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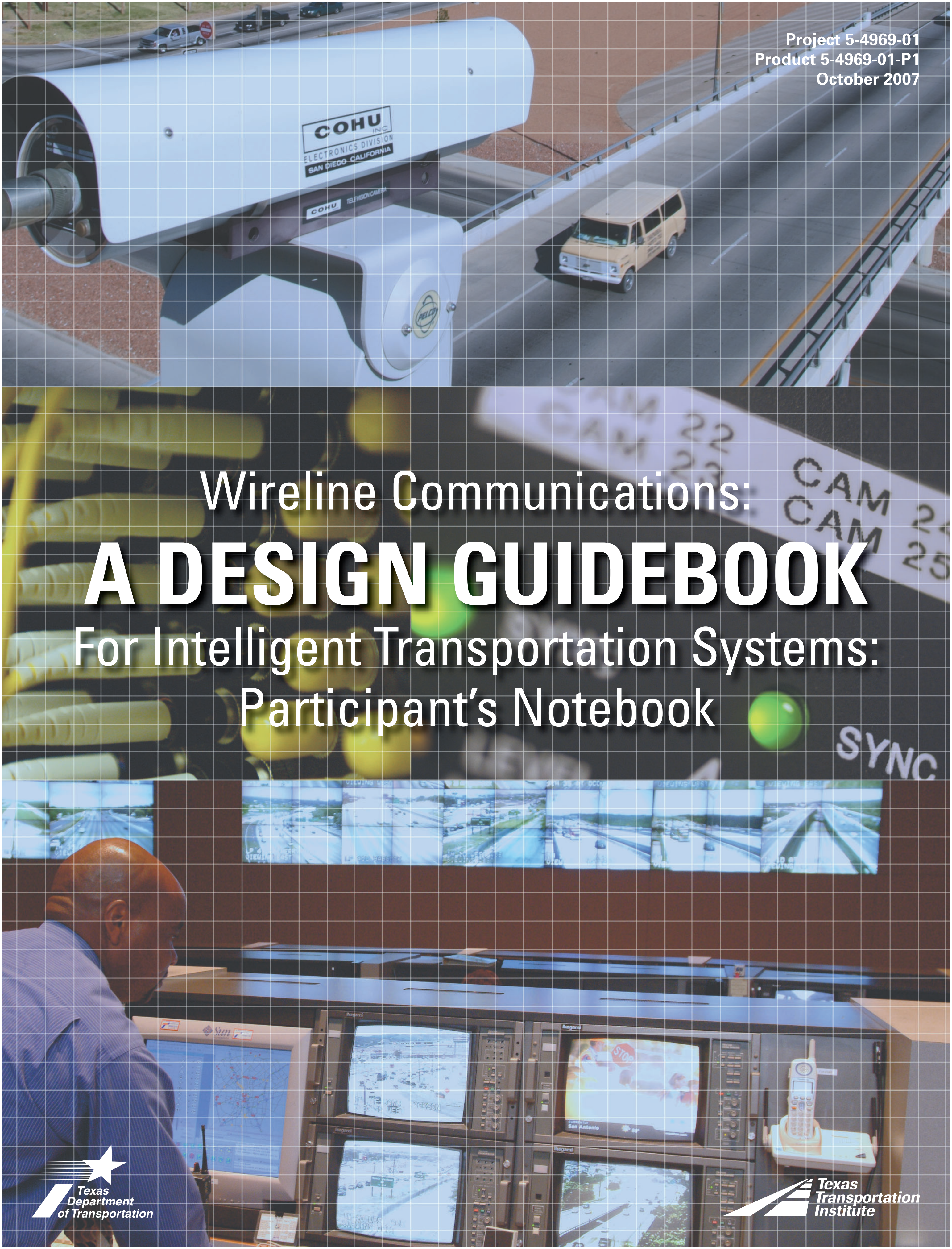

Wireline Communications:

A DESIGN GUIDEBOOK

For Intelligent Transportation Systems:

Participant's Notebook

Texas Department of Transportation

Texas Transportation Institute

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WIRELINE COMMUNICATIONS: A DESIGN GUIDEBOOK FOR INTELLIGENT TRANSPORTATION SYSTEMS: PARTICIPANT'S NOTEBOOK

Product Number 5-4969-01-P1

Performed in cooperation with the
Texas Department of Transportation
and the
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Research conducted by
Texas Transportation Institute
The Texas A&M University System
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DISCLAIMER

The contents of this notebook reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of Federal Highway Administration (FHWA) or the Texas Department of Transportation (TxDOT). This material does not constitute a standard, specification, or regulation. The researcher in charge was Robert E. Brydia.

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1. INTRODUCTION

1.1. Scope

This guidebook covers wireline communications. This text is not intended to be a comprehensive treatise on all aspects of communications systems. Rather, it is intended to be a primer or introduction to the major concepts and considerations associated with building and using modern communications systems. The goal of this guidebook is to build a broad foundation of knowledge that can quickly and easily be applied to real-world communications solutions.

The goal of this guidebook is to build a broad foundation of communications knowledge.

While it is recognized that wireless communication is an important aspect of modern communications systems, the focus of this manual is limited to wireline communications. This focus allows development of a comprehensive overview of the subject matter in a short period of time. The corresponding workshop for this guidebook is intended to last 8 hours. Additional training may be required to develop detailed or in-depth skills in the area of communications.

The guidebook first introduces the basic concepts underlying all communications and then explains the media choices available when dealing with wireline communications. The guidebook discusses the typical protocols and network configurations utilized for communications, especially those that are common within the area of Intelligent Transportation Systems (ITS). Special topics are also presented, such as video encoding.

The guidebook also provides critical information about the typical wireline technologies that are used in today's communications market. For each technology, a standardized format conveys a brief history, basic facts, advantages and limitations, cost data, and other pertinent information.

With this broad base of knowledge, the guidebook explores how to use the above information to either evaluate or design communications solutions for ITS. Flow charts and tabular worksheets present information to the reader in an easy to use and understandable format. Finally, the guidebook applies these concepts through the application of case studies as a way to practice and implement the knowledge developed in this course.

1.2. Audience

The typical audience of this guidebook (and corresponding workshop) is an employee of the Texas Department of Transportation (TxDOT) who has some level of overview or responsibility for ITS but has little or no background in the area of communications. This guidebook provides an overview of communications concepts and their application to wireline ITS technologies. It is not intended to provide comprehensive training in all aspects of communications. The level of information contained in the guidebook should be applicable to employees across the state.

1.3. Acknowledgments

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1.4. Methods of Using This Guidebook

This guidebook has been developed for use in support of either a new system design or an evaluation of a system designed by others. While the underlying concepts from Chapters 2 through 4 are the same for either task, the process for a design or an evaluation is slightly different. The flow charts and discussions in Chapters 5 and 6 account for these differences and provide a structured path for each task. Finally, a case study is applied to each task to illustrate the application of the material.

2. THE BASICS OF WIRELINE COMMUNICATIONS

2.1. Introduction

This chapter presents some basic concepts of communications. After presenting an abbreviated history of communications, the chapter examines the difference between analog and digital communications. It is important to understand that both forms of communication are in common use today.

The chapter then covers the basic media types that qualify as wireline communications. Providing this background information introduces the broad subject of communications and how the different components interact.

Subsequent chapters build upon the information in Chapter 2 by detailing the types of networks and protocols used in the ITS arena. It is important to understand that the thrust of the material in this guidebook is digital communications, as these are the more prevalent systems being designed and implemented today.

2.2. A Brief History of Communication

Throughout time, communication has been used to exchange information. The process by which this has taken place has varied considerably, from speech at the earliest juncture to the modern era of telecommunications. Communication includes all forms of expression, including the use of symbols, written language, art, and sound.

2.2.1. Sound-Based Communication

From the earliest times, sound has been a basis for communication. There is considerable debate about when the initial formation of a language truly occurred, with estimates ranging from approximately two million (2,000,000) years ago to forty thousand (40,000) years ago. Regardless, of all the living species on the planet, it is believed that only humans have created a full language with grammar, syntax, and the ability to create new words when needed.

In addition to speech and language, other systems of sounds have been used for communication. History records that as far back as 3000 BC drums were used to communicate between tribes of ancient man to provide danger alerts, information about hunts, and more. Sound was also used to indicate emotion. The rhythm of a drum at a celebration was very different from when it was used in other situations, such as a death. Drums and other instruments were often used in battles to convey orders to widespread legions of warriors.

Despite a virtually unlimited capability to create different sounds, communications of this nature posed significant problems. The largest problem was the ability to cover long distances with the message. To pass a message from one person to the next required a physical presence, which was inefficient. Drums and other instruments eliminated this problem, but had a limited vocabulary. Clearly, the communications medium had to expand to overcome these limitations.

The first communications to travel over a wire were telegraph messages. The electrical telegraph, developed in 1844, used iron wire strung on poles between stations. At the originating station, operators translated the words in a message to electronic signals by tapping a key and converting the message to Morse code. The key closed an electric circuit and created clicks. At the receiving end, operators listened for clicks corresponding to Morse code and translated the sounds back to written communication. Telegraph lines were strung across the United States, and more than 20 telegraph cables were eventually laid across the Atlantic Ocean. *(1)*

While the telegraph proved to be enormously useful, the world-wide revolution in sound-based communications occurred with the invention of the telephone. From a single connection, demonstrated in 1876, to the first telephone exchange in 1877, to the first inter-city connections in 1883, the growth of the telephone highlights the historical birth of wide area communications. Within 15 years, the number of telephones in use in the United States exploded to more than five million, in every major city. *(2, 3)* These long-distance connections were made possible by a growing system of telephone lines—primarily bare copper wire. The greatest limitation to the usefulness of the telephone was that a wire could only carry one conversation at a time. Telephone exchanges handled call switching and manually connected one wire to another to complete the voice circuit. *(4, 5)*

In the years that followed, the national telephone network continued to grow. New applications came into use, such as telephotography, a precursor to the modern day facsimile machine. This service was primarily used by newspapers to transmit photographs of events to other newspapers. *(6)*

In 1927, the first demonstration of television transmission along the telephone network took place from Washington DC to New York. *(6)* In 1941, the first segment of the national telephone network that used coaxial cable went into service. Coaxial cable was an improvement over the existing copper cable and was able to carry more calls at a lower cost. *(6)* Trans-Atlantic telephone service via telephone cable was initiated in 1956. Previously, calls had been transmitted across the ocean via radio waves. The initial telephone cable could carry 36 simultaneous calls.

In 1983, AT&T laid the first fiber optic cable on the national long distance network. Fiber optic was a new innovation that transmitted information as light pulses along a glass fiber. Today, the domestic long distance network is nearly 98 percent fiber optic. This type of wireline communication can carry thousands of simultaneous calls at a fraction of the cost of copper cabling to serve the same volume. *(6)*

2.2.2. Data Communications

At the same time that voice communication was growing in capability and service, data communications experienced similar innovations, albeit at a faster pace. History records the first electronic computer being demonstrated in 1939. Built by John Vincent Atanasoff, the machine pioneered the storage of numbers as binary representations. *(7)*

In 1946, the first general purpose computer was built from vacuum tubes. Named the Electronic Numerical Integrator and Computer (or ENIAC), its primary mission was to compute ballistics tables for the U.S. Army. Maintenance of the system, however, proved to be a massive undertaking. Innovations continued to take place in the evolving world of computers, in part due to the maintenance issues experienced by the first computers. *(8,9)*

By the 1950s, military computers had evolved to the point where they could share data. However, the only way to do so was using a telephone line, which was an analog circuit, not a digital circuit. The introduction of the modem (a shortened version of "**mo**dulation-**dem**odulation") solved this problem by translating digital signals into analog signals that could be transmitted over a phone line. The initial modems were used by the military, with the first commercial model becoming available in 1962. This first commercial modem had a data rate of 300 bits per second (bps). *(10)*

Eventually, as computers increased in speed and capabilities, modem speeds also increased. By 1991, modems operated at 14,400 bps, a 4,800 percent increase in speed over the original products. Today, modems operate as high as 56,000 bps, commonly referred to as 56K. *(10)*

2.2.3. Video Data Communications

From the time of the first demonstration of television in 1927, the envelope of transmitting images from one location to another has been pushed and expanded. Color television was demonstrated in 1929, as well as the first coaxial cable, which became the backbone of most cable TV networks. *(11)*

One of the problems with video images is that they are analog signals. In order to transmit them over communications lines, images must be digitized. For many years, the standard for signal digitizing was set by the television industry, which transmits pictures at 30 frames per second (fps). A frame is one image or picture. Transmitting multiple pictures in quick succession provides the perception of motion (similar to the concept of animation). These elements of video communication have not changed since 1927. Television actually transmits 60 half-frames per second, but the common reference point is 30 fps. *(1)*

Over time, other uses began to emerge for the capabilities of television. Security systems used multiple cameras and transmitted the images to a control center. These systems were often called closed circuit television, or CCTV, as they operated only within a building or small group of buildings. Banks, casinos, government installations, military bases, and the estates of the wealthy are all examples where CCTV was initially used. Cameras now record our actions at automatic teller machines, convenience stores, along freeways, and even at some traffic lights.

Today, high-definition television (HDTV) is the latest entry into the consumer television marketplace. While HDTV dramatically improves the quality of the television picture, implementation has not been as rapid as proposed. Originally, standard television broadcasting was scheduled to cease in 2006, although most industry participants feel that date is unworkable. *(1)*

2.2.4. Network Communications

As the applications for voice, data, and video communications have grown, so has the corresponding need for communications systems that tie devices together and allow the information to flow from one point on the system to any another point. These communications systems are often called networks.

