable Splice Box - Photograph Courtesy Adesta, LLC

- Aerial mounted splice boxes should only be used for temporary repairs - in fact, many carriers use them for permanent repairs.
- Mid-span cable meets (points where ends of cable reels meet) must be fusion-spliced and enclosed in a splice box. Never use a mechanical splice to connect cable reel ends.

## **CABLE INSTALLATION AND PULLING GUIDELINES**

### ***Pulling Tension:***

- Each manufacturer has specific instructions and specifications for the amount of tension that may be used when pulling a fiber optic cable. The contractor is required to follow the cable manufacturer's specifications and recommended installation procedures.

- Kellems or crimp-on grips are used to pull the optical fiber cable. Use the correct-sized grip for the cable being pulled.
- If Aramid® yarn is part of the cable structure; tie it to the grip to further distribute the pulling force. **NEVER EXCEED the maximum pulling tension.**
- Excessive pulling force will cause the cable to permanently elongate. Elongation may cause the optical fiber to fail by fracturing.
- Good construction techniques and proper tension monitoring equipment are essential.
- When installing aerial cable place enough cable blocks along the route to keep cable sag to a minimum. Excessive sagging will increase pulling tension.
- When pulling, do not let the cable ride over the reel flange as it may scuff or tear the jacket.
- Tail loading is the tension in the cable caused by the mass of the cable on the reel and reel brakes. Tail loading can be minimized by using little to no braking during the pay-off of the cable from the reel - at times, no braking is preferred.
- Dynamometers must be used to measure the dynamic tension in the cable.
- Break-away swivels should be used in conjunction with dynamometers to ensure that the maximum pulling tension is not exceeded.

***Cable Bending Radius Guidelines:***

- Cables are often routed around corners during cable placement. **NEVER EXCEED the minimum bending radius.** "Over" bent cable may deform and damage the fiber inside.
- Bending radius for optical fiber cable is given as loaded and unloaded.
- Loaded means that the cable is under pulling tension and is being bent simultaneously.
- Unloaded means that the cable is under no tension or up to a residual tension of around 25% of its maximum pulling tension. The unloaded bending radius is also the radius allowed for storage purposes.

- Do not exceed minimum bend radii or the maximum pulling tension.
- Follow all pulling tension and minimum bending radii instructions and specifications issued by the cable manufacturer.
- In general, plan the cable path to eliminate as many curves and bends as possible. Curves and bends add to the attenuation of the fiber optic signal.

***Pulling Strategy Guidelines:***

- Fiber optic cables can be ordered in lengths on a single cable reel and can be installed in one continuous run. However, even a typical installation of 3 - 5 miles/5 - 8.0 km offers installation challenges because of the accumulation in pulling tension along such a long route. This tension can be eased by using intermediate assist devices like a series of mechanical winches or capstan drives connected to a master controller. However, if these devices are unavailable, a midpoint cable pull must be used for installing long lengths of optical fiber cable.
- The cable is installed from a midpoint to the endpoints.
- Make certain that all conduits are clear of obstructions. Use a water based lubricant to reduce outer sheath corrosion.
- Existing conduit may need repairs - inspect carefully.
- When installing aerial cable, make certain that the path is clear of tree limbs.

***General Cable Construction Guidelines***

Cable is generally installed using one of three methods: aerial, direct burial, or in conduit. This section provides some general guidelines for using these construction methods. The methods are listed in order of cost to construct. Aerial is generally considered lowest cost with conduit placement being the highest cost.

*FHWA has produced the "Design Guide for Fiber Optic Installation on Freeway Right-of-Way", publication # FHWA-OP-02-069. Consult this document for additional information and guidance.*

### **AERIAL CONSTRUCTION**

Aerial cable is typically strung from pole-to-pole, or from building-to-pole. Two types of cable are available: self-supporting or lashed. The self-supporting cable is designed with either a heavy duty central strength member, or in a figure eight configuration that has an external strength member that can be clamped. Lashed cable is similar to cable that can be direct buried and requires a "messenger support wire" to which the cable is affixed.

When using aerial cable, the engineer must provide sufficient supporting utility poles in the route to minimize the effect of cable sag. This is caused by external forces such as wind, ice and extreme temperature changes added to the weight of the cable. Manufacturers provide specifications to assist with cable route design and planning.

Here are some general guidelines:

- Use of tight buffered cable is not recommended for aerial installation
- Use a cable with a UV protected sheath to minimize effects from sunlight
- Use a metallic armored cable to minimize damage from squirrels and birds.
- Always follow the manufacturer recommendations for self-supporting cable installations. Consult the manufacturer for additional information when varying from recommendations.
- Allow for storage of sufficient slack loops to account for problems associated with cable breaks and pole damage from severe weather and vehicular accidents.

Table 8-1 is excerpted from a Corning Cable product brochure for self supporting fiber optic cable. Please consult the cable manufacturer's documentation for recommendations about installation under severe weather loading conditions such as high wind or severe ice and snow accumulation areas.

Table 8-1: Example of Manufacturer Recommended Span Lengths for Aerial Cable Segments

Maximum Span Lengths						
Maximum Span Lengths for NESC Loading Conditions						
Fiber Count	Heavy		Medium		Light	
	m	ft	m	ft	m	ft
2 - 36	504	1655	733	2405	844	2770
37 - 72	427	1400	622	2040	721	2365
73 - 96	496	1540	671	2200	751	2465
97 - 144	500	1640	553	1815	553	1815
145 - 216	335	1100	450	1475	494	1620

Notice that as the number of fiber strands contained in the cable increase, the distance between utility poles decreases. The same is true for loading factors.

Construction of aerial cable involving the use of existing utility poles, requires access permits from the owner of the pole. In most cases, the owner is the local electrical power utility, but some poles are owned by telephone companies. Utility poles are marked with identification tags.

The electrical power lines are always placed at the top of the pole. Telephone carriers are placed at the next lower level with about 10 feet of vertical separation from the electrical lines. Other users are located above the telephone lines, but with at least 10 feet of vertical separation from the electrical utility. The lowest set of lines must be placed at least 15 feet above grade. If there is not enough room to accommodate all valid users, it is necessary to raise the height of the pole. The last user is responsible for paying the cost of installing the extension (or taller pole) and moving all users to their appropriate position. Using existing utility poles can be very expensive.

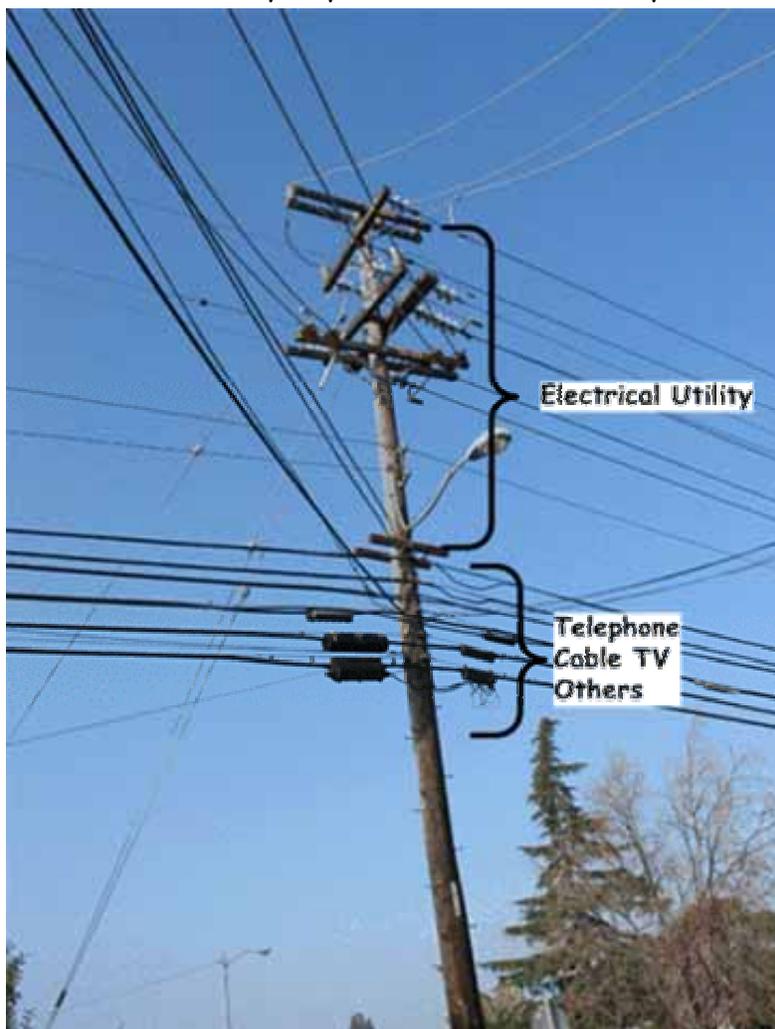


Figure 8-5: Typical Telephone Pole

### ***DIRECT BURIAL CONSTRUCTION***

Cable can be buried directly in soil using one of two general construction methods: open trench construction, or cable plow. In both instances, a cable rated for direct burial should be used. These cables are designed with a metallic armor sheath to prevent damage from rodents that may try to chew through the cable. The direct burial method is especially useful in rural and suburban locations. The non-paved portion of a rural road or highway right-of-way is a good candidate for this construction method. The route must be carefully planned taking care to avoid other buried utilities (water, electrical, telephone, gas, etc.) and meeting environmental requirements.

Using the open trench construction method, a backhoe is used to dig a 36 inch deep trench. The trench is backfilled with an appropriate material to prevent cable bends due to settlement. The trench is then filled to a level of 24 inches. A yellow warning tape is then laid in the trench before completing the fill process to terrain level. The 36 inch depth is an average. The cable should always be buried below the frost line. The actual depth of the cable may vary based on road crossings, or drainage ditch (drainage lines) crossings. The object is to keep the cable out of harm's way.

A second direct bury construction method uses a plow to open the earth, lay the cable and then cover. This is an economical and efficient construction method. However, no warning tape is installed.

Use of these methods does not eliminate the need to consider placement of slack cable and access handholes. There will always be a need to add communication devices and access nodes to a system.

Direct buried cable is always identified at the road level using orange marker poles. The poles have information indicating that communication cable is buried below together with contact information in case of damage to the cable. Markers should be placed about every 1000 feet, plus on either side of a road crossing, drive way crossing and bridge crossing.

A variant of the direct bury cable construction method is direct bury of flexible conduit. If plans call for installation of

additional fiber cables (in the same route) within a few years, the burial of flexible tube conduit with the initial cable provides significant savings over re-opening a trench. "Level 3" (a communication carrier) used this construction method to provide additional resources for the future. When "Level 3" needs to install additional fiber cable in their route, the flexible tube conduit can be used to minimize construction costs. This method also reduces traffic congestion due to construction.

### **CONDUIT CONSTRUCTION**

Placing cable in conduit is the most expensive solution for constructing a fiber optic cable route. Starting from scratch requires a significant amount of planning, especially in urban areas where most conduit is used. All utilities in (or near) the proposed construction path must be located and marked. The path may have to be realigned to avoid some of the utilities, or a proposal developed to temporarily interrupt service and then repair the damaged utility lines. Environmental issues must be addressed. Where construction is proposed for existing streets or roads, repair and restoration costs must be considered. Maintenance and protection of vehicular and pedestrian traffic must be implemented.

The conduit structure must be designed to meet bending radius requirements of the communication cable. The inside conduit diameter should be at least 25% larger than the outside diameter of the cable. This helps to prevent cable drag when pulling through the conduit.

Cable installed in conduit should be rated for immersion in water. All in-ground conduit eventually contains some water. Cables designed for this purpose are constructed with a sealant that prevents water from penetrating the fiber (or copper) transmission media.

If the conduit is buried at a depth of greater than three feet, it may be necessary to dig a trench that is wide enough to allow space for construction personnel. Trenching at a depth of more than six feet, will require "shoring" walls (see local construction codes for specific requirements) to prevent collapse and injury to construction personnel.

Most conduit used for telecommunications cable projects is high density polyethylene (HDPE). The ASTM has developed a

recommended standard, ASTM F2160, "Standard Specification for Solid Wall High Density Polyethylene (HDPE) Conduit Based on Controlled Outside Diameter (OD)". This standard was developed to assure that conduit from different manufacturers could be used with assurance that the inside and outside diameters of conduit pipe and the thickness of the conduit wall would match.

Some DOT's may require the use of steel conduit for bridge crossings or other types of construction. Using appropriate couplings, steel and HDPE can be mixed. HDPE is lighter in weight and easier to handle than steel, however, under certain loading circumstances it may not be as rigid.

### *Wireless Systems Construction*

Wireless media are used to support communication links between devices and the TCC. This is often viewed as a low cost alternative to the installation of communication cable. Many departments are using spread spectrum radio in the 900 MHz and 2.4 GHz range.

This section will focus on mounting of radio antennas and transmission line for "line-of-sight" (also called microwave) radio systems. These are the systems commonly used for traffic control and freeway management.



Figure 8-6: Installation of Wireless System - Photograph Courtesy GDI Systems, LLC

Spread Spectrum Radio, DSRC,

and the emerging 802.16 Wi-Max, or WLAN systems all require line-of-sight design. The design and construction of towers and poles is completed within standard civil engineering practices and local codes. This also holds true for building mounted antenna supporting structures.

**"Line-of-sight" is a term used in radio system design to describe a condition in which radio device antennas can actually see each other. High frequency radios, such as those used in Spread Spectrum Radio require line-of-sight between antennas.**

### ***PLANNING FOR WIRELESS SYSTEMS***

System planning is critical to the successful installation, operation and proper performance of any communication system, wireless systems are no exception, and this is especially true for line-of-sight (microwave) wireless. Unless your proposed microwave link will be operating over a very long path, you should be able to confirm whether a visible line-of-sight path exists between the two proposed antenna sites. This is only a first-step process, and is often accomplished by using a combination of strobe lights, mirrors (which reflect the sun), binoculars and spotting scopes. Being able to see one site from the other will not guarantee that the visible path is appropriate for a microwave signal, but at least you know that the possibility of such a path exists.

In many instances there may be obstacles to overcome such as buildings, trees, small hills and elevated roads, and it may not be possible to confirm that line-of-sight exists without additional aid. Keep in mind that even a "perfectly clear" visual path may not actually be so. As an example, small branches of deciduous trees, barren in the winter, may not be visible until spring or summer when growth appears. Even the skeleton of a new building may not be visible until the sides go up! Establishing line-of-sight for traffic signal systems should be easy to accomplish because of the short distances involved (a few blocks).

When establishing line-of-sight, it is extremely important to plan for the future. In urban areas, new building construction may result in total path obstruction. In areas where construction is not anticipated, the rapid growth of trees or foliage may severely affect the path over time. While a number of software products are available for assisting with path work, combining a topographical mapping of the path with a subsequent path walk or drive is often an excellent way to start the line-of-sight confirmation process.

Assuming an appropriate line-of-sight path from radio site to radio site can be established, both the feasibility and viability of a point-to-point microwave radio link will be dependent upon the gains, losses and receiver sensitivity corresponding with the system. Gains are associated with the transmitter power output of the radio, and the gains of both the transmitting and receiving antennas. Losses are associated with the cabling between the

radios and their respective antennas, and with the path between the antennas. Other losses can also occur if the path is partially obstructed, or if path reflections cancel a portion of the normal receive signal. Manufacturers will state respective RF power output and gain for each of their products.