The first network was constructed in 1970 at the University of California at Los Angeles and had a total of four nodes. This first network, called ARPANET (Advanced Research Project Agency Network) pioneered many of the communications innovations in use today. Over the next three decades, the number of interconnected computers has grown to tens of millions, helped along the way by advances in hardware, software, and methods of connecting computers.

Today, networks come in all shapes and sizes. The largest network is the Internet, which is more accurately a network of networks. Small networks may connect to a larger network to exchange information. These larger networks connect to even larger networks, and so on. The entire system makes up the Internet. Networks, of course, do not have to connect to the Internet. Privacy or security concerns may limit, or even eliminate, the connection points of a network in order to protect the data used within.

2.2.5. Summary

Prior to the invention of the printing press, writing information in a book format took years. The printing press provided the ability to rapidly recreate the same information for mass distribution. In much the same way, modern communication devices such as radio, television, and computers provide the same capability. Today, a book can be transmitted across the world in mere seconds.

Quite simply, the advent of increased communications has radically changed society. Corresponding to the increased ability to transmit information is the increased availability of all types of information. Perhaps in no time frame is this more evident than the modern era, when increases in communication technology have occurred at a more rapid pace than any other time. This transformation began in the early 1980s and is predicted to continue well into the 21^{st} century.

Regardless of the type of information (analog or digital) or what particular method is used to make the exchange, modern communications provide the capability to rapidly, efficiently, and safely transmit information virtually anywhere, even into space.

2.3. Units of Information Transfer

The core concept behind all communications is the transfer of information from one location to another. It doesn't matter if that information is expressed in an analog or digital format. Over time, different techniques have been developed to transfer information in both analog and digital formats.

Regardless of the technique, the units of information transfer are the same. The smallest unit of information transfer is called a "bit." This is actually a contraction from **bi**nary digi**t**. A bit can have a value of only 0 or 1. The only difference between analog and digital communication is the definition of a single bit. In an analog system, a bit is one cycle of the waveform. In a digital system, a bit is one pulse of the timing mechanism.

A bit is either 0 or 1.

Although the bit is the smallest unit of information, not everything can be represented by just two values. Therefore, bits can be combined to provide larger values. For example, two bits can be combined to express four distinct values, as shown in Table 2-1.

Table 2-1. Values from 2 Bits of Information.

Bit #	Value			
Bit 1	0	1	0	1
Bit 2	0	0	1	1

8 bits to a byte.

To represent larger numbers with discrete values, additional bits are aggregated. For example, 8 bits can combine to produce a total of 256 discrete values ranging from 0 to 255. This is called a byte. A byte represents a character, whether it is the letter ‘a,’ the number ‘2,’ or the symbol ‘#.’

For example, the number 2 represented in bits (1 byte) is actually:

2 = 00000010

Although numbers can be represented directly by bit notation, it is not the simplest format to read, use, and quickly understand. The standard is to use numbers, letters, and symbols defined by American Standard Code for Information Interchange (ASCII), a code for representing English characters as numbers. For example, the ASCII code for an uppercase ‘M’ is 77, whereas that for an uppercase ‘F’ is 70. These numbers are translated to the 256 discrete values so that characters can also be represented as bits. Although there is more detail behind the conversions and storage mechanisms, the fundamental concept is that the root of information exchange in communications is the bit.

Because a bit is such an elemental unit of information, it takes a large number of them to actually convey an adequate amount of information. Take for example, the famous sentence from typing class:

“The quick brown fox jumps over the lazy dog.”

The sentence contains 44 characters, including spaces. That translates to 44 bytes, or 352 bits. You can see that even a short document could therefore contain tens of thousands or even millions of bits. Other types of media, such as pictures and video streams, contain an even greater amount of information.

To help describe this vast amount of information, blocks larger than a single bit are utilized. For example, a kilobit is defined as 1024 bits. The number 1024 is used because it is the natural progression of the base 2 mathematics upon which most computing is based.

Table 2-2 identifies the values and abbreviations for the rate of information transfer. Media such as video are not discussed in terms of the total amount of information transferred, but rather the amount of information transferred in a certain amount of time. Most often, this time frame is a second, so a rate is expressed as bits per second (the abbreviation would then be bps). When information transfer rates are used or quoted, however, a kilobit is equal to 1000 bits, not 1024 bits.

The one remaining aspect of understanding the terms associated with information transfer rates is the difference between uppercase and lowercase designations. Because both bits and bytes start with the same letter, a lowercase 'b,' by convention, refers to bits. An uppercase 'B,' by convention, refers to bytes. This is a very important aspect to remember because being wrong means that your rate calculations are off by a factor of eight!

Transfer rates are most often expressed as some level of bits per second.

Table 2-2. Information Transfer Rates Terms and Abbreviations.

Term	Definition	Abbreviation	Rate Abbreviation
Kilobit	1000 bits	Kb (also kb)	Kbps (also kbps)
Megabit	1,000,000 bits 1000 kilobits	Mb	Mbps
Gigabit	1000 Mbits 1,000,000,000 bits	Gb	Gbps
Terabit	1000 Gbits 1,000,000,000,000 bits	Tb	Tbps

2.3.1. Bandwidth

In communications, the term "bandwidth" refers to how much data can be transmitted in a certain amount of time. In most situations, bandwidth is expressed in terms of bits. The larger the number of bits that any given technology can transfer in the same amount of time, the larger its bandwidth. In essence, bandwidth is a measure of the size of the pipe.

Bandwidth is often expressed in terms of its ultimate capacity. However, like many situations, the ultimate capacity is rarely achievable. Inefficiencies in the system propagate to create a practical limit to how much bandwidth can actually be achieved with any given technology. Future chapters present the ultimate and usable bandwidths associated with each of the various technologies that are discussed. For now, it is important to understand the concept and the relative size of the pipes by the value of the information transfer rates.

2.4. Types of Information Transmission

The world around us contains all types of information. Temperature, time, sound, color, noise, and even pollen levels are just a few of the types of information we encounter on a daily basis. Much of that information is best expressed using an analog system. Analog simply means that the information is represented by a continuous change in values information.

As an example, consider the levels of sound or noise that are heard every day. They may vary from a whisper to shouting to a siren or a piercing whistle. They are all different and can vary continuously across a range. A similar example can be detailed for temperature, color, and time. The analog nature of time can best be represented visually by looking at a clock. The hands of the clock travel in a circle and can be at any location in the circle. Each location of the hands represents a value of time. Each piece of time is an analog signal.

All information can be expressed in either an analog or digital format.

In contrast, a digital representation has a discrete value. There are no in-between states. The simplest digital system consists of only two values, on or off. A light switch is either on or off. A door is either locked or unlocked. The values of these examples are represented by either 1 or 0. Digital representations can get more complicated than simply on or off. For example, a typical three-way light switch has four possible values (off, 50 W, 100 W, or 150 W). What's important is that each value is known and does not vary.

2.5. Analog Transmission

Figure 2-1 shows a typical representation of an analog signal. As time progresses on the horizontal axis, the signal value can vary infinitely, both positive and negative. The signal in Figure 2-1 is also said to be a waveform, the communications term for a plot of amplitude versus time. One cycle of the waveform is a bit.

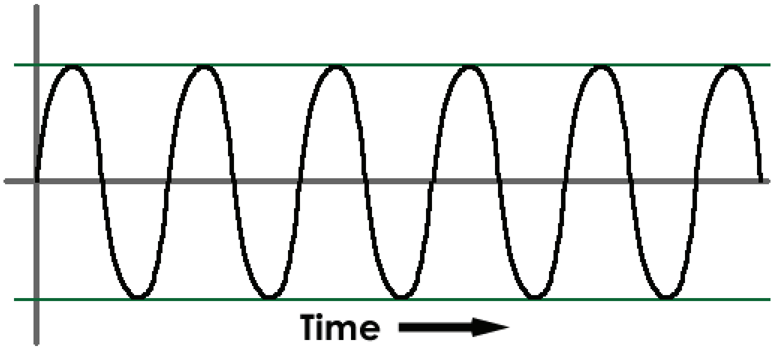


Figure 2-1. Example of Analog Communications.

While there are several methods for transmitting analog information, the two most common are amplitude modulation (AM) and frequency modulation (FM). You may recall these terms from listening to the radio, as these are the exact same methods in use by radio stations to transmit information.

As illustrated in Figure 2-2, AM changes the height or amplitude of the waveform. Note that in an AM system, only the height changes. The wavelength, or time between each part of the wave, remains constant. This type of system requires an amplitude reference point so that changes in the height of the waveform can be translated to individual units of information.

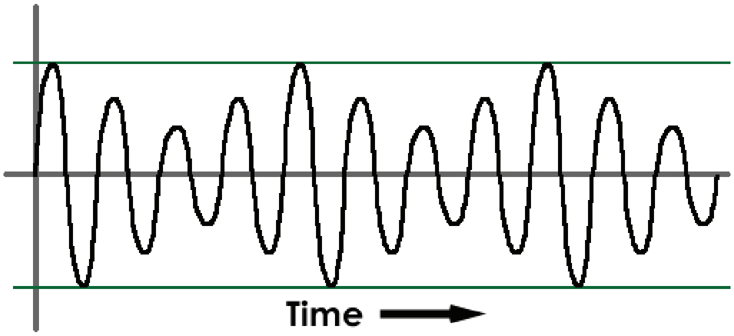


Figure 2-2. Amplitude Modulation.

In contrast, Figure 2-3 illustrates FM. In frequency modulation the wavelength, or timing between portions of the waveform, change but the height does not. This type of system requires a frequency or timing reference point so that changes in the frequency of the waveform can be translated to individual units of information.

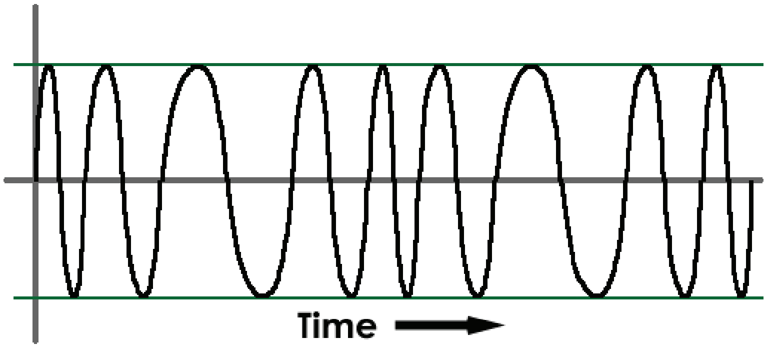


Figure 2-3. Frequency Modulation.

Analog communications employ other modulation schemes as well, but altering either the frequency or amplitude are the most common. Each method has advantages and disadvantages related to cost, simplicity of equipment, transmission distance, and more.

In some situations, analog bandwidth may be expressed in hertz, or cycles per second. There is no universal conversion between hertz and bits that holds true in every situation. However, the use of hertz to express bandwidth is increasingly less common.

2.6. Digital Transmission

Figure 2-4 illustrates the concept behind digital communications. The waveform is composed of only two values, either 0 or 1. The typical technique for transmitting digital communications is to 'pulse' the medium. The amplitude of each pulse is read and translated into the value of 0 or 1. Each pulse is a bit.

Digital systems are typically clocked, meaning each pulse has a specific time allotment. This uniformity in spacing can be seen in Figure 2-1. Media for digital communications can be either copper, which transmits electrical signals, or fiber, which transmits optical or light signals. Both types of media utilize the same principles of pulsed communications; they simply differ in what is being pulsed.

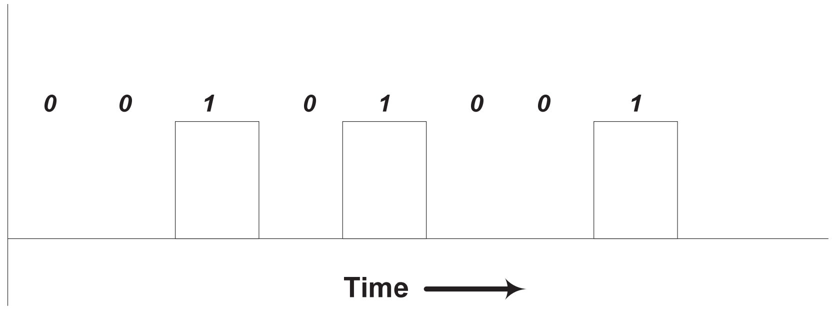


Figure 2-4. Example of Digital Communications.

In times past, the concept of analog versus digital was critically important to the design of communications systems. Thankfully, as equipment has improved, the need for the end-user (the reader) to take action to account for these differences has basically gone away. Nonetheless, understanding the difference on the conceptual level is an important starting point for the overall scope of building communications systems.

The reader should also be aware that there are a number of aspects of signaling (either analog or digital) that are not covered in this text. Detailed technical descriptions of concepts such as frequency, amplitude, and bandwidth are beyond the scope of this guidebook because they are generally handled automatically by modern communications equipment.

As any type of signal moves across a transmission medium, the quality of the signal degrades – no perfect medium exists that can transmit signals without loss. Eventually, the signal needs to be “fixed” so that it accurately represents the original information. In analog communications, the signal is simply amplified (boosted) at various points. In digital communications, the signal is actually regenerated. This is an important concept because limits exist as to how many times a signal can be amplified without suffering distortion. Consider trying to receive an FM radio station 100 miles away from the radio tower and how much static the signal would contain. By contrast, because digital communications regenerate the signal at various locations, the information can generally travel much longer distances. Although the equipment is readily available, it is generally more expensive to regenerate digital signals over long distances.

This guidebook focuses on digital communications, as they are the most prevalent types of systems being designed and implemented today.

2.7. Wireline Media

In wireline communications, it's either copper cabling or fiber optics. [Wireline communications use either copper or fiber optic cabling?]

Wireline communications require some type of physical cable, or medium, to move information from one point to another. In the early days of networking and computers, this medium was limited to a metallic wire. Some of the original communications were done using a bare, or open, wire with no insulation. Today, those types of installations are mostly nonexistent.

Metallic cables still make up the bulk of the physical media used in communications, especially internal to buildings. Typically, the metal used is copper, which can be formed into several different types of cabling, as needed. Optical cable, typically called fiber, is an alternative to copper wiring that is increasingly popular, for many reasons.

2.7.1. Copper Media

In today's communications environment, copper cabling comes in two basic forms, twisted pair and coaxial.

2.7.1.1. Twisted Pair

Copper cabling can be twisted pair or coaxial.

Paired cabling, known as twisted pair, was originally developed for analog connections. The twisting in each pair cancels the electrical noise from adjacent pairs. In modern cabling, each copper wire is typically sheathed in plastic to insulate and protect the copper core. Some brands of twisted pair cabling also surround the pairs with paper as an additional insulator.

Figure 2-5 shows a typical four-pair copper cable assembly. Note that each individual copper core utilizes a color scheme on the insulating jacket. This allows technicians to assemble the wires into a connector in a standardized method. With every connector being the same, wiring problems can be minimized.

Figure 2-5. Typical Paired Cable Assembly.
(Source: Reference 1)

A typical connector for twisted pair copper cabling is shown in Figure 2-6. The connector, known as an RJ-45, has slots for eight distinct cables, arranged according to communication standards.

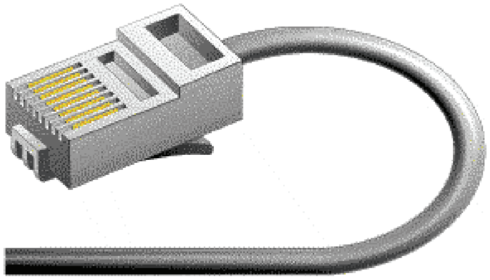


Figure 2-6. Typical Paired Cable Connector.
(Source: Reference 1)

Table 2-3 shows some of the common types of paired cabling available today and the application for which they are typically used. Each type of cabling has different characteristics that make it appropriate to specific applications. In practice, most computer networks use Category 5 or higher. There is also an emerging trend in many new ITS deployments to use Category 5 or higher cabling for communication to field devices, such as traffic signals. There are additional items to consider in the choice of cabling such as fire code requirements for air spaces and the use of color schemes to distinguish vertical and horizontal cabling.

Table 2-3. Types of Paired Cables.
(Source: Reference 1)

Type	Use
Category 1	Voice Only (Telephone Wire)
Category 2	Data to 4 Mbps (Local Talk)
Category 3	Data to 10 Mbps (Ethernet)
Category 4	Data to 20 Mbps (16 Mbps Token Ring)
Category 5/5e	Data to 1000 Mbps (Gigabit Ethernet)
Category 6	Data to 1000 Mbps (Gigabit Ethernet) (Higher signaling rate, extra insulation)

2.7.1.2. Coaxial Cable

Coaxial cable has a single copper wire at the center of the wiring assembly. A plastic layer provides insulation between this center conductor and a shield, made of braided metal. The shield is a ground and helps to block interference from outside sources. The entire assembly is usually covered in a rubber sheath. Figure 2-7 shows a typical coaxial cable assembly.

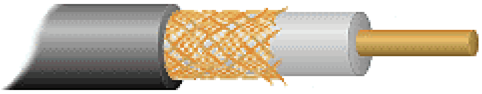


Figure 2-7. Typical Coaxial Cable.
(Source: Reference 1)

There are many different types of coaxial cables with designations like RG6, RG58, RG59, RG11, and more. These designations define cables with different characteristics, such as impedance, loss, type of outer conductor, and more. Some listings show more than 200 RG designations, but the most typical are RG6, RG59, and RG11. RG59 and RG6 are typically used in video applications, whereas RG11 is used extensively for computer networking applications.

Impedance is a measure of opposition to an electric current. The calculation of impedance is beyond the scope of this guidebook. Impedance is determined by the size and spacing of the conductors and the type of dielectric used between them. For ordinary coaxial cable used at reasonable frequency, the characteristic impedance depends on the dimensions of the inner and outer conductors. Some common impedances are:

- 50 ohm – widely used with radio transmitter applications.
- 75 ohm – an international standard, based on optimizing the design of long distance coaxial cables. This impedance is the coaxial cable type widely used in video, audio, and telecommunications applications.

Figure 2-8 shows the typical connector used in coaxial cable assemblies. The connector is known as the Bayone-Neill-Concelman, or BNC, connector. Additional types of connectors used with coaxial cable include barrel, T, and terminator.

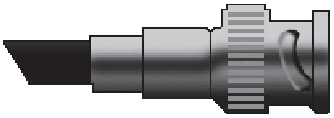


Figure 2-8. Standard BNC Coaxial Cable Connector. (Source: Reference 1)

Figure 2-9 shows two assembled coaxial cables with a BNC connection. Figure 2-10 shows a wide variety of the connectors that can be used with coaxial cable.

Figure 2-9. Assembled Coaxial Cable.

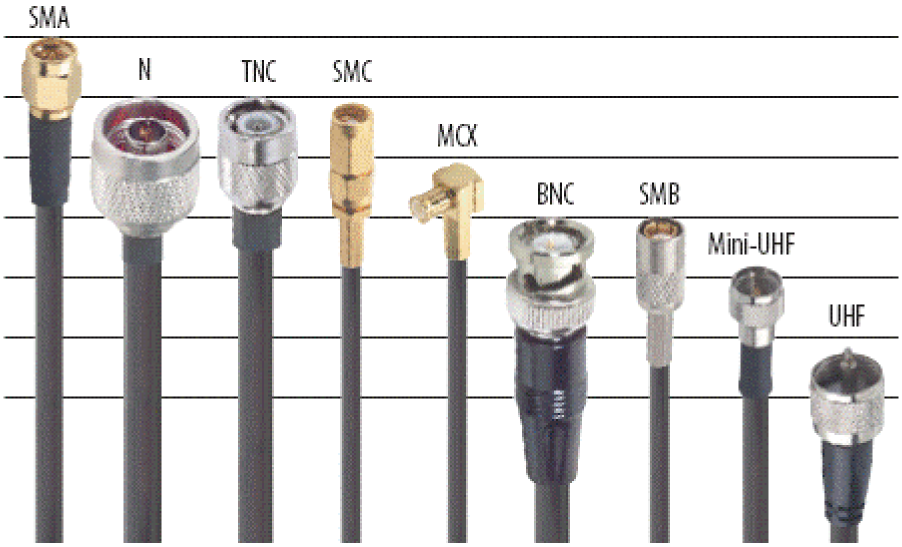


Figure 2-10. Typical Connector Types Used with Coaxial Cable. (Source: Reference 1)

2.7.2. Fiber

Unlike copper-based cabling, there is no wire inside a fiber optic cable. In fact, the core of a fiber optic cable is glass. The glass core is generally surrounded by several layers of protective materials. Figure 2-11 shows a typical fiber optic cable assembly.

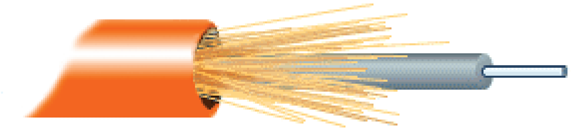


Figure 2-11. Typical Fiber Cable. (Source: Reference 1)

Fiber optic cable (typically referred to as just "fiber") transmits light instead of electronic signals. This eliminates the problem that copper cabling has with electrical interference, which makes fiber cabling an ideal medium for many environments. Fiber has also been heavily utilized for outdoor network and connections between buildings because it is impervious to most problems from environmental conditions.

A main advantage of fiber over copper-based cabling is the ability to transmit information over much longer distances without the need to regenerate the signal.

A typical cable assembly consists of two glass cores, each in a separate jacket. Since each glass core only passes light in one direction, an assembly of two cables is required for a transmit and receive type of operation.

Fiber optic cabling can be single-mode or multi-mode.

Fiber optic cable comes in two main types, single-mode and multimode. The two types of cabling have different physical characteristics. Multimode allows more than one stream of light to travel in the glass core at a single time, separated by the frequency of the light source. In contrast, single-mode allows a single stream of light to travel in the glass core. Typically, single-mode fiber installations can carry information longer distances than multimode installations.

Fiber optic cabling is generally rated and sold based on the thickness of the glass core. Single-mode cable is typically listed as 9 µm, while multimode cable is typically listed as either 50 µm or 62.5 µm.

In the past, use of fiber was limited due to its procurement cost, but the cost of fiber has dropped significantly in recent years. However, the costs associated with installation can still be significant, as they include trenching, cable access boxes, and conduit. Additionally, fiber cables must often be spliced together, a process that fuses the glass cores to provide a continuous flow of light and, therefore, data. Although the splicing process is fairly automated, it is exacting and must be done with a great deal of care and precision, adding to the costs.

2.7.2.1. Typical Fiber Cable Assemblies

There are many types of fiber optic cable assemblies available for purchase. The choice of cabling depends on the task requirements. Other considerations include the need for fire retardant plenum cable for use in air spaces or riser cable to run vertically between floors in buildings. Cable assemblies also come in different modes, size bundles (number of fibers), and lengths.

Zipcord is another name for a fiber patch cable. Zipcord is very flexible multimode fiber that runs in pairs for transmit and receive. Zipcord is for indoor use and short runs. It can easily be pulled apart to make two simplex patch cords.

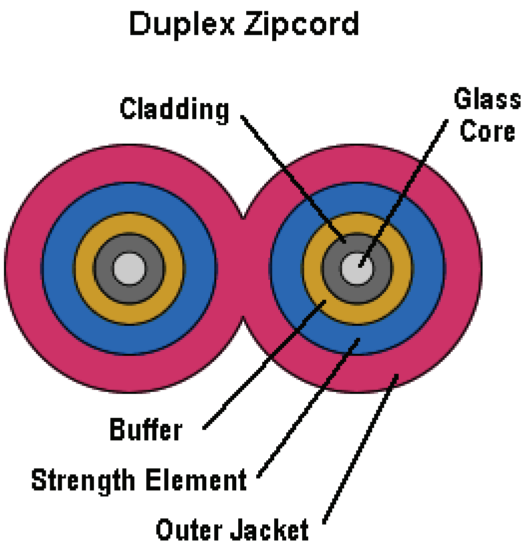


Figure 2-12. Duplex Zipcord Assembly.

Breakout cable is the most user friendly because each fiber has its own jacket and aramid strength elements. Due to this, each fiber is extremely strong and rugged. Breakout fiber is also very stiff.

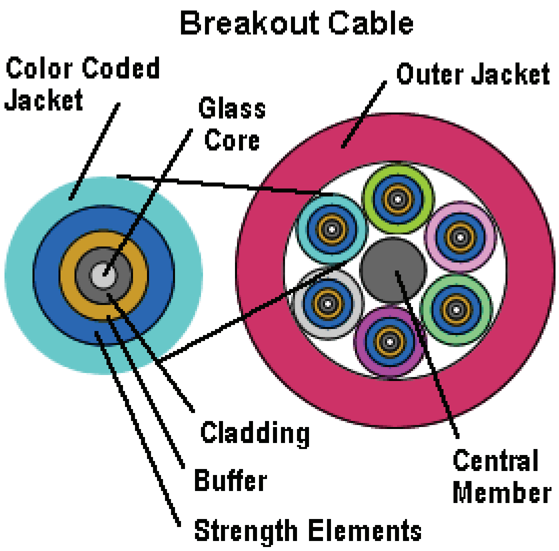


Figure 2-13. Breakout Cable Assembly.

Distribution cable is similar to breakout, but each fiber does not have an individual strength element. Distribution cable assemblies can be purchased for multiple uses, such as indoor or outdoor, as well as riser or plenum requirements.

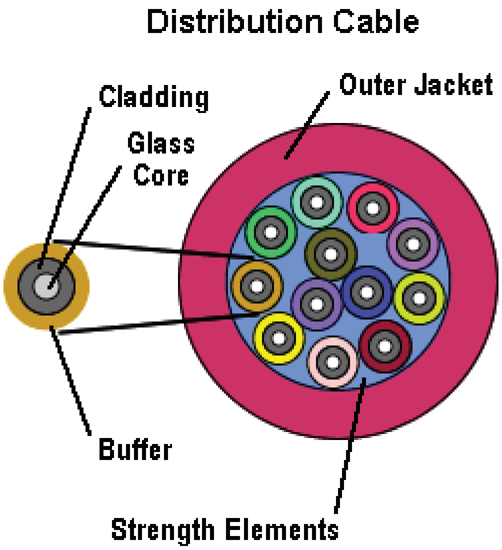


Figure 2-14. Distribution Cable Assembly.

Armored cable is often used for rodent protection in direct burial applications. This cable is non-gel filled and can also be used in aerial applications.

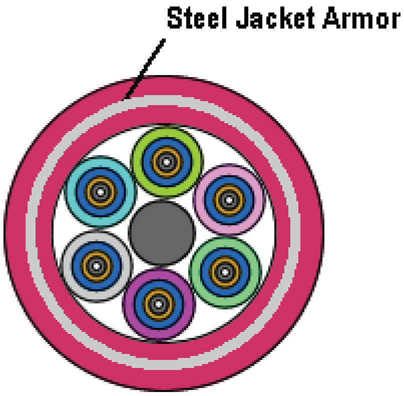


Figure 2-15. Armored Cable Assembly.

Hybrid cables have many different configuration combinations. The typical combinations are Fiber/CAT5, Fiber/Coax, Fiber/Copper, or Fiber SM/Fiber MM. Hybrid cables offer the convenience of installing different cables in one installation run. Hybrid cables are used extensively in deep-sea applications, with the copper cabling providing the power for the repeaters.