Radio transmitters are described in terms of power output expressed in watts. The power output may also be expressed in terms of decibels of gain (dB). Radio receivers are rated in terms of sensitivity (ability to receive a minimal signal). The rating is listed in terms of milliwatts (mW), or decibels of gain (dB). Antenna cable is rated in terms of signal loss per foot and expressed as dB of loss per foot. The antenna is rated in terms of gain (dB). There are a number of software programs that will calculate path loss by frequency and use the specifications of the system hardware to help determine the overall system feasibility.

One of the first items to consider for any microwave path is the actual distance from antenna to antenna. The further a microwave signal must travel, the greater the signal loss. This form of attenuation is termed free space loss (FSL). Assuming an unobstructed path, only two variables need to be considered in FSL calculations:

- The frequency of the microwave signal - numerically higher frequencies require more power to cover a given distance.
- The actual path distance - the greater the distance the greater the signal loss.

A signal transmitted at a frequency of 6 GHz will have more available power than a signal transmitted at 11 GHz. For example, a microwave system at 6 GHz can expect to cover about 25 miles between communication points. The same system using a frequency of 11 GHz will only cover about 10 miles.

When RF energy is transmitted from a parabolic antenna, the energy spreads outward, much like the beam from a flashlight. This microwave beam can be influenced by the terrain between the antennas, as well as by objects in or along the path. When the centerline of a beam from one antenna to another antenna just grazes an obstacle along the path, some level of signal loss will occur due to diffraction. The amount of signal loss can vary dramatically, influenced by the physical characteristics and the distance of the object from the antenna.

A microwave beam can also be reflected by water or relatively smooth terrain, very much in the same way a light beam can be reflected from a mirror. Again, since the wavelength of a microwave beam is much longer than that of a visible light beam, the criteria for defining "smooth terrain" is quite different between the two. While a light beam may not reflect well off of an asphalt road, a dirt field, a billboard, or the side of a building, to a microwave beam these can all be highly reflective surfaces. Even gently rolling country can prove to be a good reflector.

A microwave beam arriving at an antenna could effectively be canceled by its own "mid-path" reflection, causing tremendous signal loss. Long microwave paths can also be affected by atmospheric refraction, the result of variations in the dielectric constant of the atmosphere.

For relatively short 2.4GHz microwave paths, only reflection points and obstructions are usually of real concern. The effects of atmosphere and earth curvature will not usually come into play, so the engineering of these paths is quite straightforward. For long or unusual paths, however, all aspects of path engineering must be considered.

Interference Issues - Spread spectrum microwave radio systems are among the most interference tolerant communication networks in use today. Spread spectrum signals are very difficult to detect and, by their nature, are highly resistant to jamming and interference. As more and more signals are transmitted, the "noise level" in the band increases accordingly. Once the noise reaches an identified level, communication in the band is effectively negated.

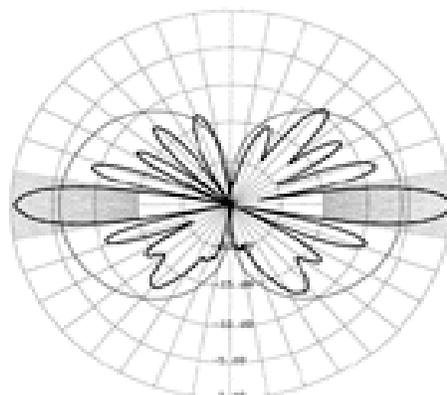
In the U.S., the 2.4GHz band is license free, making it very difficult to know whether or not another spread spectrum radio is operating in a manner which could possibly interfere with one's own link. While these links are usually able to spread narrow band interference, other spread spectrum signals in the 2.4 GHz band could possibly interfere if they are of the proper frequency and amplitude. It is extremely difficult to predict the effect of an interfering signal unless specific information is known about the interferer. In general, other spread spectrum signals in the 2.4 GHz band tend to raise the band's noise floor. For this reason, even when working with paths which are very short and not

subject to any sort of fading condition, a fade margin of 15 dB or greater should always be maintained for the path.

### **A WORD ABOUT ANTENNAS**

All RF systems have an antenna (or several in an array). The transponder used in a vehicle for toll collection has an antenna. The fact that it can't be seen doesn't mean that it isn't present. The antenna is built in-to the package. A cost comparison of all the elements that make up a radio system would show the antenna as the lowest cost piece. However, most of the problems that a radio system may have can be traced to either improper installation, or improper selection, of the antenna. Follow the recommendations listed below for proper installation.

All antennas have similar characteristics. They are designed with vertical and horizontal polarity. The manipulation of these characteristics creates a specific antenna coverage pattern. Some antennas are designed to provide a circular pattern referred to as omni-directional. Others have an elliptical pattern referred to as uni-directional. Antenna manufacturers will routinely provide the horizontal plane pattern as part of their product literature. An engineer can request a copy of the vertical pattern if necessary. The antenna pattern display is for an Antenna Specialists, Inc., 2.4 GHz Spread Spectrum radio system. The antenna projects two highly directional lobes. When setting up a radio system, it is critical that the installers match the pattern lobes to the system design. If the direction of the lobes is off by just a few degrees, that may cause the system to have a marginal performance.



**ASPT2976**

Figure 8-7: Example of Antenna Coverage Pattern - Antenna Specialists Products

### ***GUIDELINES FOR HANDLING & INSTALLATION OF WIRELESS ANTENNA AND TRANSMISSION CABLE***

RF Transmission cable should be treated with the same care as fiber optic communication cable. This is important. To prevent interference with other radio systems on the tower the transmission cable is constructed with an internal shield of

copper or copper foil. If this shield is broken, your system could cause interference with other systems at the site. Also, once the shield is cracked, your system is subject to interference. Some radio transmission cable uses a hollow copper tube to act as a "wave guide". If the hollow tube becomes damaged your system might not function properly. The following guidelines apply:

- All cable should be inspected and tested when received.
- All test results should be compared with factory pre-shipment tests.
- Inspect the cable nomenclature to make certain that you received the correct product.
- Notify the supplier (or manufacturer) of all discrepancies as quickly as possible.
- Follow the manufacturer recommendations for installation
- Cover all exposed cable ends to make certain that moisture does not penetrate the cable assembly.

Mounting cable on a pole or tower structure requires the use of qualified personnel, test equipment, and care to prevent damage to the transmission line:

- Use a hoist line that supports the total weight of the cable -refer to manufacturer specifications
- Use pulleys at both the top and bottom of the pole (or tower) to guide the hoist line.
- Support the cable reel on an axle so that the cable can be freely pulled from the reel. Have a crew member control the rotation of the reel.
- Short lengths of cable coiled and tied. Uncoil the cable on the ground away from the pole before hoisting.
- After raising the cable to the top of the pole, anchor it to the support structure from the top down.
- Never anchor the cable to an electrical (or lighting) conduit.
- The top and bottom of the cable attached to the pole should be electrically grounded to the pole with a grounding kit.
- The antenna input connection cannot be used as the cable ground at the top of the pole.

- Test all connectors to make certain that they do not "leak" RF power.

### ***Conclusion***

The information provided in this chapter should be reviewed by project managers responsible for the design and implementation of communication networks outside plant. Construction of communication infrastructure is expensive - don't add to the cost by permitting contractors to take short-cuts. Require that manufacturer installation guidelines be followed.

There are times when guidelines must be modified. Make certain that you understand potential problems and require that contractors provide a written explanation for the record.

### ***RESOURCES:***

The Rural Utilities Service (RUS) is a division of the United States Department of Agriculture. RUS provides assistance to Rural Telephone Companies via the publication of construction and equipment standards. These publications are based on existing telecommunications industry practices and are available to the general public via the internet. There is a list of accepted products for purposes of obtaining RUS loans and grants. This does not infer that other products won't meet the requirements of a specific project.

[http://www.usda.gov/rus/telecom/publications/pdf\\_files/1755.pdf](http://www.usda.gov/rus/telecom/publications/pdf_files/1755.pdf)

<http://www.usda.gov/rus/telecom/publications/bulletins.htm>

## 9. CHAPTER NINE – THE INTERNET

### *Introduction*

The internet is a major communication tool used by commercial enterprise, and government agencies to support trade, operations, and interaction with customers and suppliers. Many individuals use the internet every day, at work and at home. Throughout the world, the internet is used as a primary source of communication and information services. In fact, the International Telecommunications Union (ITU) estimates that, as of 2002, more than 650 million individuals, worldwide, use the internet. A Harris Poll Survey, in January 2004, revealed that 146 million adults in the United States use the Internet, and 37% have access to broadband connections. In this chapter, you will learn about the Internet's structure, how it works, and its history. The chapter will also look at how transportation agencies use the internet to provide information and facilitate interaction with other government agencies. Consistent with the other chapters in this Handbook, the information presented is basic and designed to provide an elementary understanding of the internet and communication requirements.

### **WHAT IS THE INTERNET?**

The Internet is an international network of computers connected by wires such as telephone lines. Schools, businesses, government offices, and many homes use the Internet to communicate with one another. You probably have access to the Internet via a computer at work, and may have access from your home computer. Many have access via their cell phone, and soon, you may have access via an embeded device in your automobile.

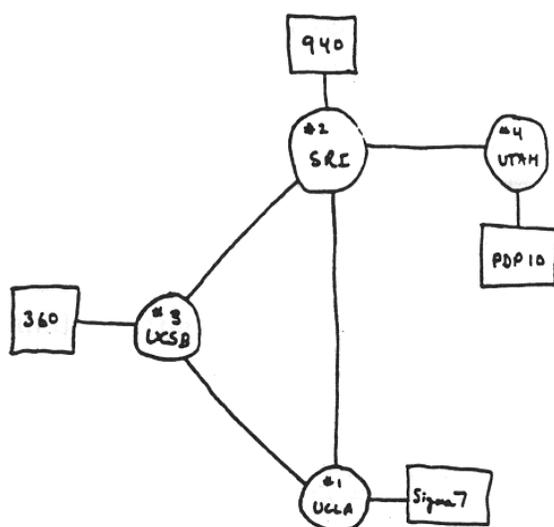
Gaining access is simple. A computer, modem, telephone line, an account with an Internet Service Provider (ISP), and web browser software, is all that's necessary. Most individuals and businesses pay for internet access, but there are also a number of providers that will permit access without fees.

The term "World-Wide-Web" is a verbal description of the image presented by the interconnecting communication links between the network nodes - it appears to emulate a spider web.

The most popular component of the Internet is electronic mail (e-mail). The use of e-mail has changed the way in which individuals, corporations and government agencies communicate. E-mail allows for the almost instant delivery of information, and has caused a reduction in the use of voice communication via the telephone. In general, the use of e-mail is becoming a universal tool for communication.

Organizations and individuals are able to create web sites to post information about their products, services, and themselves. Departments of transportation post information about roadway maintenance, traffic congestion, and other traveler information on their websites.

### HISTORY OF THE INTERNET



THE ARPA NETWORK

DEC 1969

4 NODES

Conceptual Sketch of Original Internet

Figure 9-1: Actual Sketch of the Original Internet

The Internet evolved from a network developed originally to support scientific research to the "World Wide Web" (WWW) over a period of 40 years. In the early 1960's, the United States Department of Defense (DOD) created the Advanced Research Projects Agency (ARPA). One of its first projects was to create a system to link research centers and Universities for purposes of sharing information.

<sup>13</sup>Today, it is a worldwide operation consisting of millions of computers and computer networks. A public, voluntary, and cooperative effort

<sup>13</sup> Drawing found on internet – source CERN

between the connected institutions and not owned or operated by any single organization. The underlying infrastructure is, however, owned and operated by a number of telecommunication companies.

The Internet and Transmission Control Protocols were initially developed in 1973 by American computer scientist Vinton Cerf as part of a project sponsored by the United States Department of Defense Advanced Research Projects Agency (DARPA) and directed by American engineer Robert Kahn.

Internet technology was a primitive precursor of the Information Superhighway, with the goal of computer communications to provide schools, libraries, businesses, and homes universal access to quality information that will educate, inform, and entertain. The original demonstration project was small and consisted of four nodes. Each node provided a combination of processing and network connectivity capability. The current system has a combination of generalized nodes and specialized nodes providing different types of support for the world-wide-web.

### *The Internet and the World-Wide-Web*

The average individual did not become aware of the internet until the mid-1990s. It was basically the province of scientists and university researchers and a few computer "geeks" able to understand how computer networks and software functioned to



Figure 9-2: Map - Location of Major MCI Internet Nodes in United States

allow this type of communication. Not until the introduction of graphical user interfaces (GUI) and the innovations of companies (CompuServe, America-On-Line and others long forgotten) wanting to popularize and commercialize the process did the internet evolve into the "world-wide-web" (WWW). America-on-Line (AOL) introduced a user friendly graphical interface, in 1994, which made it easy for a person with limited computer skills to access (or browse) and use the internet. Other companies soon followed the example with their own proprietary web interfaces. These interfaces are commonly referred to as "Web Browsers". Originally, a user had to enter a specific destination code (more later). The new GUI interface systems provided the less experienced internet user with a way to simply "browse" web pages as if they were reading a magazine.

The World Wide Web, is a network that links computers together via a world wide communication network. The communication network is composed of a hierarchy of nodes, linked via an infrastructure of fiber optic, copper, and wireless communication facilities. This is sometimes referred to as the "Infostructure".

The nodes are owned and operated by companies that are in business to provide a service to other companies that provide internet access to businesses and individuals. A subsidiary of MCI operates major internet switching nodes in the United States.

This map (figure 9-3) shows the location of the primary internet switching points in the United States. These nodes are owned and operated by a subsidiary of MCI.

These nodes are interconnected to efficiently manage internet traffic and prevent "bottle-necks". They are connected via a series of survivable fiber optic (chapter 2) communication rings. Nodes in the United States are connected to other nodes in Europe and Asia to support a world wide web of internet systems.

Internet nodes can be very large and be spread over several buildings, or very small occupying only enough space to house several small computers. The MCI MAE-East facility is located on Long Island, but is supported by a number of alternate nodes spread throughout the New York City metro area. Major internet service providers, such as AOL, AT&T WorldNet, MSN, and Yahoo have major access points located in close proximity (same building, or within a few blocks) of the MCI facilities. This allows

these major ISPs to provide a large number of users efficient access to the internet. Major ISPs have multiple high bandwidth links (OC-192 or 10 GB) to the MCI nodes. This is also true for the major telecommunication carriers such as Sprint, Verizon, SBC QWEST, AT&T, etc. These companies are considered as Tier One carriers. All other providers access the internet via one of the Tier One carriers.