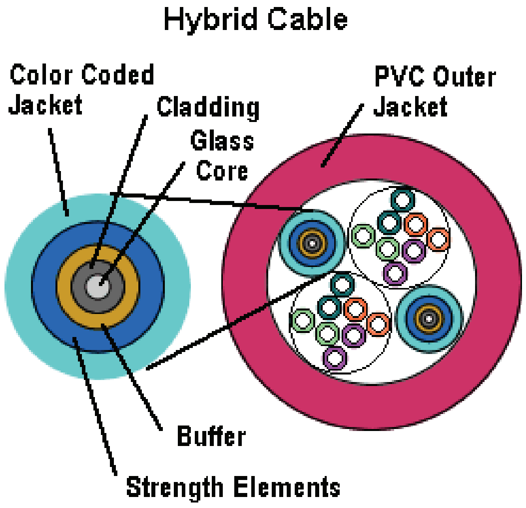


Figure 2-16. Hybrid Cable Assembly.

In a gel-filled design, color-coded plastic buffer tubes house and protect optical fibers. A gel filling compound impedes water penetration. Loose-tube cables typically are used for outside-plant installation in aerial, duct, and direct-buried applications.

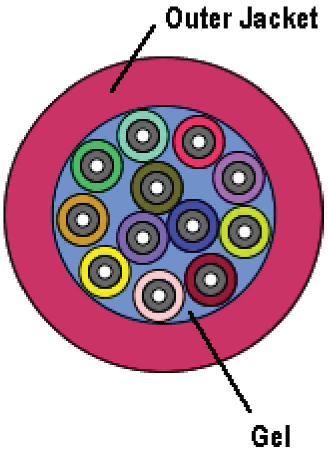


Figure 2-17. Gel Filled Cable Assembly.

Messenger cable is another name for aerial cable. These cables provide a steel strength member external to the fiber assembly, which is used to string and secure the cable. Aerial cabling can have a distinct advantage over direct burial cable in terms of installation time and cost.

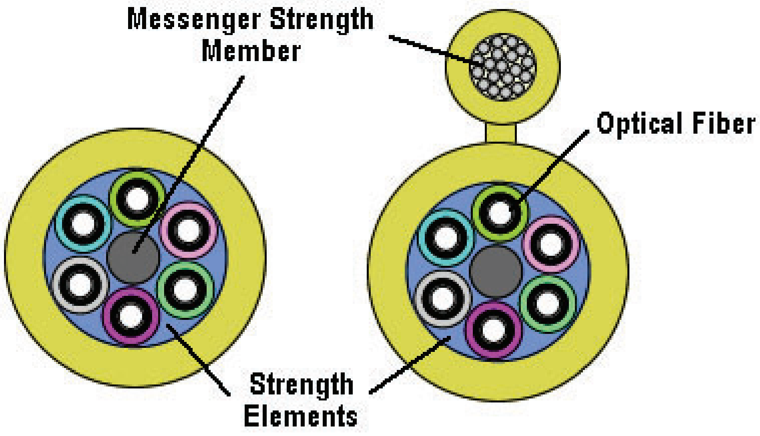
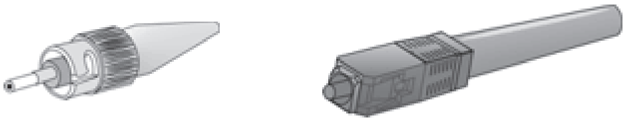


Figure 2-18. Typical Messenger Cable Assembly.

2.7.2.2. Typical Fiber Connectors

Many different types of connectors for fiber optic assemblies have been developed over time. Figure 2-19 shows the two most common types of connectors. ST (straight tip) is a round connector that pushes on and twists to lock. SC (subscription channel) lines up correctly in only one direction. It then pushes in and locks into place.



ST Connector SC Connector

Figure 2-19. ST and SC Fiber Cable Connectors.
(Source: Reference 12)

Some additional connectors are identified in Table 2-4.

Table 2-4. Typical Fiber Connectors.

Connector Type	Connector Name	Coupling Type	Fibers Per Connector	Typical Applications
ST	Straight Tip	Twist on	1	Networks
FC	Ferrule Connector	Screw on	1	Data Communications, Telecommunications
SC	Subscription Connector	Snap on	1	CCTV, Test Equipment
LC	Lucent Connector	Snap on (RJ45 Style)	1	Gigabit Ethernet, Video Multimedia, Telecommunications
MU	Miniature Unit-coupling	Push/Pull	1	Traditional, medical, and military use
MT-RJ	Mechanical Transfer - Registered Jack	Snap on (RJ45 Style)	2	Variety of network and telecommunication applications. Smaller format makes it ideal for applications with limited space.
MPO (MTP)	Multi-fiber Push On (Mechanical Transfer Performance)	Push/Pull	4, 8, 12, 16, 24	Multifiber patch cord suitable for high-density back plane and printed circuit board (PCB) solutions in data and telecom systems.

2.7.2.3. Wavelength Division Multiplexing

Wavelength division multiplexing (WDM) is a technology used in fiber applications where several discrete wavelengths (ranges of light) are combined onto one fiber. Although expensive, this greatly increases the total bandwidth that a fiber can carry if using only a single wavelength.

Equipment is needed at both ends of the fiber run to accomplish this multiplexing. The technology is available for both analog and digital networks. There are several levels of WDM capability, with the most complex systems able to multiplex 64 different wavelengths on a single fiber.

2.7.3. Other Media Topics

2.7.3.1. Attenuation/Loss

When working with cables, power loss can always be expected. In general, fiber optic cables have less loss than copper. When attenuation occurs, the received signal is lower in power than the transmitted signal because of losses in the transmission medium. Attenuation is measured in decibels. It is the opposite of gain.

With fiber optic cable, the two main losses are insertion loss and return loss. Insertion loss is optical power loss, generally due to diffusion, dispersion, scattering, absorption, microbending, or insertion devices within the circuit splices and connection points. Insertion loss is usually expressed in decibel per kilometer.

Return loss is another common form of loss in fiber optic cable. Return loss is the ratio of the power launched into a cable and the power of the light projected down the fiber.

2.8. What Does the Future Hold?

Predicting the future of communications is a risky business. Aside from technological changes, society can also have a dramatic effect on communication solutions. Today, society is increasingly embracing having information at the fingertips. High-speed is the name of the game and video on mobile devices is seen as the next hot commodity. In some countries, the cellular networks have already been upgraded to provide almost continuous access to high-speed mobile information.

From the technology standpoint, it is clear that increased capability at a smaller size and lower price will continue to be the trend for some time. Since the 1970s, electronics have generally followed Moore's Law, which states that electronics will double the number of transistors on a chip every 18 months. This doubling has led to the integration of computers, electronics, video, and digital media into a vast array of devices with increasing capabilities. Future advances in technology will eventually allow open communication between items used in our everyday lives, such as clothes that could automatically adapt to information received from a weather station broadcast. Automobile manufacturers have already demonstrated systems that adapt to a broader range of driving conditions than was ever thought possible.

Another trend for the future is likely to be increased standardization. Today's free market demands interoperability and information exchange between devices, software, and systems. These trends are likely to increase in the future, especially as electronics continue to operate in a more global marketplace.

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3. UNDERSTANDING TELECOMMUNICATIONS TECHNOLOGY

3.1. Introduction

This chapter introduces a wide variety of topics in telecommunications. It is intended to provide an introduction and broad-based overview of these topics rather than an in-depth technical analysis.

By first providing background information on the most common protocols used today across both copper and fiber media, the chapter presents the wide breadth of telecommunication solutions available in the ITS marketplace. Second, by providing background information on how networks are assembled or arranged, the chapter illustrates how the protocols can be utilized to form communications systems. Finally, this chapter presents some special topics that are of prime consideration in the ITS arena.

3.2. Protocols

One of the most basic concepts in telecommunications is the concept of protocol. In Chapter 2 we discussed the types of media used for sending information. In Chapter 3, we build upon that knowledge by adding knowledge of "how" information gets onto that media. This is done using protocols.

There are five traits common to any protocol.

In essence, a protocol is a standardized method of breaking information up into discrete units that can be sent along a media. Although it sounds somewhat complicated, a protocol is really nothing more than a set of rules for handling and exchanging information.

As a basic example, consider a standard telephone conversation between two people. You initiate a call by picking up the phone and listening for a dial tone. If present, you dial a set of numbers to reach a destination phone. The person at the other end hears the phone ring, picks up the phone, and says "Hello." At that point you begin your conversation by identifying who is calling and what you are calling about.

A protocol works in the same manner, using a defined method of transmitting data between two devices. All protocols have the following common traits:

- specification of a standard format for transmitting data between two devices,
- specification of the type of error checking to be used,
- specification of any data compression utilized,

- specification of how the sending device will indicate that it has finished sending a message, and
- specification of how the receiving device will indicate that it has received a message.

Like the telephone conversation, protocols do not send all of the information at once. A telephone call involves give and take, where the caller provides some information, waits for the receiver to say something in return, and then continues. Protocols typically divide information up into equal-sized "chunks." Most protocols have a procedure (rule) to send a "chunk" of information, wait for an acknowledgement that the "chunk" was received, and then send another "chunk." This process repeats until all of the information has been sent.

A common question is why are there different protocols? Why isn't one sufficient? Let's return for a moment to the example of a telephone conversation. While one conversation may take place in English, another may utilize French, and a third may use Spanish. Each conversation transmits information on the same media, using established rules, but they all do it a bit differently.

A protocol is similar. You can use more than one set of rules to transmit the same information. While each protocol may do many of the same tasks, each one does those tasks a little differently. One protocol may work with copper media. Another protocol may only work with fiber. Yet others may work with both.

Another important aspect of protocols is understanding that multiple protocols can work in conjunction. In fact, many protocols may be required to send information. Returning once more to the example of the telephone, a protocol is used for dialing a telephone number. A protocol is used to "negotiate" the connection between the two devices. There is also a protocol in use for the two parties to exchange information. Each of these protocols work together to accomplish the overall goal of having a telephone conversation.

There are hundreds of communications protocols in existence today. While some work independently, others work cooperatively with other protocols. There may be other specialized aspects to many protocols, but all protocols meet the minimum specifications above, which are necessary to regulate the exchange of data. In addition, each protocol has advantages and disadvantages, which must be evaluated for the particular need. Protocols can be implemented in both hardware and software.

3.2.1. Protocol Stacking

When multiple protocols are involved in the transmission of information, they are said to be "stacked." Each layer adds additional features and capabilities not provided by the underlying protocols. Not only is protocol stacking common, it is essential to providing interoperability.

An international standard has been defined for establishing a framework for interoperability in communications. Known as the Open Systems Interconnection (OSI) model, the framework is implemented in seven layers, starting from the application, or top layer, at one side and progressing to the physical (bottom) layer.

Figure 3-1 illustrates the seven layers of the model and how data from each level are assembled and passed to the point where it is transmitted across the wire, where the process then reverses. At each level, information from the layer above is encapsulated or surrounded with additional information. As an example, information originating from Layer 7 is encapsulated in Layer 6, which is encapsulated in Layer 5, and so on, until it reaches Layer 1. At Layer 1, the information is sent over the wire (either copper or fiber in our case) to another device. The other device receives the information and passes it back up the seven layers with each layer stripping away the extra information. At the top of the stack, it arrives at Layer 7 and is passed back to the application that can use it.

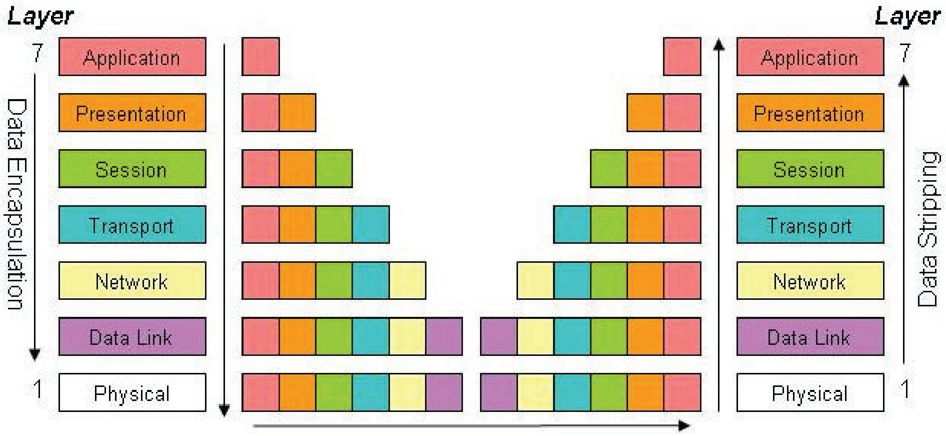


Figure 3-1. The OSI 7-Layer Model for Communications Interoperability.

As an example, consider the typical application of visiting a website from your desktop computer. The protocols used to create that capability are:

- HTTP (Hypertext Transfer Protocol),
- TCP/IP (Transmission Control Protocol/Internet Protocol),
- plus the networking protocol of Ethernet, ATM (asynchronous transfer mode), etc.

In addition, if your computer is part of an Ethernet network and sends e-mail, the protocol stack might look like:

- Ethernet,
- TCP/IP,
- HTTP, and
- SMTP (Simple Mail Transfer Protocol).

The choice of which protocols to implement, such as digital subscriber line (DSL), Ethernet, etc., is actually a decision about some of the lower layers in the seven-layer model.

3.3. Common Protocols

The following sections identify and provide background information on several of the protocols most commonly used within the ITS industry. This is not a comprehensive treatment of all available protocols. Although there are hundreds of protocols in existence, many of them are specialized and not immediately applicable to the ITS communications environment.