Departments of transportation using the internet will contract with a service provider (Internet Service Provider) for access. The ISP will arrange for all necessary communication connections, access servers, webmaster support, and help desk to trouble shoot problems. Later in this chapter internet connection and setup options will be discussed. All ISPs provide similar services:

- Communication connectivity to Carriers.
- Routers to direct internet traffic
- Switches to create virtual communication paths
- Computers to support internet traffic.
- An electrically protected environment for computing and communication equipment.
- Shared floor space for companies to place equipment for internet access.
- Modem banks for dial-up access

The following diagram (figure 9-3) shows a typical set of connections for ISP and large corporate users to access the internet. Notice that the large corporate user has installed a

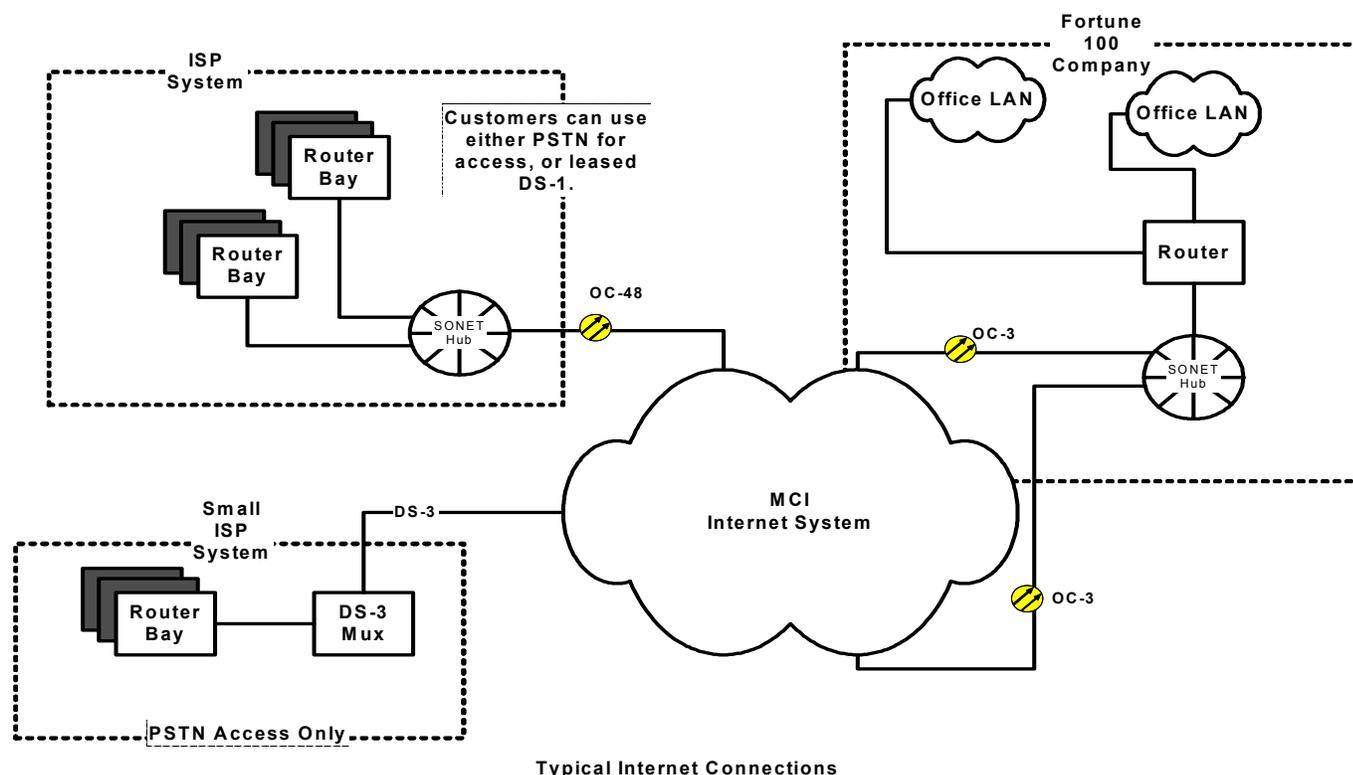


Figure 9-3: Diagram General Internet Architecture

redundant communication link to the internet. Internet Service Providers may also install redundant links, or they may have a distributed network that provides redundancy without the need for duplicate communication links. The drawing shows SONET hubs and SONET broadband communication links. Once standards are fully implemented, this architecture will most likely change to Gigabit Ethernet hubs (or switches) with 10 GigE/GigE communication links.

The use of redundant links serves two purposes. First, the need to maintain a connection for services. Second, redundant links can also be used to support temporary requirements for increased capacity. Traveler information systems (ATIS) may become overloaded during a major incident. The primary communication link may not be able to provide adequate throughput, and the redundant link is used to temporarily share the load. Most broadband communication links provide service for both voice and data and TMCs have both center-to-center and center-to-public

requirements. Later sections in this chapter provide more information about how Transportation Management Centers can use the internet or internet like services to fulfill "mission critical" requirements.

### ***How Does the Internet Work?***

Two primary elements make the internet work. First, the internet is built as an overlay to the world wide telecommunications infrastructure. Portions of the network were specially built to meet the needs of the internet. However, most of the communication network is based on the use of the common infrastructure. Second, there is a common set of communication protocols and an agreed set of standards for the software language used by web browsers. This commonality permits a person in Japan to view web pages created in France.

The Internet - or the World-Wide-Web - is formed by connecting local networks through special computers in each network known as gateways. Interconnections are made through various communication paths, including telephone lines, optical fibers, and radio links. The connections between the main gateways are permanent; however, the connections for individual users (at home, or the office) are setup as needed. Additional networks can be added by linking to new gateways. Information to be delivered to a remote machine is tagged with the computerized address of that particular machine. The following diagram (figure 9-4) is a schematic of how an individual in a small corporate office might obtain traffic congestion information via the internet. Notice that only the ISP is directly connected to the internet system. All other users are routed to the internet via the PSTN or leased lines from an intermediate communication carrier.

The DOT must enter into agreements with both the ISP and a carrier to be able to provide traveler information services via

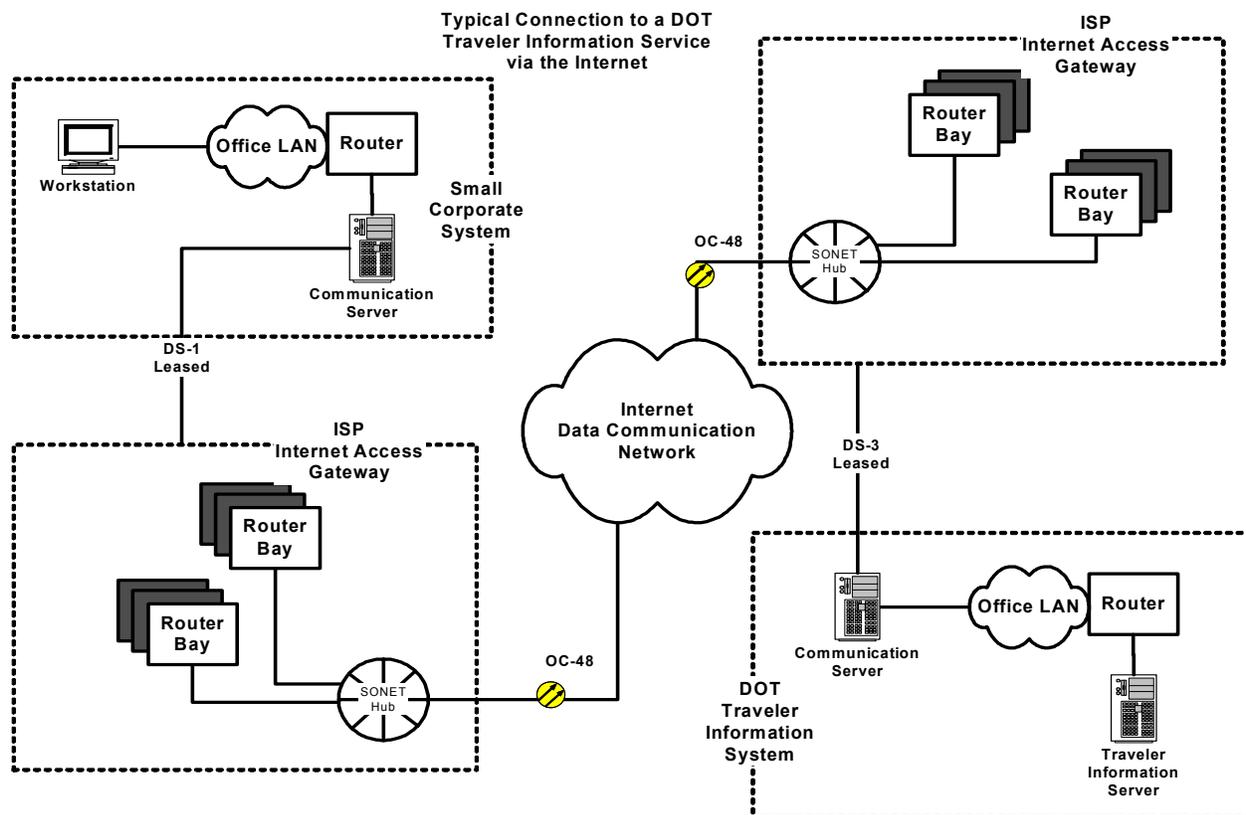


Figure 9-4: Diagram - Traveler Information Provided via the Internet

the internet. An alternative solution is available. The ISP provides all of the services and systems as part of a package. However, the DOT can provide its own services. This would require developing a network of internet servers and routers. The DOT would have to duplicate the systems and services that it obtains from an ISP. The decision to do this is based on economic and organizational requirements.

In the example above, the connections are all permanent by virtue of the high speed leased lines. However, if users at home wanted to access the DOT Traveler Information web pages, their connection would be temporary. The network would be created on an "ad hoc" basis. As soon as the home user logged off, the connections would go away.

### **ADDRESSING – FORMATS**

Various addressing formats are used by the different services provided by internets. Addressing is similar to a telephone number- it lets the system know which web site you want to visit.

One format is known as dotted decimal, for example: 123.45.67.89. Another format describes the name of the destination computer and other routing information, such as "machine.dept.univ.edu." The suffix at the end of the internet address designates the type of organization that owns the particular computer network, for example, educational institutions (.edu), military locations (.mil), government offices (.gov), and non-profit organizations (.org). Networks outside the United States use suffixes that indicate the country, for example (.ca) for Canada. A (.us) suffix is now available for the United States.

Once addressed, the information leaves its home network through a gateway. It is routed from gateway to gateway until it reaches the local network containing the destination machine. Internets have no central control, that is, no single computer directs the flow of information. This routing is referred to as the Internet Protocol (IP). This protocol specifies how gateway machines route information from the sending computer to the recipient computer. Another protocol, Transmission Control Protocol (TCP), checks whether the information has arrived at the destination computer and, if not, causes the information to be resent. The overall protocol is referred to as TCP/IP - Transmission Control Protocol/Internet Protocol.

To support a diverse set of users across the Internet, it is important to use a technology that is independent of a computing platform so that any network device can access the web service. Such a technology should be compact using little bandwidth and very portable so it can be used on many devices. There are several very powerful languages and protocols that are used between disparate systems located on the Internet, such as:

- Extensible Markup Language (XML)
- Simple Object Access Protocol (SOAP)
- Java

### ***Extensible Markup Language***

XML was created during the mid to late 90s as a way to take raw data such as text, graphics, or binary transmissions from nearly any source and apply an organizational structure that is both contextual and visual. XML can be used to deliver structured content including text, vector graphics, and electronic transactions across a network like the Internet.

### ***Simple Object Access Protocol***

SOAP follows the typical client/server model and is designed to use standard technologies like XML to transmit small amounts of information across a network using a standardized language and format. SOAP does not use any specific transport protocol and does not use any programming model. It is a language that can be used to send commands and information as well as a standardized method of organizing and encoding information. Because SOAP is independent of transport protocol and programming model, it is well suited for communication between systems that would not otherwise be able to communicate. Therefore, a SOAP-aware application is able to create, send, receive, and interpret the commands between disparate systems and act upon them as intended.

### ***Java***

A programming language that is designed to be platform-independent and portable. In other words, Java is not based on a specific computing platform; it is based on its own workspace, which can exist in any computing environment. Java applications can operate exactly the same on any computer regardless of the operating system or hardware configuration used. Java creates a self-contained computing environment that can run within other operating systems and interact with an operating system to perform tasks. Java consists of three major components:

- Java programming language
- Java application libraries
- Java virtual machine

Each of these technologies is used in some capacity to deliver web services. However, the World Wide Web Consortium (W3C) is beginning to standardize which protocol should be used when delivering web services. In a working draft created in May 2003 called *Web Services Architecture*, the W3C outlines the core technologies behind a web service and gives some guidelines on how the service should be developed, designed, and deployed. The W3C seems to have agreed upon XML as the basis for a standardized web service, but only time will tell which language will be chosen. More than likely there will still be a variety of languages used to create web services, even after a standard has been established.

For more information see: *Web Services Architecture* - (<http://www.w3.org/TR/ws-arch/>) - W3C Working Draft May 14, 2003.

Computer interaction has dramatically changed our world, bridging the barriers of time and distance, allowing people to share information and work together. Evolution of the Information Superhighway is continuing at an accelerating rate. The available content has grown at a rapid pace, and will continue growing rapidly, making it easier to find any information on the Internet. All Government Agencies, Universities, and virtually all commercial enterprises use the internet as a primary means of providing information to the public. New applications provide secure business transactions and new opportunities for commerce. New technologies continue to increase the speed of information transfer. Internet users are now able to download feature length movies and Broadway Shows.

#### ***TYPES OF INTERNET NETWORKS***

There are several different configurations of internets. Most common is the Internet used by millions every day. The system is open to anyone with a modem, telephone line, and a web browser. Companies, government agencies, schools and other organizations have discovered that the simple common internet protocols can be used to create a very powerful internal communication network. Setting up an internal internet provides organizations with the ability to communicate using the same software and systems used for external communications.

### ***Intra-Net***

These networks are called "Intra-Net". They are only accessible by individuals directly connected via a local area network. Most users are familiar with the PSTN version that allows access via a standard telephone line connection using a modem. Access can also be gained via cable TV system links, broadband DSL links, and direct connections via DS-1 or DS-3 links. Intra-Nets are private networks contained within an enterprise. It may consist of many interlinked local area networks and also use leased lines in the Wide Area Network. Typically, an intranet includes connections through one or more gateway computers to the outside Internet. The main purpose of an intranet is to share company information and computing resources among employees. An intranet can also be used to facilitate working in groups and for teleconferences. An intranet uses TCP/IP, HTTP, and other Internet protocols and in general looks like a private version of the Internet. With tunneling, companies can send private messages through the public network, using the public network with special encryption/decryption and other security safeguards to connect one part of their intranet to another. Typically, larger enterprises allow users within their intranet to access the public Internet through firewall servers that have the ability to screen messages in both directions so that company security is maintained.

### ***Extra-Net***

An extranet is created when part of an intranet is made accessible to customers, partners, suppliers, or others outside the organization. A DOT could create an extranet to share information with incident responders. Local police departments could be provided with images from CCTV cameras to support coordinated management of a specific incident.

An Extra-Net is a private network that uses the Internet protocol and the public telecommunication system to securely share part of a business's information or operations with suppliers, vendors, partners, customers, or other businesses. An extranet can be viewed as part of a company's intranet that is extended to users outside the company. It has also been described as a "state of mind" in which the Internet is perceived

as a way to do business with other companies as well as to sell products to customers.