3.3.1. Serial Communication Protocols

This guidebook reviews several protocols that are common in ITS installations:

- **Serial**
- **DSL**
- **Frame Relay**
- **ATM**
- **SONET**
- **TCP/IP**
- **Ethernet**
- **Special Protocols**

Serial communications have been in use for decades. Developed in the early 1960s by the Electronic Industries Association, serial communication was designed and utilized as a common interface standard between communications equipment. It is important to understand that a serial interface is an electrical interface. A change in the electrical signal across the wire is translated into data. While the concept was simple, the actual design necessary to ensure reliable communications proved to be relatively complex. Serial protocols can specify signal voltages, signal timing, signal function, information exchange rules, and mechanical connectors.

Perhaps the most well-known serial protocol is RS-232. A prevalent application of RS-232 is in the computer industry, where the protocol is used for many devices including printers, mice, keyboards, and modems.

Over time, additional serial protocols were developed for other situations, to address the limitations of RS-232. The other protocols in common use in transportation communications are RS-422 and RS-485.

3.3.1.1. How It Works

An in-depth description of the explicit mechanism for serial communications would be quite lengthy. In overview, however, there are a few core concepts. The first is that serial communications transmit information as a pattern of bits. The RS-232 standard defines the voltage levels that correspond to logical 1 and logical 0 levels. The standard works with signals that are ±3 to 15 V, although signal levels of ±5, ±10, ±12, and ±15 V are all common, depending on the power supply available within a device. The negative voltage is defined as “1” or “off,” while the positive voltage is defined as “0” or “on.”

The second core concept is that serial communication utilizes pairs of wire. RS-232 uses a single pair of wires along with a ground. RS-422 utilizes two pairs plus ground. RS-485 can use either one or two pairs, although the most common is a single pair plus ground. These sets of wires can be balanced or unbalanced, meaning they can carry either the same or different voltages. The arrangement of these lines, the voltages they carry, and how they relate to the ground voltage are in the specifications for each type of serial communication. As an example, RS-232 is an unbalanced communications system, while RS-422 is a balanced system. In computer networking practice today, serial communications are often accomplished using Category 5 cabling.

Another important concept is that serial communications can be asynchronous or synchronous. Asynchronous communications do not require the use of a common clock to keep coordinate signals, whereas synchronous communications do.

Finally, the most common format for transmitting information over serial links is known as “asynchronous start-stop.” Asynchronous start-stop uses a start pointer called a start bit followed by some number of data bits and ending with another pointer called a stop bit. Additionally, there may be a parity bit, which checks data integrity.

3.3.1.2. Performance

The performance of serial communications varies. Serial protocols work at very low speeds such as 9600 bps (9.6 Kbps) to more than 200 Kbps. Specific performance depends on the equipment, the particular standard in use, the distance between devices, and the application, as well as the quality of the wiring between devices.

3.3.2. Digital Subscriber Line (DSL)

DSL was first developed in 1989. At that time the telephone industry typically transmitted data at speeds of 56 Kbps. DSL originally was capable of transmitting up to 144 Kbps. However, cable television was achieving much higher speeds of up to 10 Mbps, and speeds of up to 50 Mbps were being planned by satellite companies. One way in which telephone companies expected to compete was by providing services such as Video on Demand (VOD). VOD would allow subscribers to access movies or programs at any time on any television. DSL was designed to meet the needs of the telephone companies to provide the high download speeds needed to stream video over an existing network of telephone cabling.

The demand for VOD was much lower than expected, while at the same time Internet usage began to increase. Providing users access to the Internet became a large part of the telephone market. The telephone companies quickly realized they needed a product that was more competitive than their current 56 Kbps service. DSL emerged as the primary solution. Today, DSL comes in many different types and is sized to meet a variety of user needs.

3.3.2.1. How It Works

DSL transmits data over existing phone lines. These same phone lines were used by phone companies for POTS (plain old telephone service). In order to improve voice service, telephone companies traditionally filtered the phone lines, limiting the frequencies that the lines carried. Human voices, in a normal speaking range, can be transmitted at a frequency range of 0–3400 Hz. This is a small range of frequencies when compared to the capability of the lines with no filter. By removing the filters, much higher rates of transmission can be accomplished on the same wires. In addition, by sending data over the lines digitally, rather than by analog, the wider frequency range can be safely used to transmit data without the problem of interference.

There are many different implementations of DSL. The most popular, asymmetrical DSL (ADSL), divides the frequencies into channels. One channel is used for POTS, while the others are used for uploading and downloading data. ADSL services operate under the premise that most users download more information from the Internet than they send to the Internet. ADSL, therefore, provides a wider range of frequencies for downloading, making it much faster for the user than ordinary phone service. Other approaches to DSL include symmetric DSL (SDSL), which doesn’t allow use of a phone at the same time but has equal speeds for uploading and downloading.

3.3.2.2. Performance

The performance of DSL has some significant benefits when compared to other communications protocols. The most noticeable benefit is the increase in speed when compared to an analog modem. DSL is capable of transmitting data to a user at a rate of up to 1.5 Mbps, whereas an analog modem's maximum speed is 56 Kbps. DSL is also beneficial because it uses existing phone lines that are already in place. Eliminating the need for running new wire lowers the cost of implementing a DSL solution. Finally, unlike the typical setup for an analog modem, DSL is always connected. Therefore, there is no wait for a dial-up connection to be made.

Along with the benefits, there are drawbacks to using DSL. DSL quality depends on the distance from the central office. The farther from the central office, the slower the connection. Indeed, at a certain distance DSL is not even available.

DSL is capable, in theory, of offering up to 8 Mbps download at a distance of approximately 6000 feet. Generally, speeds are offered at a maximum of 1.5 Mbps. The typical distance limit on DSL service is 18,000 feet from the central office. Many providers do not offer the service at longer distances, due to quality concerns. Because of these limitations, DSL is not available at all locations.

3.3.3. Frame Relay

Frame Relay is a network standard that builds upon the base of packet switching. With packet switching, data are assembled into small groups called packets. Each packet has its own identifier (ID) and destination address. The packets are transmitted across the network and are reassembled into a complete data stream at the destination.

Each individual packet can take a different physical path to get from the source to the destination. In each path, the packets may pass through various network devices, such as switches. Each switch checks for errors and, if any are found, performs a correction before the packet passes through. This error checking and correction, while improving reliability, leads to a large amount of overhead and makes traditional packet switching slow.

Most modern computer networks are digital at the core. Digital technologies and equipment can typically transmit information faster and over longer distances with less interference and equipment. Correspondingly, traditional error checking and correction needs from earlier networking systems have diminished. Frame Relay uses this reliability of networks to improve the speed of traditional packet switching by removing error checking and correction. Frame Relay provides much higher speeds than traditional packet switching, up to 45 Mbps.

3.3.3.1. How It Works

In Frame Relay, chunks of information are called frames. An interesting aspect of frames is that they are variable in length. The data, or payload, can be anywhere from 0 to 4096 bytes. By using variable-size payloads, Frame Relay can support the different packet sizes of various other protocols that may be used in conjunction with Frame Relay in the seven-layer model. This property of Frame Relay makes it completely protocol independent. Data from any protocol can be received and transmitted using the Frame Relay protocol.

Before transmission, the data, known as a protocol data unit (PDU), is encapsulated into a frame. A frame contains header and trailer information needed by the network in order for it to be transmitted. Frame Relay does not attempt to convert any protocols to its format. It simply encapsulates the data and sends it along the transmission media. This increases the speed over other variations of packet switching.

The Frame Relay protocol was designed so that it can co-exist with other protocols. This is especially important in shared communications systems where multiple protocols may be running over the same transmission media. Frame Relay also uses the concept of an origination and destination address, so that network equipment can send it to a particular location. Each frame is tagged with this addressing. At the destination address, frames are received one by one and reassembled into the complete information.

The use of a shared network can offer a more cost-effective solution. Many businesses can share the same communications media, each utilizing and paying for a portion of the total capacity.

3.3.3.2. Performance

Frame Relay was primarily designed to be used between networks. This type of connection is often called a wide-area network (WAN) link. The speeds available with Frame Relay can vary from 56 Kbps to 45 Mbps. However, the actual performance varies greatly depending on network congestion and other factors.

Overall, Frame Relay networks are a good choice when there is a high volume of data to send, but the arrival time of that information is unpredictable and depends on traffic loads. Frame Relay may not be the best choice for multimedia networks, as these applications require consistency in the arrival of information.

3.3.4. Asynchronous Transfer Mode (ATM)

ATM is a high-bandwidth, low-delay technology that is capable of very high transmission rates. Like Frame Relay, ATM is a packet switching technology. The main difference between ATM and other packet switching technologies is the packet size, which does not vary in ATM. The telecommunications industry realized early on that as the speed of networks continued to increase, carrying real-time data with different-sized packets would become unmanageable. ATM, therefore, fixed the packet size, providing an advantage to applications requiring continuous steams of data, such as video. In the 1980s the International Telecommunications Union-Telecommunications Services Sector (ITU-T) adopted ATM as the technology of the future. ATM became the first worldwide standard that was accepted by the computer, communications, and entertainment industries.

3.3.4.1. How It Works

ATM divides data into fixed-sized cells, each 53 bytes in length. Each cell contains a 5-byte header and a payload field of 48 bytes. The header information allows each cell to be transferred via the network devices in a “start-stop,” or asynchronous, manner. The payload, or amount of information in each ATM cell, is quite a bit smaller than other protocols.

The size of the payload field was a compromise in order to meet a wide variety of user needs. While larger blocks are more efficient for large amounts of data, other applications such as voice and video prefer small amounts of data, which are faster and more efficient to transmit. In order to make ATM the best service for supporting a wide range of data, the smaller 48-byte payload eventually prevailed.

3.3.4.2. Performance

By using small fixed-length cells, ATM offers faster transmission speeds than traditional packet switching technologies. By allocating bandwidth on demand, ATM satisfies many types of applications simultaneously. ATM currently provides speeds of up to 622 Mbps, with a backbone of up to 2.5 Gbps. Early plans for ATM would have allowed even faster transmission in the future; however, the fervor over ATM has decreased in recent years as other technologies have made substantial increases in speed while reducing costs.

3.3.5. SONET

Synchronous Optical Network (SONET) is an optical interface standard. SONET was one of the first protocols developed to allow complete vendor interoperability. Unlike the previous protocols that can run on either copper or fiber, SONET runs on fiber only. The complete SONET standard defines an optical line rate, a frame format, and an Operations, Administration, Maintenance, and Provisioning (OAM&P) protocol. The development of SONET began in the early 1980s, and the first standard was issued by the American National Standards Institute (ANSI) in 1988. The main goal of SONET was to create a standard for manufacturers to build fiber optic hardware and ensure operability with other fiber optic equipment. This also allowed some of the first users of the protocol, such as telephone companies, the opportunity to construct multivendor networks without being forced to use a single vendor.

3.3.5.1. How It Works

SONET works by converting electrical signals to optical signals that are then sent via the fiber. SONET networks also convert the signal back to electrical when they leave the SONET portion of the network. SONET breaks transmissions up into 810-byte frames. As with other protocols, these frames are made up of data as well as other overhead information used by the network.

One piece of overhead information included in the SONET frames is a pointer that indicates where the data begin. This is necessary due to the way SONET sends frames. Frames are sent at a steady rate of 8000 per second, even if they contain absolutely no information. This method can lead to data starting in the middle of a frame. The pointer ensures that the receiver of the information knows where the data begin.

3.3.5.2. Performance

One of the items SONET defines is the optical line rate, known as the Optical Carrier (OC) signal. The base rate, OC-1, is defined at 51.84 Mbps. Higher OC rates are multiples of the base rate and range up to 39.812 Gbps, or OC-768. SONET provides the highest network speeds, although not every OC rate is widely used. Most North American implementations use the same rates available in European installations for compatibility. The European version of SONET standards is known as Synchronous Digital Hierarchy (SDH).

Most SONET networks are constructed using the concept of ring topology and use multiple fibers for redundancy. This redundancy ensures that in the event one of the fibers suffers a major problem, at least one other fiber is still available to the network. Ring and other types of network topologies will be discussed in a later section.

3.3.6. Transmission Control Protocol/Internet Protocol (TCP/IP)

TCP/IP is a low-level networking protocol used by computers and other hardware to communicate across networks. In reality, TCP and IP are two separate protocols that are part of a large number of Internet protocols. TCP/IP has, however, become known to the industry to stand for the family of common Internet protocols. The protocols stem from a Defense Advanced Research Projects Agency (DARPA) project dealing with the interconnection of networks in the late 1970s. By 1983 it was mandated for all U.S. defense long-haul networks. Over time, TCP/IP became accepted throughout the world and is now an internationally known and supported protocol.

3.3.6.1. How It Works

The IP of TCP/IP works as the “messenger” part of the protocol – its functions are to address and send data packets. The IP protocol contains three pieces of information: the IP address, subnet mask, and default gateway. The IP address, which is the identity of each node on the network, is 4 bytes long, each separated by a dot. It contains two pieces of information, the node’s network ID and the system’s host ID. The subnet mask, also 4 bytes separated by dots, is used to extract the network and host ID from the IP address. The default gateway is the entrance point to the nodes network.

The TCP in TCP/IP is a reliable connection-oriented protocol. TCP is a connection-oriented protocol, meaning that it establishes a communications pathway or connection between two devices before sending data. Once the connection is established, TCP begins sending data, broken into chunks of information (called packets) across the network to the intended recipient. TCP numbers each packet as it is sent so that the receiving end knows the correct order in which to reassemble them as they are received. TCP also verifies that the data are correctly received. This is done using a "checksum" calculation on both the sending and receiving ends. If the calculation is the same on both ends then an acknowledge response is sent to the sender, verifying that the data were properly received by the intended target. If the results do not match, a request to resend is sent by the recipient and the sender resends the necessary data.

3.3.6.2. Performance

TCP/IP is the most complete networking protocol available. Because of this it has also become almost universally accepted and can be utilized in virtually any networking environment.

In addition protocol support, the source code is available on many operating systems. This has made it much easier over time to extend the suite of protocols. In addition to the software source code, virtually every piece of network software produced has TCP/IP support. TCP/IP packets are actually "encapsulated" or surrounded by the network protocol in use, such as Ethernet, Frame Relay, ATM, etc. Because TCP/IP is universal, it can be used to provide functionality and communications across disparate networks.

3.3.7. Ethernet

Ethernet began as a Local Area Network (LAN) standard used to connect computers, printers, and workstations within a small area, usually a building or campus. Ethernet runs on Layer 2 of the OSI model, providing services at the DataLink layer. Other protocols, such as TCP/IP, run on top of Ethernet, adding features enhance the overall performance and capabilities.

The first Ethernet network was designed and built in 1973 by Bob Metcalfe, who was with the Xerox Corporation. From these modest beginnings and low speeds, Ethernet has evolved to handle the most demanding applications with increasing scalability, reliability, and cost-effectiveness. Today, Ethernet networks can be 10 Mbps, 100 Mbps, 1000 Mbps (1 Gbps), or 10,000 Mbps (10 Gbps) in bandwidth.

3.3.7.1. How It Works

Historically, Ethernet networks used coaxial copper cable as the medium to transfer data. As technology has improved, Ethernet networks have migrated to twisted pair and fiber optic cabling. Each device on the network is connected to the communications medium and has a unique Ethernet address.

As with other protocols, the Ethernet protocol is a set of rules on how to construct frames, or small packets of information. Each frame is required to have a source and destination address. When a frame is sent via the medium, each node on the medium sees that frame. If a node sees a frame that is not intended for it, the frame is simply ignored, but if a node receives a frame that has its Ethernet address as the destination address, it reads the frame. While this is the same basic task done by other protocols, Ethernet accomplishes it in different ways, with different sized payloads of data, and with different performance characteristics.

The Ethernet protocol also has a broadcast feature. Some information is meant to be seen by every device on the network. When information is addressed as a broadcast, the protocol replicates it to every device on the network.

Communications using the Ethernet protocol are regulated using a technique known as Carrier-Sense Multiple Access with Collision Detection (CSMA/CD). This algorithm ensures that data are transmitted in an Ethernet network as smoothly as possible.

When a node on the network sends a frame it listens a specified amount of time for a collision. If it hears a collision, it assumes it was the cause of the collision and that it must retransmit its information. The node then waits a dynamically random amount of time to attempt to transmit again and the process is repeated. Chapter 4 discusses the design of Ethernet and highlights some specific situations with regard to Ethernet collisions.

3.3.7.2. Performance

Ethernet networks can be 10, 100, or 1000 Mbps (1 Gbps) in bandwidth. These theoretical limits are often not obtained in actual implementation. When Ethernet networks become congested, and collisions increase, they run at lower bandwidth than their theoretical limit. This can be resolved by adding intelligent devices to the network design to reduce congestion and increase performance.

When properly equipped and configured, Ethernet performance can approach theoretical limits.

3.4. Other Protocols

In addition to the major protocols listed above, modern communications utilize other protocols that provide additional specialized services. Typically, these specialized protocols run on top of the protocols described above. For example, World Wide Web (WWW) applications use HTTP. It is not possible to use HTTP alone – HTTP also requires a base-level protocol such as TCP/IP in order to provide the basic transfer capabilities. HTTP provides specialized functionality to either improve information transfer or to improve the existing transfer capability.

Awareness of these protocols is important for ITS deployments, as they are commonly used by equipment manufacturers to transmit information and control equipment in networks. The following list identifies some of the most common protocols and the functionality they provide:

- HTTP – Hypertext Transfer Protocol – HTTP defines how to format and transmit messages and what actions web servers and browsers should perform.
- FTP – File Transfer Protocol – FTP defines how to transfer files over the Internet.
- SOAP – Simple Object Access Protocol – a messaging protocol based on the eXtensible Markup Language (XML) that is used to encode information into a format known as a web service.
- SNMP – Simple Network Management Protocol – a set of protocols used to remotely manage networks and devices.
- NTP – Network Time Protocol – a protocol used to ensure accurate synchronization of clock times in a network of computers and devices.
- SMTP – Simple Mail Transfer Protocol – a protocol for sending electronic mail messages between servers.

3.4.1. National Transportation Communications for ITS Protocol (NTCIP)

NTCIP is a family of standards for transportation systems.

NTCIP is a family of standards that was created to address the communications needs of both current and next-generation transportation systems. NTCIP contains both protocols and objects. We have already defined protocols as the sets of rules for communicating information between devices, or the “how” of information transfer. Objects are the vocabulary, or the “what” in information transfer. NTCIP defines both the protocols and the language that is transmitted between devices. This vocabulary allows equipment from different manufacturers to exchange information in a standardized format and with known definitions. The terms of objects in the vocabulary are rigidly defined and supported across multiple vendors.

NTCIP is a first for the transportation industry, as it allows systems to be built with devices from multiple manufacturers with complete interoperability. A benefit of NTCIP is the promise to reduce reliance on a specific vendor and customized one-of-a-kind software solutions. 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).

As seen in Figure 3-2, NTCIP is closely related to the OSI model explained previously. NTCIP is implemented in five levels. The first level, the Plant level, is merely a reference layer. NTCIP does not prescribe any specific media that must be used for communications.

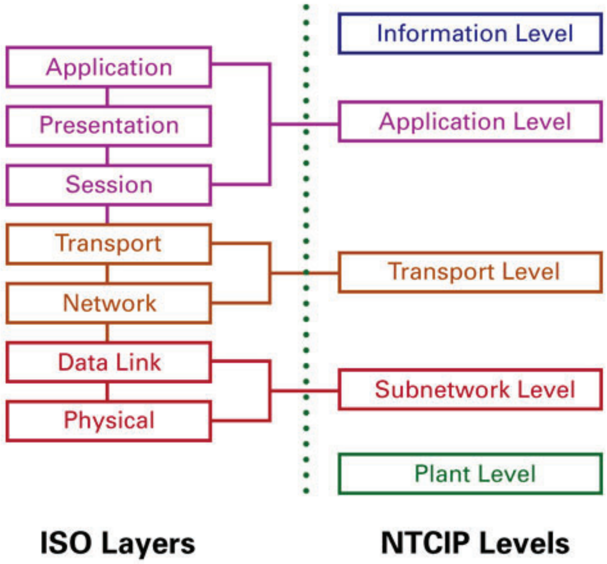


Figure 3-2. NTCIP Mapping to OSI Layers.

In the NTCIP framework, the Subnetwork layer maps to the DataLink and Physical layers of the OSI model. This layer governs the transfer of information between two adjacent devices on a communications link.

In contrast, the Transport level governs the transfer of information between two devices that are not adjacent. This level incorporates the functions of the OSI model that provides information routing between points A and B across a network and through devices which may lie in between. The Application level of the NTCIP model maps to several layers in the OSI model. This level takes information that was transported from another location and utilizes it internal to a device or software application.

Finally, the Information level of Figure 3-2 provides the dictionary or vocabulary functions of the NTCIP model. There is no equivalent mapping to the OSI model.

It is critical to note that NTCIP utilizes a host of other protocols to accomplish its goal of equipment interoperability. In fact, as seen in Figure 3-3, many of the protocols under discussion in the earlier parts of this chapter are utilized within NTCIP at the Subnetwork and Transport levels for information transfer. In addition, many of the specialized protocols discussed in Section 3.4 are utilized at the Application level to provide specific functionality.

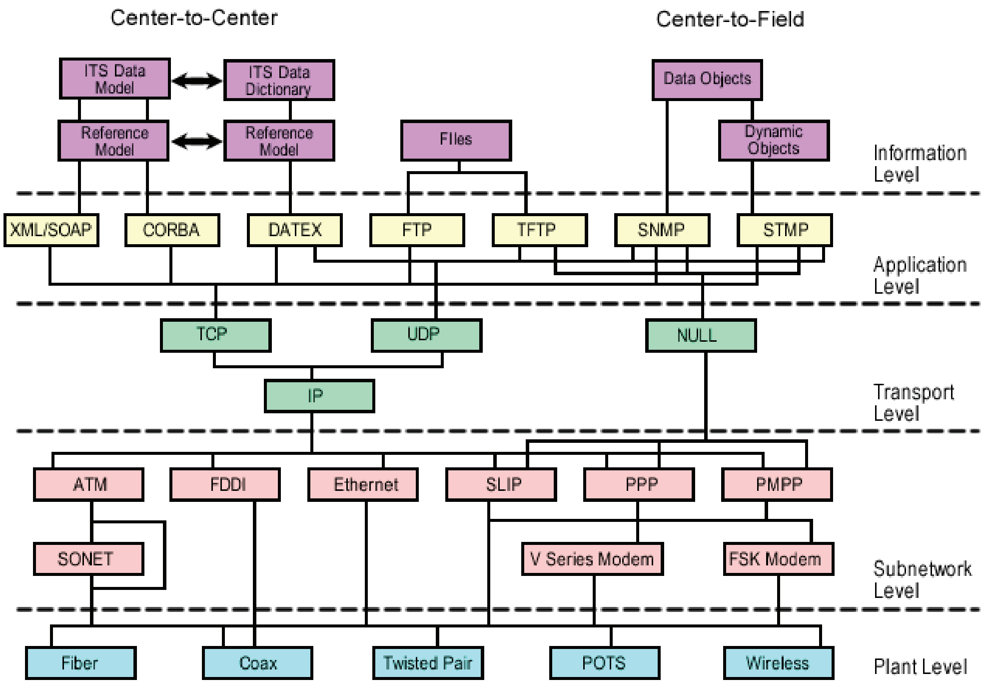


Figure 3-3. Protocols Utilized by NTCIP.

3.5. Topologies

3.5.1. What Is a Topology?

There is a limited number of ways to create a network: Point-to-Point, Ring, Star, Bus, or Hybrid.

The word topology refers to the arrangement of computers or devices inside a network. Topologies can be either physical or logical. A physical topology describes the actual location and connections at various devices. In contrast, a logical topology is the way that data passes through a network from device to device without concern for how they are physically connected or where they are located.

In practice, there is a limited number of topologies, which will be briefly described in the sections below.

3.5.2. Point-to-Point Topology

Point-to-point topology can be thought of in two ways. First, it is the simplest form of direct connection between two devices or computers. In reality, at this level of connection, there is no true networking involved. Rather, the two devices communicate across the shared communication line to exchange information.

Point-to-point topology is also used in many types of Internet dial-up. Under this scenario, point-to-point is a logical topology as opposed to a physical topology. Figure 3-4 illustrates point-to-point topology.

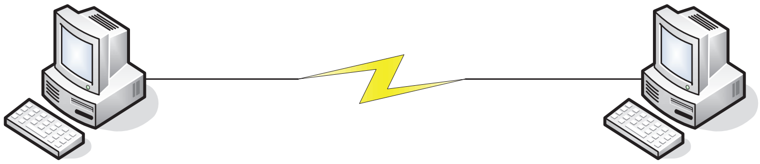


Figure 3-4. Point-to-Point Topology.

3.5.3. Star Topology

In a star topology every node in the network is connected to a central device, such as a server or switch. The central device acts as a managing station, controlling the links between the different nodes in the network. Figure 3-5 shows the typical configuration of network with star topology.

A major benefit of the star topology is that a problem in any single node does not affect the entire network. Also, it is easy to add and remove nodes from the network configuration. If, however, the central device fails, the entire network goes down along with it.

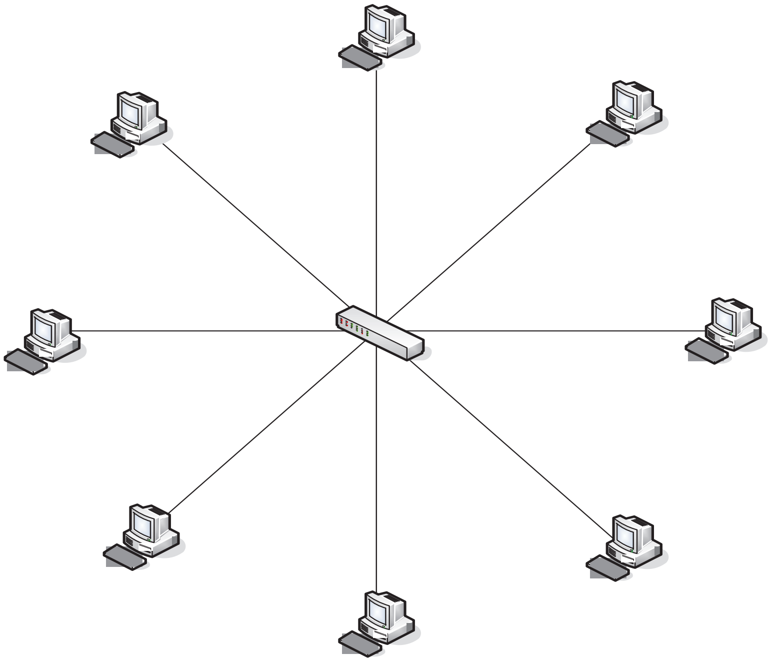


Figure 3-5. Star Topology.

3.5.4. Ring Topology

In a ring topology, every device is connected within a loop system. When data are sent into the ring they pass from one node to the next, along one direction of the ring, until they reach the desired destination. Each node acts as a repeater and forwards messages intended for other nodes in the network to the next node. Each node does the same. A typical ring topology is shown in Figure 3-6.