An extranet requires security and privacy. They require firewall server management, the issuance and use of digital certificates or similar means of user authentication, encryption of messages, and the use of virtual private networks (VPN) that tunnel through the public network. Companies can use an extranet to:

- Exchange large volumes of data using Electronic Data Interchange (EDI)
- Share product catalogs exclusively with wholesalers or those "in the trade"
- Collaborate with other companies on joint development efforts
- Jointly develop and use training programs with other companies
- Provide or access services provided by one company to a group of other companies, such as an online banking application managed by one company on behalf of affiliated banks
- Share news of common interest exclusively with partner companies

### ***Role of the Internet for Traffic, ITS, Freeway Management & Traveler Information***

If the Internet was viewed from the perspective of the National Architecture, it would be shown as a communication element. The architecture model might be modified showing the Internet as an underlying element of wide area wireless and wire line communications systems.

Departments of transportation have looked to the internet as a way to communicate with the traveling public. The Web is

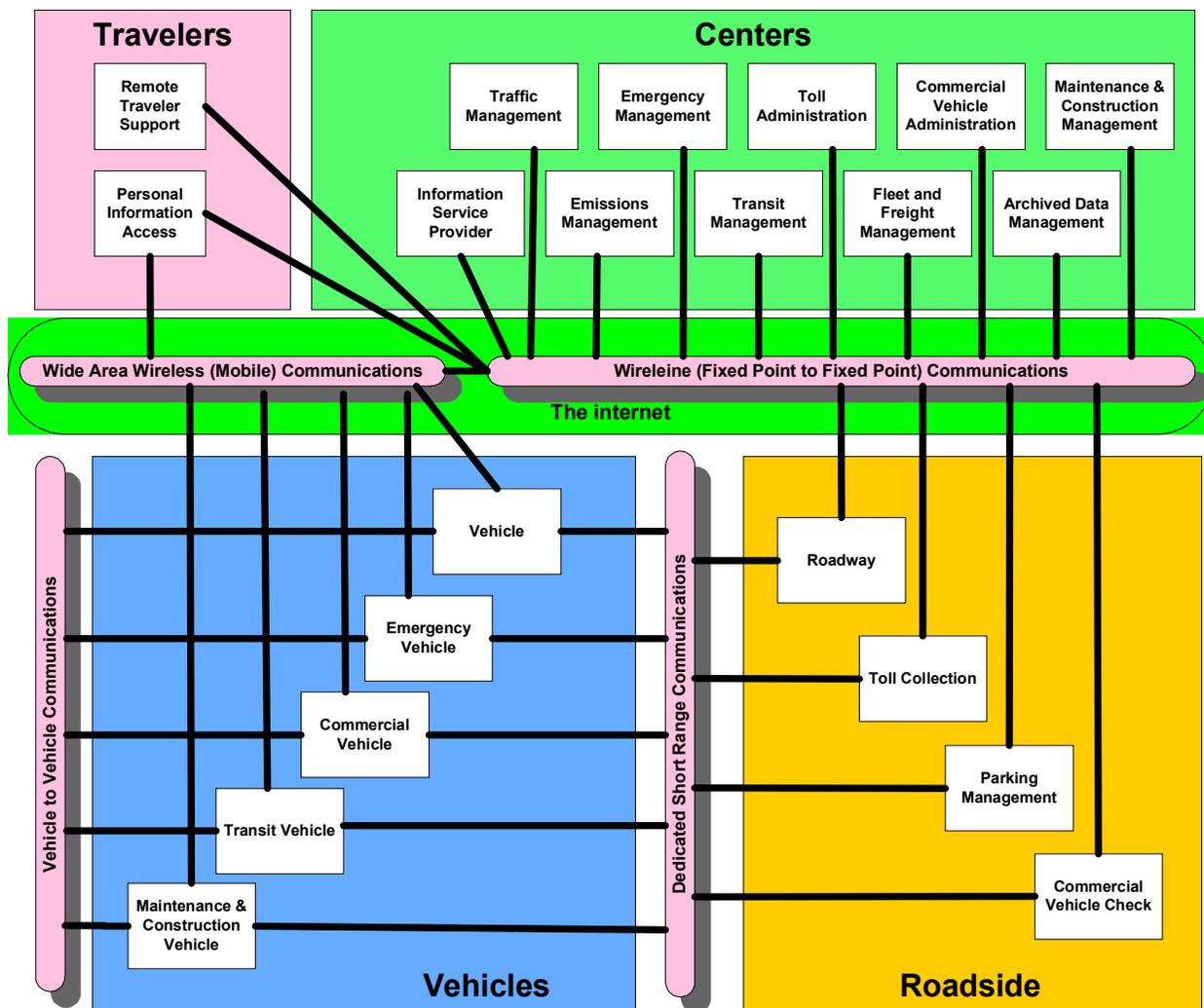


Figure 9-5: National ITS Architecture Sausage Diagram with Internet added

primarily used to provide information about current travel conditions, including:

- Locations of congestion
- Video views of highway sections
- Video views of intersections
- Highway segment travel times
- Construction locations and possible travel times
- Special events

- Weather conditions affecting travel
- Link to other transportation agencies
- Link to Department of Motor Vehicle services

#### Examples of current internet sites

- Virginia Department of Transportation:  
[http://virginiadot.org/default\\_myvdot.asp](http://virginiadot.org/default_myvdot.asp)
- Kansas Department of Transportation:  
<http://www.ksdot.org/public/kdot/>
- California Department of Transportation:  
<http://www.dot.ca.gov/>

The above are a few examples of DOT web sites. More can be found at the following resource web site: <http://www.betterroads.com/linkspages/linksdot.htm>. Better Roads is a publication of James Informational Media, Inc.

Many DOT sites provide a significant amount of traveler information in a traditional WWW access mode. Some sites provide access to driver license and automobile registration via secure links. Others even provide access for trucking firms to file for travel permits. This is all accomplished through the use of secure web pages that allow users to complete a financial transaction on-line. Many of these sites require the user to complete an application for secure access to the financial transaction web pages. However, the telecommunication portion of the system has no impact on the overall transaction. It is in fact, transparent, and simply provides the connection between service provider and customer.

#### ***USE OF THE INTERNET FOR CENTER-TO-CENTER COMMUNICATIONS***

The internet can be used as a telecommunication tool to allow transportation agencies to provide for a more efficient operation. In addition to providing access for the public to obtain services and receive information, it can be used to help support secure, efficient "Center-to-Center" communication links. Using a combination of internets, intranets, and extra-nets, agency-to-agency links are easy to accomplish.

To better understand the role of the internet and its various telecommunications applications, let's look at the basic elements needed (table 9-1), and a schematic. The elements (from a telecommunication perspective) are as follows:

Table 9-1: Internet Communication Elements

Basic Elements	
Elements	Explanation
Web Based Applications	The actual set of web pages and capabilities of the specific DOT system
Application Servers	One or more, computers used to run and store the applications, web pages, user information, required databases, etc.
Communication Servers	One or more computers used to manage access between the WWW and the application servers
Routers	Used to route information to and from the WWW, and between the application and communication servers
LAN	Local Area Network (the physical network) connecting routers application and communication servers
Communication Network Access Hardware	The actual equipment that connects the DOT Web system to the WWW
Communication Facility	This is the actual copper, fiber, or RF path used to get from the DOT computer site to the WWW

The above table and schematic (figure 9-6) show how a typical DOT system may connect to the internet. However, there are several variations.

Some DOTs may have contracted their system to a company that provides all of the necessary application servers and communication pathways. In that case, the DOT would have remote access to the system to provide updates and additions.

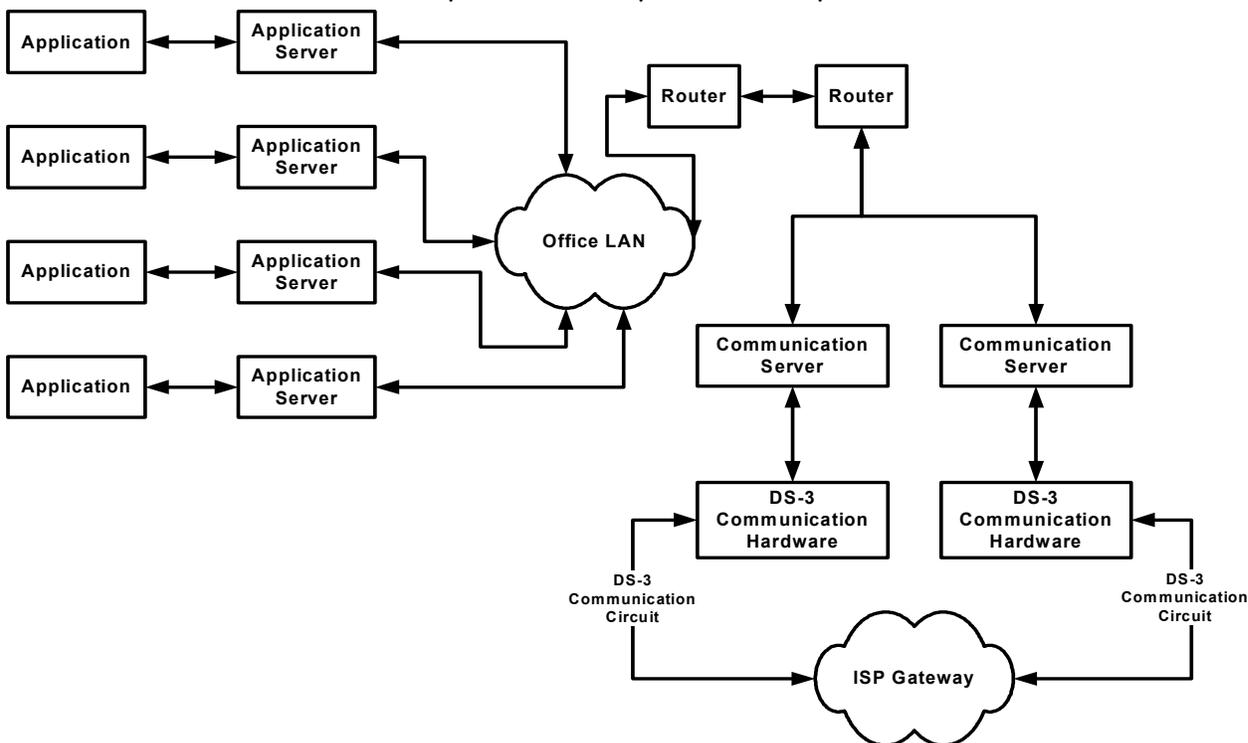


Figure 9-6: Internet Elements Schematic

The contract with the private company would include all necessary services, including periodic maintenance and equipment updates. Overall design of an internet system is normally handled by a specialist using support from the Information Technology Department (IT), the ISP, and the carrier providing the leased communication facility.

The Internet is a powerful tool and can be used as part of an operational program for distributing information between DOT facilities and allied traffic management agencies (Center-to-Center). An operational scenario that has traffic incident data shared by a state DOT district TMC, local streets TMC, local police, and disaster management agency can take advantage of the internet infrastructure. The

A virtual permanent connection - "VPC" - is communication path that is permanently in place, but is not a fixed communication link such as a T-1. The communication path is always available and private, but does not always take the same route between two points; therefore, it is "virtual".

internet can be used to provide a robust and economical communication network. The primary advantage being that connectivity is via an existing telecommunication system that is maintained and updated on a regular basis. Cost of the base system can be proportionately shared, with communications access links paid individually by each user agency. Effectively, the combined agencies create a wide-area intra-net. The network is closed to web surfers and the public via the use of fixed communication access circuits called "virtual permanent connections" (VPC).

Special secure web pages are created providing authorized users access to the system using a standard web browser. All

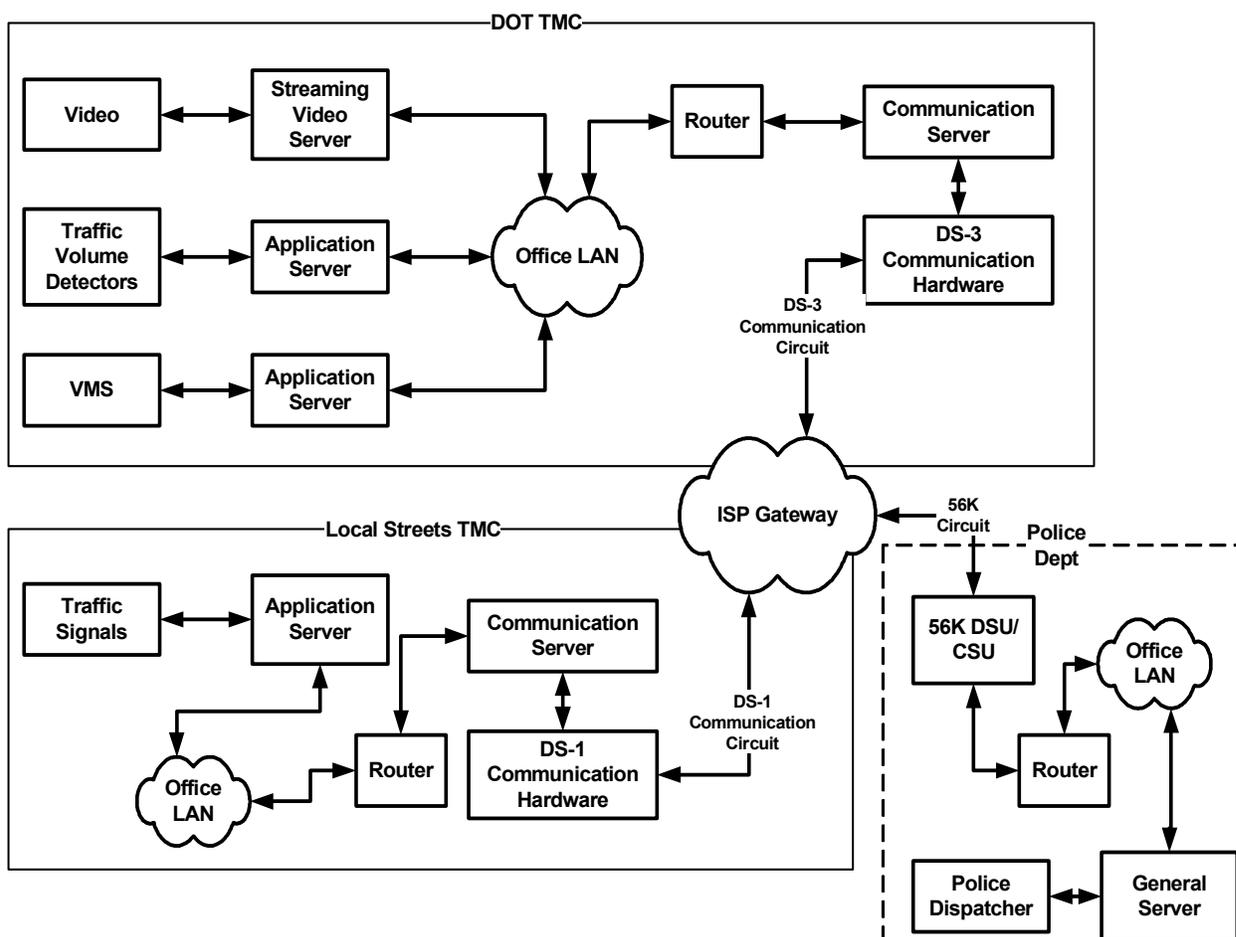


Figure 9-7: Schematic - Multiple Agency Center-to-Center Links via the Internet

information is provided in the same general format to all users. A central database is created to allow for retention of information that can be used at a later date for statistical research. The

data contained on the web pages can have additional security layers with some users able to only view the information, and others being able to download the data. Figure 9-8 is a schematic of a system that can be used by several agencies to share information.