The design of a ring topology has both advantages and disadvantages. A main advantage is that because each node acts as a repeater, a network using this topology is able to span longer distances than other topologies. However, as the ring fills with nodes, the performance of the network slows because the data must travel through every node in the path to get to the destination. In early ring designs, the loss of one node could bring the entire network down because they were built using coaxial cable, which ran from device to device.

In today's networks, most rings quickly recover should one node go offline. This is because most current rings are logical, not physical. Today's ring networks are physically no different than the star configuration. Most modern ring technologies actually utilize several rings, keeping each area small and fast while transferring data between rings at strategic locations.

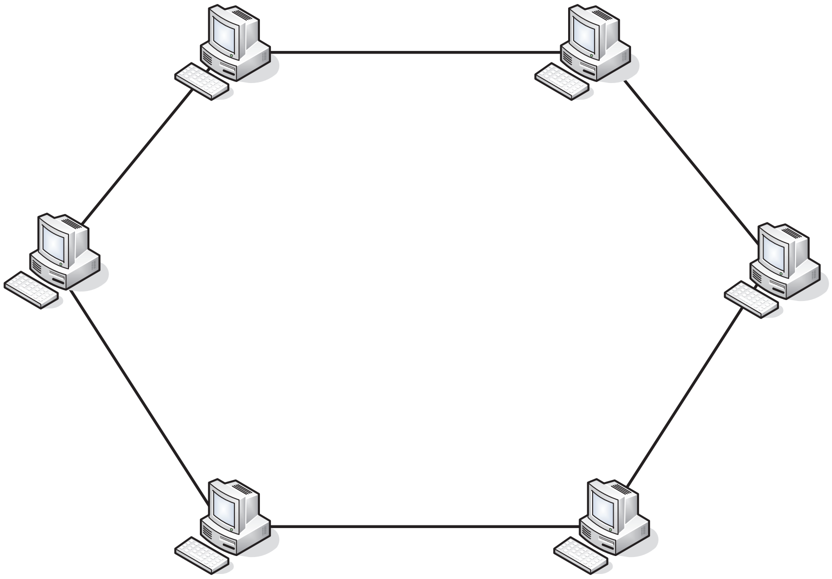


Figure 3-6. Ring Topology.

3.5.5. Bus Topology

Figure 3-7 shows a typical bus topology, where all nodes connect on a single line. This line terminates on each end. In a bus topology, at any given time, one node is the "master" and is allowed to send data. Until this machine is finished sending, no other node can send data, it must listen.

To help manage this exchange of data, some rules are needed to help resolve situations when multiple machines try to send simultaneously. For example, Ethernet uses decentralized control. Each node is allowed to send whenever it has data to send. When two packets collide along the network, the sending nodes simply wait a random amount of time and attempt to send again.

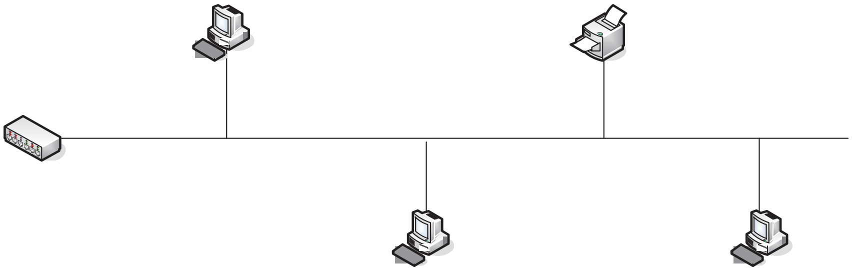


Figure 3-7. Bus Topology.

3.5.6. Hybrid Topology

A hybrid network topology is a mixture of multiple topologies. Figure 3-8, for example, shows a star-bus mix. In this figure, a single bus, called the backbone, may connect a series of smaller star configured subnetworks. This backbone is usually a high-bandwidth connection, where the smaller subnetworks are slower speed connections.

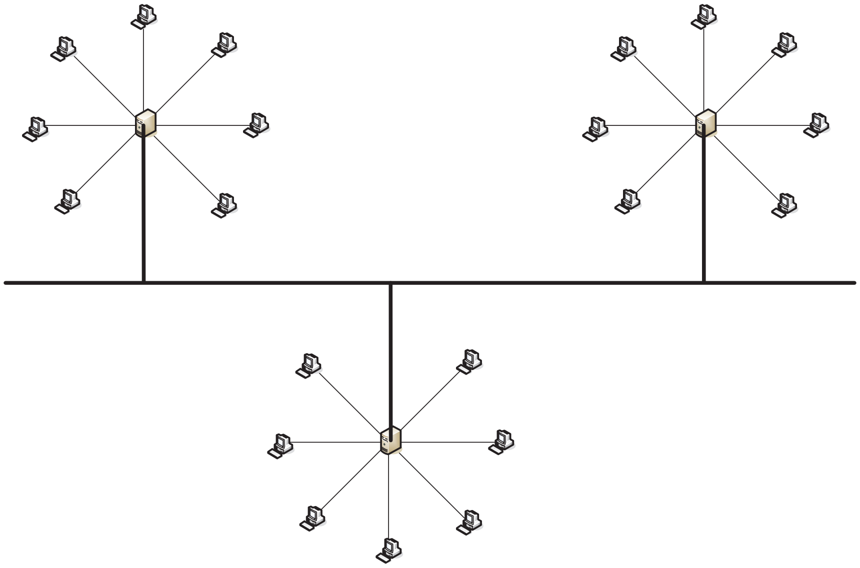


Figure 3-8. Hybrid Topology.

3.5.7. Modern Networks

Modern networks typically utilize a variety of topologies in order to create robust communications systems. In many cases, devices are connected to provide multiple paths to devices. This provides redundancy in case of failures along one part of the network. As shown in Figure 3-9, in many spots, the network may look like a mesh or grid, with each network device being connected to at least two other network devices.

As discussed in the next section, network devices such as hubs, switches, and routers form the backbone of modern networks, mange the flow of information, and create capable and efficient networks.

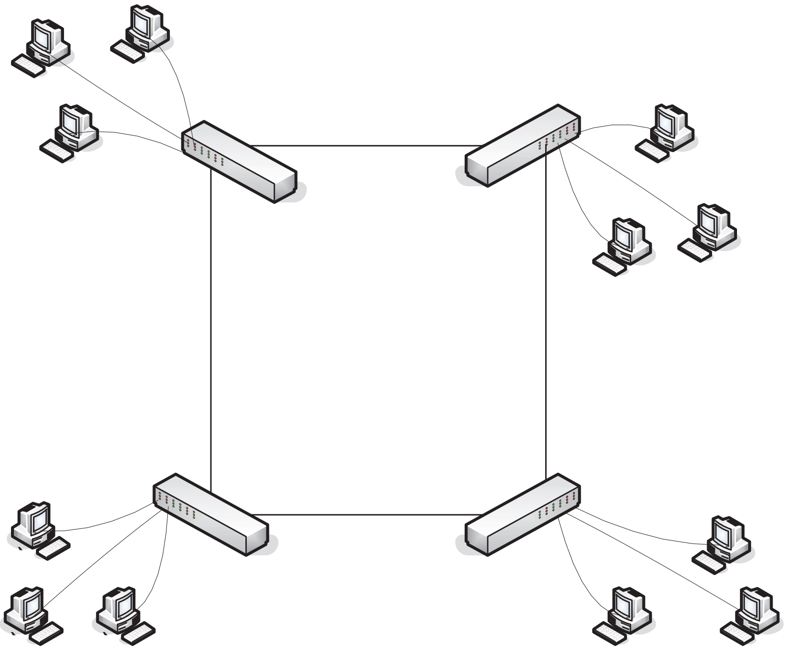


Figure 3-9. Example of a Modern Network.

3.6. Typical Communications Equipment

A modern communications network can comprise hundreds of devices and span large areas. Through special techniques, devices located in different states or even different continents can be on the same network. While this guidebook is not a detailed course on equipment, several items of network infrastructure should be common knowledge. Figure 3-10 shows an illustration of these items.

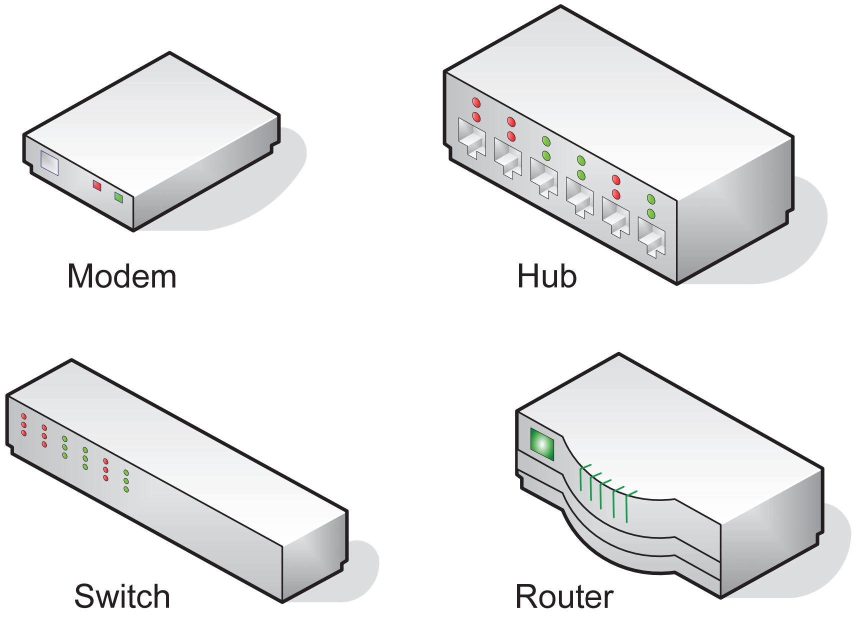


Figure 3-10. Typical Networking Equipment.

3.6.1. Modem

A modem is a device that transmits and receives information over a communications line. When using dial-up services, or DSL, the media is twisted pair. When using cable technologies, the media is coaxial cable.

A modem, which stands for modulator-demodulator, is really a converter. It converts signals from digital to analog and analog to digital so they can be passed between the device and the communications wire. Although there are different speeds and capabilities, modems have long been standardized for interoperability. A typical modem for a computer costs between $20 and $40. A typical modem for cable or DSL costs between $50 and $100.

3.6.2. Hub

A hub is a simple piece of network equipment that connects various devices to a network. These connections are established at points on the hub called ports. A port is simply a two-way street for information. Information can flow into the hub from the device or it can flow into the device from the hub.

Hubs are a building block for networks and are independent of the specific protocols in use. It should be noted that, typically, hubs are not intelligent devices. The most common form of operation for a hub is to distribute information to all ports. There is no effort to identify which port should receive which particular piece of information. The hub acts like a megaphone, announcing everything to anyone that is connected.

A hub can come in many different sizes, based on the number of ports it has. For home use, a hub with four ports can be purchased for as little as $20. For commercial use, larger hubs can have 12, 24, or even 48 ports, with pricing that varies depending on the configuration.

3.6.3. Switch

Perhaps the easiest way to think of a switch is that it is an intelligent hub. Whereas a hub broadcasts everything to everyone, a switch figures out where (specific port) the information should go and sends it directly to that port. A switch is like a courier service, dispatching couriers constantly to specific destinations.

The advantage of the switch is that it is more intelligent and sends information only where it is needed, potentially increasing the speed and efficiency of the network. The disadvantage is that this intelligence costs money, making switches more expensive than hubs. However, switches for home use can now be purchased for as little as $30. Prices for commercial applications vary, depending on the level of intelligence and the number of ports. Commercial switches with 12 ports can typically be purchased for $500 to $1500. As with hubs, switches come in many different port sizes and capabilities.

3.6.4. Router

The final piece of equipment illustrated in Figure 3-10 is a router. Like a switch, a router sends and receives information only to those destinations that need it; however, instead of connecting individual devices, a router typically connects networks.

To continue the analogy of the courier services from the discussion of a switch, a router actually owns and manages two or more courier companies. It must therefore examine every item of information and decide which company (network) should receive the information and then send it down the right wire. The switches in each network then look at the information and decide which device should receive the courier.

Routers can be very expensive items to purchase. Routers can cost anywhere from a few thousand dollars to tens or even hundreds of thousands of dollars. The difference, of course, is the level of capabilities and the speed of each router. Speed is a critical consideration in choosing the right router for a network or application. Routers must understand the protocols in use on the network and therefore may be specific to a particular type of network. Some routers are expandable so that multiple protocols can be supported and routed through one device.

3.6.5. Pricing Information for Communications Equipment

The price points listed in the above sections are typical pricing for communications equipment that is specifically designed and built for the ITS/outdoor environment. This environment typically has substantial physical performance requirements related to withstanding heat and condensation. In addition, the price points for the equipment discussed above are representative of high-performance commercial communication environments that are designed to operate on a 24 hour per day, 7 day per week (24x7) basis.

While it is recognized that many pieces of equipment bearing the same name can be purchased at local electronics store for considerably less money, the reader is cautioned that the performance level and reliability of these items are substantially different for both the physical and operating characteristics.

3.7. Addressing

An important facet of network communications is addressing. Information or data sent into a network is typically addressed to a particular location. With the exception of hubs, which simply repeat everything they hear, network devices examine the destination addressing of the data to ensure timely and efficient delivery.

Multiple addressing schemes can be employed, depending on protocol Perhaps the most common addressing scheme is the one employed with TCP/IP. In this addressing methodology, each device is assigned what is known as an IP address. A typical address may look something like 128.146.223.65. Each section of the address, separated by a period, represents a hierarchy of networks, and therefore the flow of information. Using this IP addressing methodology, a computer in California can communicate with a computer in New Hampshire even though they are not physically connected and are not on the same network.