Notice also, in figure 9-7, that each entity has a different communication link. The size and cost of the Intra-net link is determined by user requirements and is paid for by the using agency. In this schematic, the DOT and Local Streets are each providing applications to the shared system. The serving agency controls the release of information. Each agency can set varying levels of access and determine which information will be provided. The ISP charges a fee for operating and maintaining the internet gateway and the overall web site. Users share this cost and the cost of any mutual applications. Notice that there is no direct PSTN access to the

"Firewall" - is a term used to describe a software application designed to prevent unauthorized access to the initial entry point of a system.

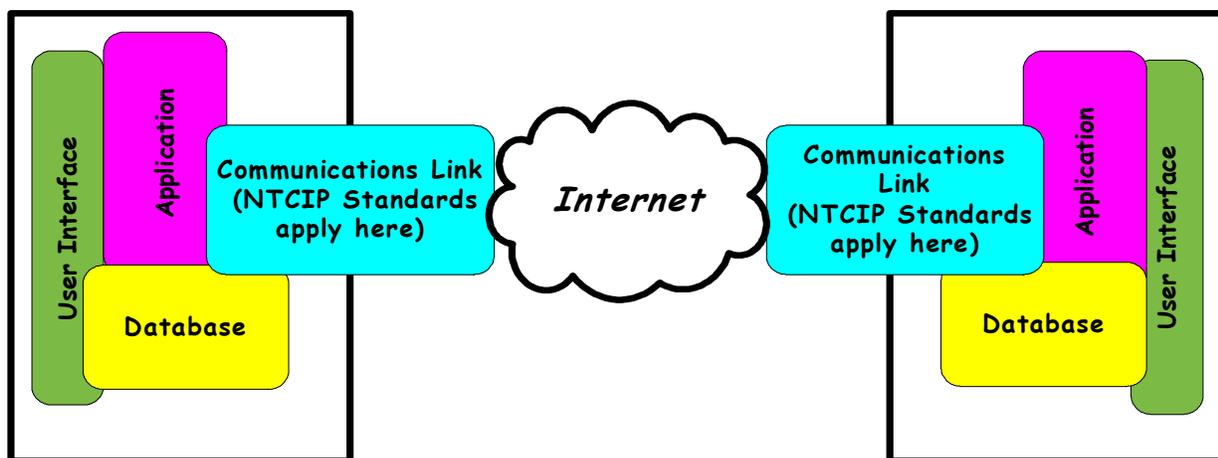


Figure 9-8:ITS Center-to-Center Communication Diagram

system.

Individual agencies can provide dial-up access via their own system for selected employees. A firewall is used to prevent

unauthorized access to the system. Only specific users are permitted access for limited applications.

The NTCIP committee is in the process of developing Center-to-Center communications protocols. These protocols can be used in the above scenario. Figure 9-8 provides a relationship diagram of the NTCIP protocols.

### *Conclusions*

The internet is a powerful tool used to disseminate information to many individuals. Since 1995, the internet has become a "ubiquitous" form of communications. Individuals, corporations and government entities use the internet extensively for sharing information, running operations, and transacting business. Some of the largest users are financial institutions. Following is a list of examples of how transportation agencies are using the internet:

- Amtrak sells tickets and provides schedules
- The Bay Area Rapid Transit Systems (BART) uses the internet to provide schedules, station locations, ticket sales, and other information.
- Colorado DOT provides access to "oversize - overweight" permit applications.
- Mississippi allows current residents with a valid driver's license to pay for a renewal online.
- The City of Houston, Texas provides access for payment of minor violation and parking ticket fines online.

Most states and many municipalities provide extensive information about transportation services and general and specific traveler information via the internet. Commuters can log onto web sites throughout the country to get the latest traffic and mass transit condition information before leaving work for the trip home. Traffic and transit updates can be delivered via wireless services while a traveler is enroute.

The internet and the WWW have become the defacto standard for communications services. Transportation agencies have embraced the use of the Internet and the World Wide Web as part of their overall operational program.

## 10. CHAPTER TEN – THE FUTURE

### *Introduction*

Predicting the future is always a little dangerous, especially for technology intensive systems and services such as telecommunications. This handbook was written over a two year period that saw major developments in the way that telecommunication services are provided, and in their supporting technologies. The intent of this chapter is to provide a look at some of the telecommunications technologies that may have an impact on the development of Transportation Management Centers, Traffic Signal Systems, and Freeway Management Systems. The following information is provided based on technology developments at the time of publication of this document.

### **CIRCUIT SWITCHED Vs. PACKET SWITCHED**

Prior to 2004, most industry analysts were indicating that the major telecommunication carriers would continue to invest most of their money in the maintenance and upgrade of existing circuit switched voice based networks- the general consensus being that the significant investment in those types of networks would continue through 2050. In January 2004, several major telecommunication carrier companies announced that they were shifting the investment of those dollars to implementation of packet switched internet telephony networks. They indicated that the shift would be aggressive, looking to make services based on those systems available network wide by 2010.

The overall effect of these changes will make the transmission of digital data via these networks less expensive and require less hardware. Departments of Transportation will derive significant benefits from the changes. Traffic signal systems that traditionally used dedicated leased telephone lines will be able to use packet switched circuits. Instead of paying for a leased line on a 24/7 basis (even when the line is not in use) they will pay for the amount of data actually transmitted (the number of packets used). Hardware for these systems will be less complex, and lower in cost. DOTs will see a reduction in the overall complexity and cost of hardware required in the TMC together with a reduction of the cost to operate and maintain this equipment.

### **Chapter 10**

Between 1998 and 2004, the IEEE 802 committees developed a number of standards for the efficient transmission of data using both wireline (including fiber) and wireless. These new standards help to provide for the "seamless" transmission of data from one medium to another. All of these new standards will be easier to implement via the new packet switched networks. The new standards allow for relatively simple transition from wireline to wireless, and back, with minimal degradation of data quality and bandwidth.

A major problem created by the transition from circuit switched to packet switched is the requirement to identify the origin and destination of the communication. Currently, telephone numbers are used. The caller simply enters the telephone number of the called and the system recognizes the hierarchal (a thirteen digit code) order to route the call. Each circuit can be identified via the:

- Country Code (3 digits)
- Area Code (3 digits)
- Exchange Code (3 digits)
- Circuit Code (4 digits)

The pair of wires connected to each telephone instrument can ultimately be identified (and called) by a telephone number.

The Cellular Telephone system simply replicated the circuit switch method by providing each wireless handset with a traditional telephone number. The system works for voice connectivity, but is problematic for broadband data networking. The emerging requirement for wireless handsets to be mobile computers (rather than mobile telephones) has created a need for a new switching and connection protocol.

"Session Initiated Protocol" (SIP) is an emerging communication protocol that improves the ability of packet switched networks to identify origin and destination points within a network. SIP uses the universal resource locator (URL) protocol to provide connections. These are the same identifiers used to browse web pages. A URL is a type of address that describes the location of information on the World Wide Web, e.g., [www.fhwa.dot.gov](http://www.fhwa.dot.gov). With SIP, even phone numbers are converted to URLs. Reaching an individual can be as simple as entering his or her e-mail address. The similarity of SIP to HTTP not only makes it ideally suited for

the IP environment, but it's easy for HTTP experts to program it without learning a new language

### ***Trends for Transportation***

A number of new telecommunication technologies will begin to be used on a broad scale by Departments of Transportation and Tolled Facilities operations. Some of these are:

- High speed Ethernet
- Resilient Packet Ring (RPR)
- Broadband Wireless
- Radio Frequency Identification(RFID)

### ***HIGH SPEED ETHERNET***

Ethernet is generally considered as a high speed telecommunication topology, but for purposes of this discussion one (1) gigabit (GigE) and ten (10) gigabit (10GigE) are considered as high speed. There are (as this handbook is being written) discussions of higher speeds (beyond 10 Gig) for Ethernet.

Many devices used in Traffic Signal and Freeway Management systems are being manufactured with Ethernet communication ports. This will allow for direct connection of the devices without the need to use protocol converters (serial to Ethernet).

### ***GigE***

GigE will provide significant capabilities for transporting video and other data from field devices to the TMC. Most desktop computers and work stations started shipping with GigE capability embedded into the "motherboard" by the fourth quarter of 2003. Eventually, GigE will become the standard for LAN for desk-top to desk-top communication within the center. Two processes, voice and video over IP, will be greatly facilitated by the use of GigE.

Chapters 2, 5, and 7 presented the concept of VIP (video over IP). CCTV cameras are designed with built-in video CODECS and Ethernet transmission ports. The use of these devices will simplify the deployment of visual observation systems for traffic

and transportation management. The following is a comparison of traditional CCTV systems and VIP systems:

Table 10-1: Comparison Traditional CCTV vs. VIP Systems Requirements

Traditional	VIP
CCTV Camera	CCTV Camera with internal CODEC & VIP
PTZ Unit	PTZ Unit with built-in connection via the VIP module
Video Encoder	Router
Fiber (or copper) Transmission System	Fiber Transmission System
Video Decoder	Software in operator Work Station
Video Switch	
Analog Monitors	
PTZ Controller	
PTZ Communication System	
Rack system to hold all of the hardware in the TMC	No additional equipment, electricity or HVAC required in TMC
Electricity to power the equipment in the TMC	
Added HVAC capability in the TMC	

Fewer pieces of hardware reduces the overall complexity of the system, and reduces the total cost of deployment and maintenance. This is one example of how new telecommunications standards and systems will help provide economies and efficiencies in the development of Freeway and Traffic Management systems.

Voice-over-IP (VoIP) will provide an ability to reach individuals regardless of the type of communication system being used. Dispatchers at a desktop work station will be able to reach field

personnel by selecting an individual's personal identification number in an application such as Microsoft Outlook. The dispatcher won't have to worry about pushing buttons on a communication console, or which communication network to use. A software application will take care of the process.

### **10GigE**

A primary objective of the 802.3ae working group was to develop a 10 Gbps communication protocol with a transmission link distance of up to 40km over single mode fiber<sup>14</sup>. The 10 Gbps 802.3 solution was developed to extend Ethernet capabilities providing higher bandwidth for multimedia, distributed processing, imaging, medical, CAD/CAM, by improving the performance of:

- LAN Backbone and Server and Gateway Connectivity
- Switch aggregation
- the MAN, WAN, Regional Area Network (RAN), and Storage Area Network (SAN)<sup>15</sup>

10GigE is (as of the publication of this handbook) only starting to be deployed. Its initial use is as a backbone transport system. There is no (current) plan to use this type of system for desktop-to-desktop communication.

Department of transportation could take advantage to 10GigE for Center-to-Center communications, and connecting major field communication hubs to a TMC.

### **RESILIENT PACKET RING (RPR)**

Fiber optic networks are widely deployed throughout the world. They are normally deployed in a ring architecture. These rings are currently using protocols that are neither optimized nor scalable to the demands of packet networks. An RPR networks standard (IEEE 802.17) is being developed to provide for the optimization of bandwidth allocation and throughput, resiliency to faults. This will also result in reduced equipment and operational costs.

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<sup>14</sup> <http://grouper.ieee.org/groups/802/3/ae/objectives.pdf> - IEEE 802.3ae committee, July 2001.

<sup>15</sup> <http://grouper.ieee.org/groups/802/3/ae/criteria.pdf> - IEEE 802.3 High Speed Study Group, Criteria

The current SONET standard was developed to provide for the efficient operation of fiber optic ring networks. However, its primary goal was to support circuit switched networks. Moving data in and out of a SONET network is very cumbersome, and requires significant investment in multiplexing equipment. Additionally, SONET is bandwidth inefficient. That's because it is a traditional TDM protocol that provides fixed bandwidth for data circuits - even those that are unused. The biggest advantage of SONET is its ability to restore circuits within a ring architecture. Communication circuits are provided an alternate path within 50ms of an outage due to physical damage.

RPR is being developed to support Packet Switched networks and utilize the 802.3 series of communication protocols. Bandwidth is provided when needed. RPR also provides for circuit restoration as efficiently as SONET.

Engineering personnel responsible for the design and development of Traffic and Freeway management systems should learn more about RPR. There is a strong likelihood that RPR will play a significant role in communication networks of the future. You can learn more by visiting the following web sites:

- The IEEE 802.17 Working Group - <http://grouper.ieee.org/groups/802/17/>
- The RPR Alliance - <http://www.rpralliance.org/>

### **BROADBAND WIRELESS**

IEEE published the 802.16 standard in April, 2002. The standard was developed to provide for broadband internet access and to meet the demand for low cost (by comparison to trenching) deployment of services. The standard is designed to support spectrum in the 10 to 66 GHz range. A modified standard, 802.16a has also been approved to support both licensed and unlicensed spectrum in the 2 to 11 GHz range.

The new standards are actually referred to as the "air interface" for broadband services. They are designed to complement the 802.3 wireline standards and provide for efficient media transitions in a mixed system. There is a need to be able to extend the reach of broadband internet access beyond the wireline infrastructure. DSL for example has a limited distance (typically 18,000 feet from a central office). Wireless systems are seen as the answer. An IP based wireline system can be

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extended using a wireless broadband link without changing the communication protocol. The transition from one media to the next is seamless.

Wireless communication links have been used by many Departments of Transportation to connect remote devices to a main system on a limited basis. The City of Irving Texas decided to upgrade its entire traffic signal communications infrastructure to an 802.16a standards based system. The City was originally looking at a fiber communications network that was estimated at more than \$10 million. The broadband wireless system is being implemented (as this handbook is being written) for less than \$750,000.

Dedicated Short Range Communications Systems (DSRC) are part of the broadband wireless services. However, current system development is based on the 802.11a standard. There is a difference between the two standards. 802.11 was developed as a wireless local area network (LAN) and 802.16 was developed to support "fixed" broadband access. Both complement and work together within the overall series of 802 standards.

DOTs will continue to look at wireless as part of an overall telecommunication strategy. Broadband wireless will play a key role in the development of future systems.

More information can be found at the following web sites:

- IEEE 802.16 Committee - <http://grouper.ieee.org/groups/802/16/>
- Worldwide Interoperability for Microwave Access - <http://www.wimaxforum.org>
- Wireless Communication Association - <http://wcai.com/>

### ***RADIO FREQUENCY IDENTIFICATION (RFID)***

RFID systems first appeared in the 1980s for tracking and access applications. RFID has been used to track containers moving from ships to dock storage to land transportation. Manufacturing has used RFID to track major parts (such as automobile axles) through a warehouse and onto an assembly line. RFID devices are used to open gates to a parking lot. The "tags" used by Toll Collection Authorities are a type of RFID.

Technology advancements over the past 20 years have seen the development of RFID into a universally accepted means of asset tracking and data collection. RFID Tags have been reduced in size from their original inception. Manufacturers are beginning to embed the tags in many items, and major retailers are starting to require the tags to help prevent theft. In the not too distant future, tags may replace bar-coding as the universal form of product identification. Theoretically, a shopping cart full of groceries could be scanned without having to remove the items from the cart. A shopper could pack items into bags in the cart. The cart would have an active reader that would display a running total. When finished, the shopper could charge the purchase to an account and leave the store without having to wait in a checkout lane.

A major advantage of RFID devices is that they can be embedded within the structure of an item. The tag activates on receipt of a radio signal from a reader device. A drivers license could have an embedded tag for instant identification.

RFID Tags could be placed in sections of roadway. Maintenance crews could be directed to locations that need repair or restoration. Their vehicle would have a tag reader that reports the completion of the repair. A police officer at the scene of an accident could scan in an identification tag in a damaged section of guardrail. The information would be directly reported to a DOT District maintenance office to schedule repairs.

A number of organizations are working to develop standards for RFID. More information is available at the following locations:

- RFID Standards - <http://www.aimglobal.org/standards/rfidstds/RFIDStandard.htm>
- RFID Journal - <http://www.rfidjournal.com/>

### *Conclusions*

Between 1876 and 1986 the most that could be said about telecommunication technology and process was that it is consistent. In the laboratory, change was dramatic, in the field, change was very slow. Since 1986, new technology and process has been introduced almost as rapidly as it was developed.

Carriers are being forced by the new technologies to change the way they do business. The traditional telephone companies are now forced to compete with cable companies and wireless companies. Time-Warner Cable company is effectively competing with Verizon for traditional telephone services with the introduction of VoIP. Many individuals are now using wireless carriers for their primary voice telephone services.

All of these changes will have a profound impact on how departments of transportation deploy and use technology for management of traffic signal and freeway management systems. The use of Gigabit Ethernet and broadband wireless technologies will provide significant implementation savings over current systems technologies. These same technologies will make it easier to provide for interoperability between transportation agencies, as well as public safety and other municipal and state agencies.

# 11. APPENDIX

## *IEEE 802 Standards & Working Groups*

Table 11-1: IEEE 802 Standards List

IEEE 802 Standards & Working Groups	
Standard	Status
802.1 Internetworking	Active
802.1d Spanning Tree Protocol	Active
802.1s Multiple Spanning Trees	Active
802.1q VLAN Frame Tagging	Active
802.2 Logical Link Control	Inactive
802.3 Ethernet (CSMA/CD)	Active
802.3u Fast Ethernet	Active
802.3z Gigabit Ethernet	Active
802.3ae 10 Gigabit Ethernet	Active
802.4 Token Bus	Inactive
802.5 Token Ring	Inactive
802.6 Distributed Queue Dual Bus (MAN)	Disbanded
802.7 Broadband Technology	Disbanded
802.8 Fiber Optic Technology	Disbanded
802.9 Voice/Data Integration (IsoEne)	Inactive
802.10 LAN Security	Inactive
802.11 Wireless Networking	Active
802.11a 54 Meg Wireless Network	Active
802.11b 11 Meg wireless Network	Active
802.11g 54/11 Meg wireless Network	Active
802.12 Demand Priority Access LAN (100BaseVG-AnyLan)	Inactive
802.14 Cable Modem	Disbanded
802.15 Wireless Personal Area Network	Active
802.16 Wireless Metropolitan Area Networks	Active
802.17 Resilient Packet Ring	Active
802.18 LAN/MAN Standards Committee	Active

802.19 Coexistence TAG	Active
802.20 Mobile Broadband Wireless Access	Active
802.21 Interoperability WG	Active

### ***Comparison Analog Voice & VoIP***

- **Technology** – analog to digital. VoIP erases the line between voice and data. VoIP converts analog information (the human voice) into data packets, the same digital containers used to shuttle email messages and download web pages.
- **Network** – PSTN to IP. A traditional phone call stakes out a single path over the public switched telephone network (PSTN). VoIP uses Internet Protocol, the language of the Internet. It separates a conversation into packets, which flow over data networks – the Internet, company intranets, or proprietary IP networks managed by Carriers (such as: Verizon, SBC, Sprint, MCI, etc) or alternate service providers (such as: AOL, COMCAST, etc.).
- **Network connection** – phone line to broadband. In a traditional voice system, desktop phones connect to the outside world via a telephone line, and data systems connect through a data/broadband network. With VoIP, phones plug into a broadband connection (through a modem or similar device) or the in-house company LAN. This convergence helps to drive down costs by combining the voice and data networks.
- **Phone numbers** – place to device. In the pre-VoIP world, a phone number belongs to a location. With VoIP, the number goes with the device.

## *Calculating Fiber Optic Loss Budget*

### **CRITERIA & CALCULATION FACTORS**

Design of a fiber optic system is a balancing act. As with any system, you need to set criteria for performance and then determine how to meet those criteria. It's important to remember that we are talking about a system that is the sum of its parts.

Calculation of a system's capability to perform is based upon a long list of elements. Following is a list of basic items used to determine general transmission system performance:

- **Fiber Loss Factor** - Fiber loss generally has the greatest impact on overall system performance. The fiber strand manufacturer provides a loss factor in terms of dB per kilometer. A total fiber loss calculation is made based on the distance x the loss factor. Distance in this case the total length of the fiber cable, not just the map distance.
- **Type of fiber** - Most single mode fibers have a loss factor of between 0.25 (@ 1550nm) and 0.35 (@ 1310nm) dB/km. Multimode fibers have a loss factor of about 2.5 (@ 850nm) and 0.8 (@ 1300nm) dB/km. The type of fiber used is very important. Multimode fibers are used with L.E.D. transmitters which generally don't have enough power to travel more than 1km. Single mode fibers are used with LASER transmitters that come in various power outputs for "long reach" or "short reach" criteria.
- **Transmitter** - There are two basic type of transmitters used in a fiber optic systems. LASER which come in three varieties: high, medium, and low (long reach, medium reach and short reach). Overall system design will determine which type is used. L.E.D. transmitters are used with multimode fibers, however, there is a "high power" L.E.D. which can be used with Single mode fiber. Transmitters are rated in terms of light output at the connector, such as -5dB. A transmitter is typically referred to as an "emitter".
- **Receiver Sensitivity** - The ability of a fiber optic receiver to see a light source. A receiving device needs a certain minimum amount of received light to function within

specification. Receivers are rated in terms of required minimum level of received light such as -28dB. A receiver is also referred to as a "detector".

- Number and type of splices - There are two types of splices. Mechanical, which use a set of connectors on the ends of the fibers, and fusion, which is a physical direct mating of the fiber ends. Mechanical splice loss is generally calculated in a range of 0.7 to 1.5 dB per connector. Fusion splices are calculated at between 0.1 and 0.5 dB per splice. Because of their limited loss factor, fusion splices are preferred.
- Margin - This is an important factor. A system can't be designed based on simply reaching a receiver with the minimum amount of required light. The light power budget margin accounts for aging of the fiber, aging of the transmitter and receiver components, addition of devices along the cable path, incidental twisting and bending of the fiber cable, additional splices to repair cable breaks, etc. Most system designers will add a loss budget margin of 3 to 10 dB

### ***CALCULATING A "LOSS BUDGET"***

Let's take a look at typical scenario where a fiber optic transmission system would be used.

Two operation centers are located about 8 miles apart based on map distance. Assume that the primary communication devices at each center is a wide area network capable router with fiber optic communication link modules, and that the centers are connected by a fiber optic cable. The actual measured distance based on walking the route, is a total measured length (including slack coils) of 9 miles. There are no additional devices installed along the cable path. Future planning provides for the inclusion of a freeway management system communication link within 5 years.

Note: All distance measurements must be converted to kilometers. Fiber cable is normally shipped with a maximum reel length of 15,000 feet (or 4.5km). 9 miles is about 46,000 feet or 14.5km. Assume that this system will have at least 4 mid-span fusion splices.

Table 11-2: Fiber Loss Budget Calculation

### ***Appendix***

Fiber Loss	14.5 km x .35dB	-5.075
Fusion splice Loss	4 x .2dB	-.8
Terminating Connectors	2 x 1.0dB	-2.0
Margin		-5.0
Total Fiber Loss		-12.875

The manufacturer of the router offers three transmitter/receiver options for single mode fiber:

Reach	Transmit Power	Receiver Sensitivity
Short	-3dBm	-18dBm
Intermediate	0dBm	-18dBm
Long	+3dBm	-28dBm

To determine the correct power option add the transmit power to the fiber loss calculation.

Reach	Transmit Power	Fiber Loss	Loss Budget
Short	-3	-12.875	-15.875
Intermediate	0	-12.875	-12.875
Long	+3	-12.875	-9.875

Compare this to the receiver sensitivity specification

Reach	Receiver Sensitivity	Loss Budget	Difference
Short	-18	-15.875	+3.0
Intermediate	-18	-12.875	+6.0
Long	-28	-9.875	+19.0

Because a loss margin of 5.0dB was included in the fiber loss calculation, the short reach option will provide sufficient capability for this system. In fact, the total margin is 8.0db because the difference between the loss budget and receiver sensitivity is 3.0db.

***Rural Telecommunications Requirements Testimony***

**STEVE ALBERT – SENATE HEARING**

**United States Senate  
Committee on Environment and Public Works  
Subcommittee on Transportation, Infrastructure and Nuclear Safety**

**Hearing on Intelligent Transportation Systems Program**

**September 10, 2001, 3:30 p.m.**

**Oral Testimony of Stephen Albert, Director  
Western Transportation Institute, Montana State University  
and  
President, Rocky Mountain Chapter  
of Intelligent Transportation Society of America**

Good afternoon Chairman Reid, Ranking Member Inhofe, and members of the Committee. I would like to begin by thanking you for this opportunity to share our views and perspective on Intelligent Transportation Systems and specifically Advanced Rural Transportation Systems or rural ITS.

My name is Stephen Albert, I am the director of the Western Transportation Institute at Montana State University. WTI's mission is to "make rural travel and transportation safer, more convenient and more accessible." Founded in 1994 by the California Department of Transportation, Montana Department of Transportation and MSU, WTI is the nation's leading research Center focusing on rural transportation issues. With over 30 ongoing research, demonstration and evaluation projects in 30 states and 10 National Parks, WTI was recognized in 1998 by ITS America for our "outstanding achievement in rural ITS." In addition to serving as WTI's director I also serve as the Rocky Mountain ITS America Chapter president.

I am here representing not only western states, but the entire rural community and we thank each of you for raising awareness of rural America transportation needs and ITS applications. My testimony was developed from speaking with stakeholder groups on the east coast, southern United States, mid-west and Alaska.

My testimony will address the following three areas:

- magnitude and severity of rural transportation challenges facing this nation;
- specific examples and benefits of successful ITS deployment;
- future focus areas where additional emphasis and resources should be placed.

#### 1. What are the Rural Challenges?

For the last ten years the rural constituents have heard our transportation leaders highlight congestion as our nation's leading challenge. Programs such as Operation Time Saver, Model Deployment Initiative and other urban initiatives have been the showcase of USDOT. However, these showcase programs have little, if any, direct application to approximately eighty-percent (80%) of our nation's surface roads, or roughly four million miles of roadway. Unlike urban areas that have congestion as the primary single issue, rural needs are more diverse, complex and only tangentially congestion-related. So what are the rural challenges?

##### 1.1 Safety and Non-Interstate Roadways

In rural areas safety is of paramount importance. According to Federal Highway Administration (FHWA) statistics, sixty-percent (60%) of the crash fatalities occur on rural highways, while only 39% of the vehicle miles traveled occur on these roads – a disproportionate relationship. These combined facts make rural crash rates 2.5 times greater than urban areas. Furthermore, single vehicle crashes on 2-lane rural roads accounted for 54% of all rural crashes in 1998.

##### 1.2 Digital Divide – no wireless communication coverage

Vast rural areas of the United States are without wireless communications, which impacts safety and increases infrastructure deployment costs. Preliminary research conducted by WTI in five

western states indicates that the notification time to learn of a crash is two to three times longer where no wireless communication exists, and near jurisdictional borders.

### 1.3 Weather Impacts Every Day Life

Weather can be deadly in many regions of the United States. According to FHWA, there are approximately 7,000 fatalities and 450,000 persons injured each year due to weather related events.

### 1.4 Tourism and Economic Viability

Tourism is a critical concern to the economic viability of many rural communities. Travel and tourism in the United States is the nation's largest export industry and second largest employer, accounting for over \$515 billion in expenditures, resulting in 7.6 million jobs and accounting for 1.3 billion domestic trips. An efficient transportation system is essential to rural communities who depend on tourism revenues for their survival. Providing real-time information to tourists, via ITS, is the key to encouraging greater tourist activity in rural areas and enhancing their economies.

### 1.5 Federal Lands, National Parks and Native Americans

In order to provide a framework on the impact of the National Parks, consider the following statistics:

Scale – 374 parks in 49 states, 18 million acres;

Employees – 19,200;

Economic activity - \$14 billion, supporting 309,000 jobs; and

Visitation – 266 million visitors, demand increasing 500 percent over the next 40 years.

The second area is our sovereign Native American lands where safety, economic viability and transportation are the key issues. Research has shown that Native Americans die in motor vehicle crashes at rates six times that of the rest of the Nation and 3/4 of Native American traffic fatalities involve alcohol. Also, only 29% of tribes have any form of transit system.

### 1.6 Animal Conflicts

Each year there are approximately 726,000 animal-vehicle crashes. These crashes rarely result in fatalities but at approximately \$2000 per incident in property damage the annual cost nationally amounts to over \$1 billion.

### 1.7 Public Mobility

According to the Federal Transit Administration, approximately 38 percent of the rural population has no access to public transportation and another 28 percent has little access. Low population density in rural service areas makes it difficult at best to deliver public transit services.

### 1.8 Commercial Vehicles, Goods Movement and Long-distance Trips

The movement of goods is critical to the economy of the United States and the rural Interstate System is an essential component in the process. Rural interstates are, in essence, the arteries over which flow the goods to be distributed to citizens throughout the country. On many rural highways, 30 percent of traffic is commercial vehicles, and their numbers continue to grow.

## **Appendix**

### 1.9 Diversity and Understanding

Rural areas are challenged in that there are few issues and application similarities among different locations and regions (i.e. Cape Cod, Mass, Brandon, VT and Eureka, CA).

I believe very strongly that now is the time for USDOT to step up to the plate and provide a level playing field and provide adequate resources to respond to rural transportation needs by providing sufficient funding and guidance that urban areas have enjoyed over the last several years.

## 2. Advanced Rural Transportation Systems Success Stories

Now, having made that last statement, I do want to recognize a number of success stories that have taken place in rural areas.

### 2.1 Crash Prevention and Security

Colorado DOT has implemented a dynamic downhill speed warning system on I-70 west of Denver, outside the Eisenhower Tunnel. The system measures truck speeds, weight, and number of axles and advises the driver of the appropriate speed. The truck speed warning system was installed on a narrow curve that has a design speed of 45 mph. The average truck speed around this curve has dropped from 66 mph to 48 mph since the installation of the warning system. The system has eliminated approximately 20 truck runaways and 15 truck related crashes per year. California DOT has implemented a similar speed system for passenger cars and trucks near Redding California along I-5 in Sacramento Canyon.

### 2.2 Emergency Services

Virginia DOT sponsored the Northern Shenandoah Valley Public Safety Initiative to enhance the collection and communication of critical accident victim patient data between the on-scene emergency medical personnel and the receiving hospital through the use of hand-held portable digital assistance devices. Use of the off-the-shelf PDA's has improved patient outcome, improved on-scene, en-route and emergency room patient services, improved data collection, all in addition to incident management coordination.

### 2.3 Tourism and Traveler Information

As you know our National Parks are experiencing increasing visitation and traffic congestion. The Yellowstone National Park Smart Pass will provide frequent users and local residents with an electronic pass and a designated lane at entrance gates to bypass congestion. Similar systems are being implemented in Rocky Mountain and Zion National Parks.

### 2.4 Traffic Management

The Arizona DOT and Oregon DOT utilize the internet whereby organizations can enter road closure, lane restrictions, unsafe road conditions, and parking information into the system and all agencies can view the status of those conditions. The ODOT TripCheck system includes images from closed circuit cameras at mountain passes and other locations. During the peak usage the number of users have exceeded 350,000 per month.

### 2.5 Surface Transportation and Weather

Accurate road and weather information can mean the difference between life and death.

## **Appendix**

The Greater Yellowstone Weather and Traveler Information System will integrate a mountain pass pavement temperature prediction model, and a road and weather condition information system that delivers trip-specific weather forecast and road reports via cellular telephone by dialing #SAFE. The #SAFE system will provide road and weather information 40 to 60 miles (or 1 to 1 ½ hours travel time) ahead of the direction of travel. The #SAFE system has been used by over 300,000 motorists, with a monthly average of 16,000 per month and the median use of the system is 25 times per year mostly in the winter.

## 2.6 Operations and Maintenance

In California and Arizona, the state DOTs have instrumented snowplows and the mountain pass roadways with technologies to allow for vehicle tracking in the roadway for lane guidance and collision avoidance systems to warn motorists of close proximity.

## 3. What are the Future Needs?

While there have been success stories as highlighted by my previous testimony, there are some very real gaps and opportunities that must be addressed. As I mentioned earlier, USDOT has predominately concentrated on urban ITS and discounted the need to address rural challenges in any realistic programmatic level. To quote one DOT Chief Engineer, “the highest use is not necessarily the highest need.” The time to address rural needs has arrived and we need federal leadership and commitment. The following recommendations are proposed from rural ITS constituents around the country.

### 3.1 Conduct Outreach and Professional Capability Building Seminars

Given that federal dollars to develop Early Deployment Plans were only available to urban areas with populations over 50,000 and guidelines exist that regionally significant projects need to develop regional architecture, there should be a commitment to provide outreach and training in rural areas more than at just a statewide level. Also, it is important that these outreach and professional capability building activities occur in rural communities where stakeholders live rather than large urban centers.

### 3.2 Integrate Funding and Increase Awareness

To integrate funding and increase awareness of opportunities, it is recommended that a blue-ribbon committee be formed to create a one-stop shopping process or even a clearinghouse, develop an awareness program for rural funding opportunities, review the project initiation approval process, and determine if a block-grant approach may be more feasible for ITS deployment that would horizontally cut-across federal agencies.

### 3.3 Improve Communications Coverage to Provide a Basic Level of Detection, Increased Safety and Reduced Deployment Cost

If we are to manage our rural roadways in a safe and prudent manner then some level of basic infrastructure to detect problems and a communication system to transmit that data must be created and funded. Rural America has large pockets of “dead zones” (no cellular wireless service). A new or improved model needs to be developed to increase communications coverage. This new model may be similar to the Rural Utility Service but at a minimum it may require a federal subsidization for private carriers that cannot achieve the return on investment that the high volume urban subscriber models deliver.

## **Appendix**

### 3.4 Develop Regional Projects and Partnerships

Travelers do not see the jurisdictional state boundaries, nor do they care, and yet most ITS projects are developed with only a single state in mind. Regional scale projects focused on the travel sheds that motorists use need to address a national system and to encourage public-private partnerships to develop the economies of scale needed to minimize risk.

### 3.5 Implement Regional Servers for Data and Information Exchange between Stakeholder Groups

To accelerate the ability to exchange data and information to provide for communication, cooperation and coordination, funds should be allocated to implement regional “internet” based servers throughout the 50 states.

### 3.6 Increase Research Funding and Provide for More Adaptive Standards

To date there has been only a marginal amount of research as to the quantified benefits of rural ITS. Funding for research, specifically targeted for rural ITS, should be set aside to allow for a more robust evaluation of current and planned deployment.

### 3.7 Create a Rural Model Deployment Initiative

If the USDOT truly wants to take a leadership role, then an opportunity I recommend is to create a Rural Model Deployment Initiative similar to the Metropolitan Model Deployment Initiative, but concentrated on a more regional/rural scale.

### 3.8 Build on Successful Tourism Partnerships to Create Jobs

Tourism is the economic engine of rural America! To allow ITS to be more effective the focus and attention toward tourism partners that may ultimately be the implementers of ITS must be increased to spur economic activity and create jobs.

In closing, while there are isolated success stories that can be highlighted, there are still many challenges yet to be addressed. In keeping to the rural spirit, the Subcommittee and USDOT have an opportunity to be “pioneers” in making a renewed rural ITS commitment. As we like to say in the West – Our forefathers were pioneers, not settlers!

## ABOUT THE AUTHOR

### **Sheldon Leader**

Mr. Leader has over 30 years of experience in the design and implementation of communications systems, including: Public Safety Wireless Systems, E 9-1-1 Operation Centers; computer aided dispatch, fiber optic SONET and DWDM communications networks; wireless communications systems; automatic GPS for vehicle location systems; voice and data communications systems. Mr. Leader has been active in the development of new communications networks that serve municipal, state and federal government agencies, and private enterprise.

Since 1991, Mr. Leader has been active in the design and development of Intelligent Transportation Systems and Freeway Management Systems. Mr. Leader has served as Chair of the Telecommunications Committee of ITS America, and Secretary of the TRB Committee on Communications.

# GLOSSARY

1000Base-LX	Gigabit Ethernet transmitted over fiber using long wave laser transmitters
1000Base-SX	Gigabit Ethernet transmitted over fiber using short wave laser transmitters
1000Base-T	Gigabit Ethernet over twisted pair.
100Base-FX	100 Mbps Fast Ethernet system based on 4B/5B signal encoding transmitted over fiber optic cable.
100Base-T	Term used for the entire 100 Mbps Fast Ethernet system, including both twisted-pair and fiber optic media types.
10Base2	10 Mbps Ethernet system based on Manchester signal encoding transmitted over thin coaxial cable. Also called Thin Wire and Cheapernet
10Base5	10 Mbps Ethernet system based on Manchester signal encoding transmitted over thick coaxial cable. Also called Thick Net
10Base-F	10 Mbps Ethernet system based on Manchester signal encoding transmitted over fiber optic cable.
10Base-T	10 Mbps Ethernet system based on Manchester signal encoding transmitted over Category 3 or better twisted-pair cable
802.1	IEEE Working Group for High Level Interfaces, Network Management, Inter-networking, and other issues common across LAN technologies
802.3	IEEE Working Group for Carrier Sense Multiple Access/Carrier Detect Local Area Networks.
802.11	IEEE standards for low power, short range wireless LAN. Also referred to as Wi-Fi.
802.15	
802.16	
802.17	
802.20	
Address	A unique identification of a device attached to a network. The address can used to identify either a specific location such as a port on a switch, or a specific device.

ADSL	Asymmetric Digital Subscriber Line. Most common form of DSL where the data rate being transmitted to the subscriber is high than the data rate transmitted from the subscriber.
Aerial Cable.	A cable suspended in the air on poles or other overhead structures
Alternating Current (AC)	Electric current that continually reverses its direction. It is expressed in cycles per second (hertz or Hz).
Analog	A signal that varies continuously such as a sound wave. Analog signal have frequency and bandwidth measured in hertz.
ANSI	American National Standards Institute
APPA	American Public Power Association.
ASTM	American Society of Testing and Materials.
ATM	Asynchronous Transfer Mode. A digital transmission switching format with cells (packets) of a fixed length to help facilitate voice and video transmission.
Attenuation	Power loss in an electrical or telecommunications system. In cables, expressed in dB per unit length, usually dB per 1000 feet, or per kilometer. This term is also used to express loss in fiber optic cable.
AWG	Abbreviation for American Wire Gauge. Based on a circular mil system. 1 mil equals .001 inch. Used to determine the size of conductors.
Backbone	A transmission network that carries high speed telecommunications between locations. This is normally the main portion of a telecommunication network, with branches going to individual buildings. In a local area network, this is usually the link between routers, switches, and bridges.
Balun	An adapter for connecting an unbalanced coaxial transmission line to a balanced two-wire system.

Band Marking	A continuous circumferential band applied to a conductor at regular intervals for identification.
Bandwidth	The information carrying capacity of the system. In analog systems, this is also the highest frequency that can be carried.
Baud	The number of signal level transitions per second in digital data. The term is often confused with bits per second. Telecommunications specialists prefer to use "bits-per-second" to provide an accurate description.
BER	Bit Error Rate. The number of bit errors that occur within the space of one second. This measurement is one of the prime considerations in determining signal quality. The higher the data transmission rate the greater the standard. A DS-1 signal is considered acceptable with a BER of $10^{-6}$ , but an OC-3 signal requires a BER of no more than $10^{-12}$ .
Bps	Bytes per second. Term used by software engineers to describe bandwidth.
bps	Bits per second. Term used by telecommunication engineers to describe bandwidth.
Bridge	A device that allows multiple communication circuits to use a common circuit. Only one circuit can be connected to the common at any given moment
Broadband	Generally used to describe data transmission requirements of greater than 128 Kbps.
Broadcast Transmission	Sending the same signal to many locations.
Building Wire	Insulated single conductors, 600 volts, used for supplying power for lighting, operating machinery, controls, etc. Usually installed through conduits/trays inside buildings.
Bundle	A group of wires (or fiber strands) contained within a single wrapper.

Bus	An electrical transmission path for carrying information, usually serving a shared connection for multiple devices.
Byte	Eight bits of data.
Cable	A group of individually insulated conductors in twisted or parallel configuration, with an overall outer jacket.
Carrier Hotel	A large building where communication carriers place equipment to provide connections between their respective systems .
Carrier Sense	Carrier Sense is the process used by devices on Ethernet to determine whether the cable is currently being used by a transmitting station. If electrical signals are detected on the cable, then carrier has been detected and a station is currently transmitting on the cable
Category 5	Commonly referred to as "Cat 5". A type of twisted pair copper cable that meets standards for transmitting high speed signals.
CATV	An acronym for Community Antenna Television.
CCITT	International Consultative Commission on Telephone and Telegraph, an arm of the ITU (International Telecommunications Union) a standards setting body.
CCTV	Closed Circuit Television.
Central Office	Commonly referred to as a "CO". A telephone company facility for switching signals among local telephone circuits. Also called a "Switching Office".
Certificate of Compliance (C of C)	A certificate showing that the product being shipped meets customer's specifications.
Certified Test Report (CTR)	A report providing actual test data on a cable. Tests are normally run by a Quality Control Department, which shows that the product being shipped conforms to test specifications.
Coaxial Cable	A cable consisting of two conductors with a common axis, separated by a dielectric.

Collision	A collision is a condition where two devices detect that the network is idle and end up trying to send packets at exactly the same time (within 1 round-trip delay). Since only one device can transmit at a time, both devices must back off and attempt to retransmit again.
Color Code	A system for circuit identifications through use of solid color insulations and/or contrasting tracers.
Composite Cable	A cable containing more than one gauge size or a variety of circuit types, e.g., pairs, triples, quads, coaxials, etc.
Conduit	A tube through which insulated wires and cables are run.
Connector	A device mounted on the end of copper, or fiber optic cables to facilitate link of the cables.
Control Cable	A multiconductor cable made for operation of control or signal circuits.
Cord	A small, flexible insulated cable.
Core	In cables, a component or assembly of components over which additional components (shield, sheath, etc.) are applied.
CPE (Construction Term)	Jacketing compound based on chlorinated polyethylene.
CPE (Network Term)	Customer Premise Equipment - a term used by telephone companies to identify equipment owned by a customer
Crosstalk	Signal interference between nearby conductors caused by pickup of stray energy. It is also called induced interference.
Crosstalk	The unwanted transfer of a signal from one circuit to another.
CSMA/CD	Carrier Sense Multiple Access/Collision Detect. The formal name for the medium access control (MAC) protocol used in Ethernet.
CWDM	Coarse Wave Division Multiplexing

Cycles Per Second	CPS. The frequency of a wave, or the number of oscillations it makes per second. One cycle per second equals one hertz.
Dark Fiber	Optical fiber installed without a transmitter or receiver. These fibers are the un-used fibers in a cable. Some fibers are held in reserve for future requirements. Others are often leased to different carriers (or large customers) for use in their individual systems.
Data Link	A data communications connection between two points.
Data Link Layer	Layer 2 of the OSI reference model. This layer takes data from the network layer and passes it on to the physical layer. The data link layer is responsible for transmitting and receiving Ethernet frames, 48-bit addressing, etc. It includes both the media access control (MAC) protocol and logical link control (LLC) layers.
dBm	Decibels below 1 mW (milliwatt)
dBu	Decibels below 1 uW (microwatt)
DCE	Data Communications Equipment. Any equipment that connects to Data Terminal Equipment (DTE) to allow data transmission between DTEs. A modem is a type of DCE.
Decibel (dB)	A unit to express differences of power level. Used to express power gain in amplifiers or power loss in passive circuits or cables. Also, a logarithmic comparison of two power levels, defined as ten times the base ten logarithm of the ratio of the two power levels.
Dielectric	Nonconductive material
Dielectric Strength	The voltage which an insulation can withstand before breakdown occurs. Usually expressed as a voltage gradient (such as volts per mil).
Digital	An encoded signal. Normally encoded in discrete levels to represent a binary signal of ones and zeros.

Digital Subscriber Line	DSL. A service that transmits digital signals (to homes and small offices) via the existing copper wire used for voice transmissions.
Direct Burial Cable	A cable installed directly in the earth.
Direct Current (DC)	An electric current which flows in only one direction.
Drain Wire	In a cable, the uninsulated wire in intimate contact with a shield to provide for easier termination of such a shield to a ground point.
DSSS	Direct Sequence Spread Spectrum – One of two types of spread spectrum radio transmission
DTE	Data Terminal Equipment. Any piece of equipment at which the communication path begins or ends. A PC is DTE.
Duct	An underground or overhead tube through which electrical conductors are pulled. Gives mechanical protection. EIA. Electronic Industries Association.
Duplex	A bi-directional transmission of the transmit and receive elements of a communication signal occurring simultaneously.
DWDM	Dense Wave Division Multiplexing
EIA/TIA 568	This is the color-code connection standard for an RJ-45 (8 conductor) connector. There are two wiring standards: 568A and 568B. The only difference between the two is that two pairs of colors are swapped. The 568B is an older standard defined by AT&T. All new installations are supposed to use 568A. What really is important is that everything be consistent in all your wiring. Otherwise, you'll get yourself confused. Note that the difference is only in what color is used for what pin, not what signal is on what pin, so in a patch cable with both ends pre-wired, it doesn't matter.
Electricity	The energy produced by the flow of "free" or valance electrons moving from one atom to another in a conductor.

E&M Signaling	Ear (receive) and Mouth (transmit), a signal outside of the voice frequency range that can be used to activate a function in a telephone switch.
EMI	Electromagnetic Interference. The noise generated when stray electromagnetic fields induce currents in electrical conductors.
Encoding	A means of combining clock and data information into a self synchronizing stream of signals.
Ethernet	A local area network standard.
F.D.D.I.	Fiber Distributed Data Interface.
Facilities	Term used by telecommunication engineers to indicate communications systems
FHSS	Frequency-Hopping Spread Spectrum – One of two types of spread spectrum radio transmission
Fiber Optics	A light wave or optical communications system in which electrical information is converted to light energy, transmitted to another location through optical fibers, and is there converted back into electrical information.
Figure 8 Cable	An aerial cable configuration in which the conductors and the steel strand which supports the cable are integrally jacketed. A cross section of the finished cable approximates the figure 8.
Filled Cable	A cable construction in which the cable core is filled with a gel material that will prevent moisture from entering or passing through the cable.
Frame	A packet of transmitted information. The frame contains all of the necessary information to indicate the origin and destination, control information and the actual data.
Frequency Division Multiplexing	FDM. Combining analog circuits by assigning each a different carrier frequency and merging them into a single communication signal.
FTTC	Fiber-to-the-Curb

FTTH	Fiber-to-the-Home
Full Duplex	Transmitters and receivers simultaneously send and receiver signals in both directions on the same pair of wires.
FXO	Foreign Exchange Office
FXS	Foreign Exchange Station
Gauge	A term used to denote the physical size of a wire.
Gbps	Giga bits per second, or Gbit/s. One billion bits persecond.
GHz	Giga Hertz. One billion hertz, or cycles per second.
Ground	A conducting connection between an electrical circuit and the earth or other large conducting body to serve as an earth thus making a complete electrical circuit.
Half Duplex	Transmitters and receivers send or receive on the same pair of wires.
HDTV	High definition (or high resolution) television
Hertz	Frequency in cycles per second
Hierarchy	A set of transmission speeds arranged to multiplex a successively higher number of circuits.
Homerun	A cable run that goes directly from a jack in a wall plate to a centralized position (patch panel). There are no stops or interruptions between the 2.
Hub	Hubs act as the center of a "star" topology. They have between 4 and 20+ ports. Internally, hubs are "dumb" devices that just resend information they receive. All devices attached utilize a part of the rated speed, be it 10 or 100Mbit/sec. Hubs know nothing about a packet's destination. Therefore, hubs are generally the cheapest connecting device in a star topography, although for a busier network, switches are more robust.
Hybrid Cable	A cable design to meet many requirements. Most commonly, hybrid cables will contain a mixture of twisted-pair and coaxial, or coaxial and fiber.

IAEI	International Association of Electrical Inspectors.
IBEW	International Brotherhood of Electrical Workers.
ICEA	Insulated Cable Engineers Association (Formerly IPCEA).
IEC	Independent Electrical Contractors association.
IEEE	Institute of Electrical and Electronics Engineers.
IMSA	International Municipal Signal Association. Publishes specifications for cables and wires used in municipal, county, and state Traffic Signal, Communication and Fire Alarm systems.
Inside Plant	Telecommunications facilities placed inside a building.
Insulation	A material having high resistance to the flow of electric current. Often called a dielectric.
Internet	The worldwide collection of networks based on the use of TCP/IP network protocols.
Intranet	A collection of networks supporting a single site or corporate entity.
IP	Internet protocol. Standard format for transmitting data via the internet.
ISA	Instrument Society of America.
ISDN	Integrated Services Digital Network. A digital transmission standard using 144 kbps containing two 64 kbps voice channels and one 16 kbps data channel.
ISO	International Standards Organization.
ITE	Institute of Transportation Engineers
IUEW	International Union of Electrical Workers.
Jacket	An outer covering, usually nonmetallic, mainly used for protection against the environment.

Jitter	Also called phase jitter, timing distortion, or inter-symbol interference. The slight movement of a transmission signal in time or phase that can introduce errors and loss of synchronization. The amount of jitter will increase with longer cables, cables with higher attenuation, and signals at higher data rates.
LAN	Local Area Network. Integration of computer and communication systems that wire computers, peripheral equipment and telephones together so they can all "talk" to each other.
LASER	Light Amplification by Stimulated Emission of Radiation.
LED	Light Emitting Diode. A semiconductor that emits light.
Light guide	An optical fiber bundle.
Longitudinal Shield	A tape shield, flat or corrugated, applied lengthwise with the axis of the core being shielded.
Loose Tube	A protective tube loosely surrounding fiber strands. The tube may be filled with gel to protect against moisture infiltration.
Loss	Attenuation of an optical or electrical signal, normally measure in decibels
Loss Budget	An accounting of overall attenuation in a system. The budget is the amount of acceptable loss.
MAC	Media Access Control. A portion of the Ethernet frame. that
MAN	Metropolitan Area Network. Backbone system deployed in metropolitan areas to connect Telephone Companies, Carriers, Carrier Hotels, and large office buildings.
Margin	Allowance for attenuation (or loss) in addition to that explicitly accounted for in a system design.
Mbps	Megabits per second. Also expressed as Mbit/s.

Messenger Cable	The linear supporting member, usually a high strength steel wire, used as the supporting element of a suspended aerial cable. The messenger may be an integral part of the cable, or exterior to it.
Microbending	Tiny bends in fiber that allow light to leak out and increase loss. microbending occurs during installation and is usually unavoidable. Loss budget margins should account for microbending.
Mil	A unit used in measuring the diameter of a wire or thickness of insulation over a conductor. One one-thousandth of an inch. (.001")
Modal Dispersion	Dispersion arising from differences in the times that different modes take to travel through multimode fiber.
Mode	An electromagnetic field distribution that satisfies theoretical requirements for propagation in a waveguide. Light has modes in a fiber.
MODEM	Modulator-Demodulator
Modem	A device used to convert signals from one form to another. It can be used to convert the output of a computer to a voice channel equivalent, or an electrical signal to an optical signal.
Multimode	Transmits multiple modes of light.
Multiplexer	A device that combines many communication circuits into one circuit
MUX	Abbreviation for Multiplexer
NAED	National Association of Electrical Distributors.
Nanometer	A unit of measurement, 10 <sup>-9</sup> meters. Light wave frequencies are stated in nanometers.
NAPE	National Association of Power Engineers.
NEC	National Electric Code. A standard published by the National Fire Protection Association (NFPA) and incorporated in OSHA (Occupational Safety and Health Act) regulations.
NECA	National Electrical Contractors Association.

NEMA	National Electrical Manufacturers Association.
Network	A system of cables or wireless pathways that link communication nodes.
NFPA	National Fire Protection Association.
NIC	Network Interface Card. This is the interface between a computer (or other device) and the Ethernet network.
Node	A communication point usually comprised of communication devices.
NRECA	National Rural Electric Cooperative Association.
NRZ	Non-Return-to-Zero. An electrical communication signal which uses a "low" signal for zero and a "high" signal for one. The electrical signal value never reaches zero.
NTSC	National Television System Committee. Analog video broadcast standard used in North America.
O.D.	Outside diameter.
OC-x	Optical Carrier rate specified for SONET; OC-3, OC-12, OC-48, etc.
OFDM	Orthogonal Frequency Division Multiplexing – a frequency division modulation technique for transmitting large amounts of digital data over a radio wave. OFDM works by splitting the radio signal into multiple smaller sub-signals that are then transmitted simultaneously at different frequencies to the receiver.
Ohm	Unit of resistance such that a constant current of one ampere produces a force of one volt.
OSI	Open Standards Integration
OTDR	Optical Time-Domain Reflectometer. An instrument that measures transmission characteristics by sending a short pulse of light down a fiber and measures the reflected light pattern.
Outside Plant	Telecommunication facilities that are placed outside of a building.

P.O.P	Point of Presences - A location of telecommunication carrier equipment
P.O.T.S.	"Plain Old Telephone Service" - a reference to basic voice telephone service
Packet	A technique used to break large quantities of data into small groups, or packets, to facilitate transmission with very few errors.
Packet Switch	A switch that moves data packets from multiple transmissions and provide for efficient sharing of communication facilities.
Patch Cable (Cord)	A twisted-pair, or fiber optic jumper cable used to make a connection between a network interface, or network port, and a media segment, or to directly connect stations and hub ports together.
PCS	Personal Communications Service. A group of frequencies in the 1.8 to 2.0 GHz range reserved for cellular telephone communications.
PE	Polyethylene.
PHY	Physical Layer Device. The name used for a transceiver in Fast Ethernet and Gigabit Ethernet systems.
Physical Address	The 48-bit MAC address assigned to a station interface, identifying that station on the network.
Plenum	The air return path of a central air handling system, either ductwork or open space over a dropped ceiling.
Plenum Cable	Cable approved by Underwriters Laboratories for installation in plenums without the need for conduit because the insulation and jacket compounds used have low flame-spread and low smoke characteristics.
Point-to-Point Transmission	Carrying a communication signal between two locations without branching to other locations.
Polyethylene	A thermoplastic material having the chemical identity of polymerized ethylene.

Polyvinyl Chloride (PVC)	A thermoplastic material composed of polymers of vinyl chloride which may be rigid or flexible depending on specific formulation.
Port	A connection point on a hub, router, bridge, switch, etc.
Protocol	A set of agreed upon rules and message formats for exchanging information among devices on a network.
Pulling Eye	A device fastened to a cable to which a hook may be attached in order to pull the cable through a duct.
PVC (Construction Term)	Polyvinyl chloride.
PVC (Network Term)	Permanent Virtual Circuit
REA	Rural Electrification Administration of the U.S. Dept. of Agriculture. Publishes telephone cable and wire specifications and a list of approved manufacturers of cable, wire and related installation supplies.
Receiver	A device that detects a communication signal and converts it into sound, data, or video.
Regenerator	A receiver-transmitter device that detects a weak signal, converts it to its original state, and then transmits it as a strong signal. Most problems in the received signal are corrected.
Repeater	A receiver-transmitter device that detects a weak signal and boosts its power for continued transmission. This device is also called an amplifier. Any problems in the received signal are simply retransmitted.
Resistance	In DC circuits, the opposition a material offers to current, measured in ohms. In AC circuits, resistance is the real component of impedance, and may be higher than the value measured at DC.
RF	Radio Frequency. A general term used to indicate a radio system.
RG/U	Abbreviation for Radio Grade, Universal. RG is the military designation for coaxial cable and U stands for "general utility".

Ribbon Cable	<p>A cable in which many conductors (copper or fiber) are embedded in a plastic material in parallel, forming a flat, ribbon like structure.</p>
RJ-11	<p>RJ-11 is standard modular phone connector. There are 3 different types: 2, 4, and 6 conductor connectors. They're all the same, except that contacts or wires are missing. Ordinary phone connectors are 4-conductor (2 pairs = 2 phone lines). Sometimes you get a phone wire that only has 2 conductors in it; this will screw you up if you're trying to run more than 1 phone line. There's also a little-bitty version of this connector that only has 2 conductors on it. It will fit in the same socket.</p>
RJ-45	<p>RJ-45 is the 8-conductor version of an RJ-11. It looks like a regular modular phone connector, only it's wider. You need to use RJ-45 for Ethernet, because the connection standard puts the Ethernet on some of the outer connectors not in RJ-11. RJ-11 plugs will fit into an RJ-45 socket, but because the plastic plug is smaller, some of the contacts will get bend back a little</p>
Router	<p>A device that has enough intelligence to be connect one, or many, devices to other devices. Typically used in Local Area Networks to connect desktop computers to printers or file servers.</p>
SDH	<p>Synchronous Digital Hierarchy. The international version of the SONET digital hierarchy.</p>
Segment	<p>A segment is a piece of network wire bounded by bridges, routers, repeaters or terminators.</p>
Sheath	<p>The outer covering of a communication cable.</p>
Shield	<p>A metallic layer placed around a conductor or group of conductors to prevent electrostatic interference between the enclosed wires and external fields.</p>

Signal-to-Noise Ratio	The ratio of signal to noise measured in decibels. An indication of signal quality in analog communication systems.
Simplex	Simple uni-directional transmission. Transmitter on one end and a receiver on the other.
Single Mode	Normally referring to commonly used type of fiber optic cable.
SNMP	Simple Network Management Protocol. A protocol specified by the Internet Engineering Task Force (IETF) for exchanging network management information between network devices and network management stations.
SONET	Synchronous Optical Network.
STP	Shielded Twisted Pair
Subscriber Loop	The part of the telephone network that runs from the central office to individual subscribers.
Switch	A device that direct electricity, or light, along different physical paths.
Switch	Switches act as the center of a "star" topology, much like hubs. They have between 4 and 20+ ports. Internally, switches are different that hubs due to their intelligent design. Switches "remember" what device is attached to what port, and will relay packets only to the proper destination port. Because of this, all devices attached are able to utilize their maximum rated speed, be it 10 or 100Mbit/sec/port. This clever design makes switches more expensive, but in a busy network, switches can keep the traffic flowing.
T - Carrier	Normally refers to a T-1 transmission system, but can be any of standard North American Digital Hierarchy transmission rates.
TDM	Time Division Multiplexing
Telemetry Cable	Cable used for transmission of information from instruments to the peripheral recording equipment.

Temperature Rating	The maximum temperature at which an insulating material may be used in continuous operation without loss of its basic properties.
Tensile Strength	The pull stress required to break a given specimen.
TIA/EIA	Telecommunications Industry Association/Electronics Industry Association. An organization that sets telecommunications standards for buildings, cables, and connectors. Also sets practices and standards for construction of telecommunication systems.
Tight Buffered	A type of fiber optic communication cable where the fiber strands are tightly wrapped by the covering sheath.
Tinned Copper	Tin coating added to copper to aid in soldering and inhibit corrosion.
Tray	A unit or assembly of units or sections, and associated fittings, made of metal or other noncombustible materials forming a rigid structural system used to support cables. Includes ladders, troughs, channels, solid bottom trays, and similar structures.
Trunk	Trunk Line. A communication link running between telephone company central offices. Also a communication link that connects a customer location to a telephone company central office, but is not directly connected to a switch.
Twisted Pair	Pair of copper wires wrapped around each other.
UL	Abbreviation for Underwriters Laboratories, a nonprofit independent organization, which operates a testing and listing service for electrical and electronic materials and equipment.
UTP	Unshielded Twisted Pair.
Watt	A unit of electrical power. One watt is equivalent to the power represented by one ampere of current under a pressure of one volt in a DC circuit.

Waveguide	A structure that guides electromagnetic waves along its length.
Wavelength	The distance an electromagnetic wave travels in the time it takes to oscillate through a complete cycle.
WDM	Wavelength-Division Multiplexing. Multiplexing of signal by transmitting them at different light frequencies through the same fiber.
WEP	Wired Equivalent Privacy – a security protocol for wireless local area networks
Wicking	The flow of a liquid in a wire or cable due to capillary action.
Wi-Fi	Wireless Fidelity
Wi-Max	Broadband Wireless
WPA	Wi-Fi protected access - a Wi-Fi standard that was designed to improve upon the security features of WEP.



**Federal Highway Administration  
U.S. Department of Transportation  
400 7th Street, S.W. (HOP)  
Washington, DC 20590  
Toll-Free "Help Line" 866-367-7487  
[www.ops.fhwa.dot.gov](http://www.ops.fhwa.dot.gov)**

**Publication No.: FHWA-OP-04-034  
Telecommunications Handbook  
for Transportation Professionals:  
The Basics of Telecommunications**