Although it is beyond the scope of this guidebook to discuss the details of addressing schemes, the reader should be aware of the concept of addressing. Additionally, the reader should be aware that addressing is used to move information around a network and that sending data to a particular destination address is more efficient than simply broadcasting everything to everyone.

3.8. Architectures

One of the concepts commonly used in ITS projects is that of architecture. Architecture is different than topology, which simply describes the arrangement of devices in the network. Architecture is more abstract, focusing on the relationship of all the components that comprise the ITS solution.

A familiar implementation of an architecture is the National ITS architecture. This architecture provides a framework for planning, defining, and integrating Intelligent Transportation Systems. The National ITS architecture utilizes a great many terms to explain the relation of the many different aspects of ITS solutions. Some of the more important terms are:

- Functions – tasks that need to be completed, such as gather vehicle data.
- Physical entities – major areas of the architecture, such as vehicles and centers.
- Subsystems – individual components of the architecture, such as emergency management or toll collection.

- Information flow – a defined path of information exchange between various subsystems, such as road network conditions or transit system data.
- Data flow – a detailed description of a path of information exchange.

Figure 3-11 illustrates the physical entity view of the National ITS architecture. This figure has been referred to as the sausage diagram and is often viewed as the figure that best represents the concepts of the architecture. The National ITS architecture was developed over a period of several years. Because of its complexity, it takes some time to understand all the facets of the architecture.

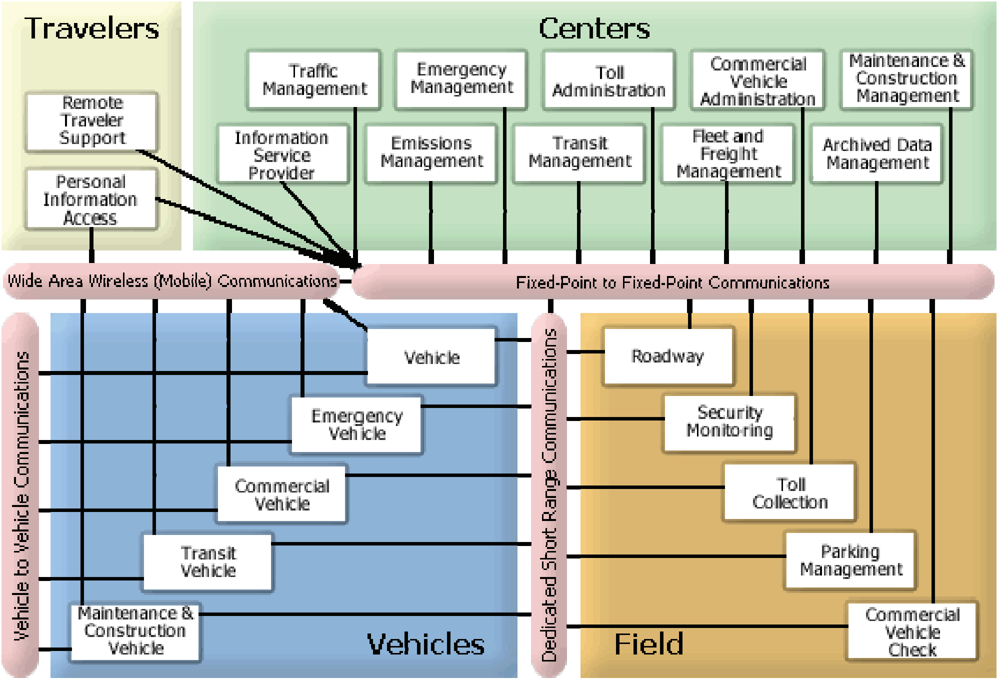


Figure 3-11. National ITS Architecture. (Source: Reference 1)

Of course, architectures can be much more specific and focused than the national level. Many states have statewide or regional architectures that utilize the same concepts but cover a smaller geographic area. Typically, there are also project-level architectures that illustrate only the data flows and subsystems that will be used to construct a particular solution.

3.9. Special Topics

Within the design and construction of modern communication systems, there are many specialized areas. To continue the overview, a few of these areas are detailed below. These topics represent only a small number of the total topics, but they are commonly used in today's ITS networks.

3.9.1. Spanning Tree

Spanning Tree Protocol (STP) is a link management protocol. Any network may offer multiple paths for connections between multiple stations. This essentially causes loops in the physical media connecting stations. When loops are present, data in the network can become stuck by continually traversing the loops. This greatly increases the amount of traffic on the network and slows down performance.

STP was designed to help alleviate this problem. STP creates a view of the entire network, keeping track of all paths between stations. If multiple paths occur, STP activates one path and puts the rest in a standby, or blocked state, removing all possible loops. Typically, the STP algorithm uses the concept of minimum time delay to choose the best route, which it keeps active. If the active path should go down, one of the standby paths becomes active, preventing prolonged downtime between stations.

3.9.2. Tunneling

Tunneling is a technology that enables a network to temporarily send data using a separate, second network. Tunneling works by having the packets from the first network encapsulated into packets used by the second network. This allows smaller networks to share larger pipes, or bandwidth, providing a cost-effective means of extending networks over long distances.

Tunneling also allows secure transmissions to be made over inherently insecure networks. One typical method of tunneling is known as Virtual Private Networks (VPN). VPN allows users to send information using the Internet, which is an insecure network, to their corporate network in a secure and private manner. There are many different tunneling protocols, but they all provide the same basic services.

3.9.3. Environmentally Hardened Equipment

A great deal of equipment utilized in ITS solutions resides in outdoor cabinets, where it is typically exposed to extreme conditions of both temperature and humidity. Cabinets are not cooled and represent a very harsh environment for electronic equipment. NEMA has long had specifications for equipment that must reside in outside cabinets. For example, the environmental requirements for a traffic signal controller include specifications for:

- voltage,
- frequency,
- temperature,
- humidity,
- vibration, and
- shock.

In addition, the specification details the exact methods of testing devices for compliance with the requirements and what is considered pass/fail conditions.

Although specifications do not currently exist for networking or communications equipment that must reside in the same environment, many manufacturers now produce, test, and support equipment for use in these harsh environments. Of particular concern is the ability to survive in a temperature range of –34°C (–30°F) to +74°C (+165°F) with a humidity specification not to exceed 95 percent noncondensing over the range of +4.4°C (+40°F) to +43.3°C (+110°F).

Before purchasing communications equipment for outdoor use, check the manufacturer's specifications to ensure that it can survive in a harsh environment. One rule of thumb is that if a piece of equipment was not designed and manufactured for harsh environments, it *will* eventually fail. Another rule of thumb is that generally equipment manufacturers will not honor warranties if the equipment is used in conditions that exceed their specifications.

3.9.4. Security

The provision of network security is a topic for a book unto itself. Suffice to say that in today's communications environment, security is an issue that cannot be ignored. Security can be achieved through a multifaceted approach that includes but is not limited to:

- physical access,
- device security,
- network design, and
- data encapsulation.

The security implications of networks used for ITS communications should be considered in the overall evaluation.

Security is often a trade-off with trust. Trust can be thought of as providing open access to data or programs. Trust is necessary for applications to run, but completely open access can expose a network to attacks from the outside or even misuse from the inside.

With some of the technology choices that will be discussed in the next chapter, the network will be owned and maintained by other agencies, such as the telephone or cable company. In these situations, there are typically limitations to how much security can be implemented on the network itself. Security is accomplished more from the device and physical access methods.

In other solutions, your agency may own, operate, and maintain the entire network, providing greater opportunities for a more comprehensive security solution.

Many large-scale installations or projects utilize some type of security monitoring. This can be done through periodic manual checks of critical systems or via software that automatically runs scans and alerts operators of vulnerabilities.

3.10. Video

Video is a critical component of many transportation systems. Typically, video is produced at a location, such as a spot along a highway or an intersection, and then transported to a remote location for viewing. This is the basic principle behind all of the traffic management centers in operation today. Among other purposes, video can be useful for monitoring critical areas of roadways, monitoring operations at intersections, verifying incidents, and for security considerations.

In order to move video from one location to another, the information must be transmitted from one location to another. In reality, there are several steps in this process.

- color representation – the process of representing each individual piece of a picture (video) with color information;
- video encoding – the process of reducing the amount of space necessary for transmitting video information; and
- video transmission – the process of moving video information from one location to another.

At the other end of the transmission, the process must be reversed to reassemble the video for display. Figure 3-12 illustrates the process of transmitting video from a field location to the traffic management center. Each of the steps in the process is described below.

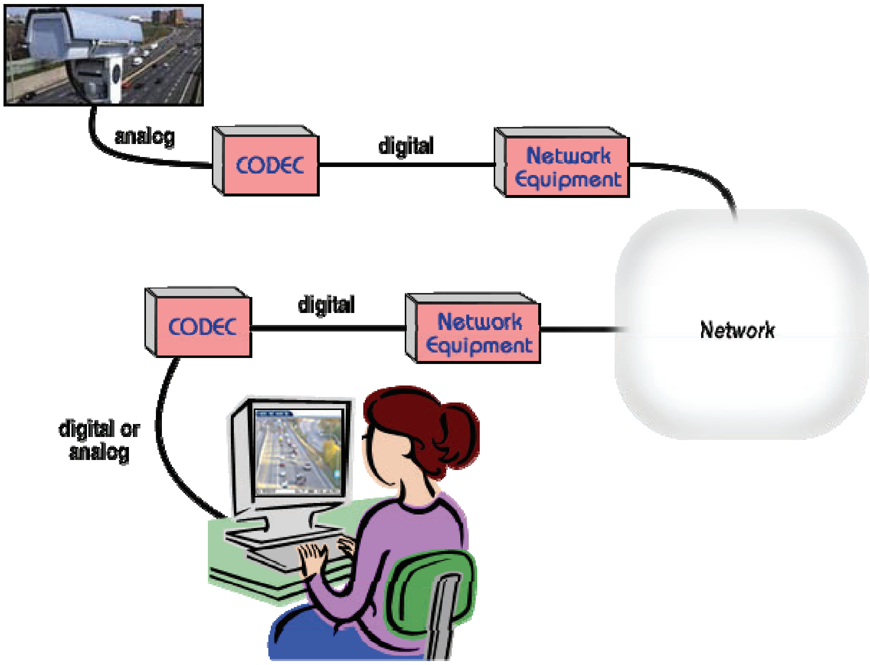


Figure 3-12. Video Encoding and Transmission.

3.10.1. Color Representation

The science behind how to represent video is fairly complicated, and multiple techniques have been developed. All methods use some combination of color and brightness information to achieve a unique representation of a particular portion of a video image, typically called an element. This representation is repeated for each individual element in the picture. The larger the number of elements that represent the picture, the more detailed the representation of the image.

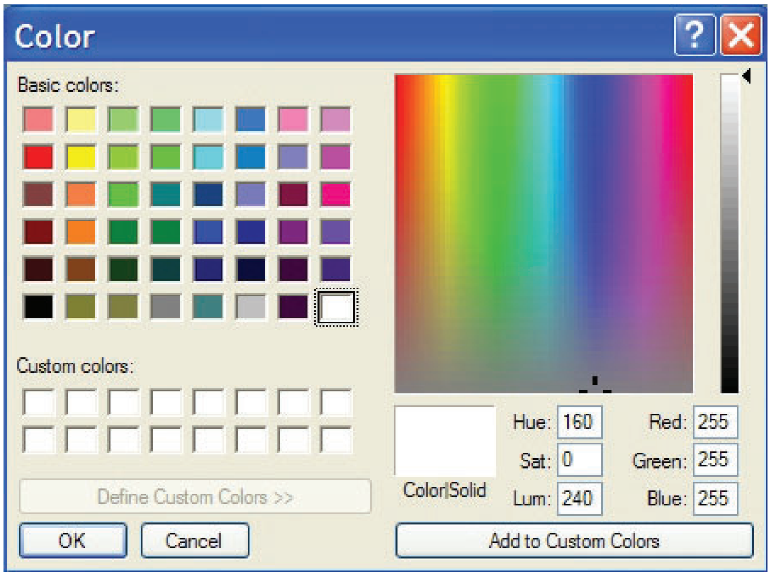
One standard format of representing color information is to use a combination of three colors. Figure 3-13 shows how multiple colors can be achieved by using overlays of red, green, and blue (RGB). The simultaneous overlay of all three colors produces the color white, as shown in the middle of the figure.

Figure 3-13. Color Representation of Video Signals.
(Source: Reference 10)

This method of color representation utilizes the intensity of each color on a scale of 0 to 1. For example, full-intensity red is represented as 1.0, 0, 0, where the 1.0 represents the intensity of red, the first 0 represents the intensity of green, and the second 0 represents the intensity of blue. Full intensity of all three colors, or 1.0, 1.0, 1.0 is white. Zero intensity of all three colors, or 0, 0, 0 is black.

In computer applications, programmers store the intensity of each color as one byte of information. Recall that one byte has 256 discrete values (2^8), ranging from 0 to 255. In computer applications, white would then be represented as 255, 255, 255, while black would be 0, 0, 0. This method lends itself very well to a digital environment.

Figure 3-14 shows a typical method of representing color in a computer application. Most Windows™ based applications utilize this color model, although some photo editing and graphics applications have the ability to utilize multiple color representations.



Hue: 160
Sat: 0
Lum: 240
Red: 255
Green: 255
Blue: 255

Figure 3-14. Typical Representation of Color in Computer Applications.

Although RGB is a common method of representing color information, in the digital world, many other methods of representing color exist, such as YUV. In YUV (and related variants) three components make up the signal information, as below.

- Y – brightness (luminance),
- U – color information, and
- V – color information.

YUV is thought to portray the human perception of color more closely than the RGB model. Variants of YUV exist for both the analog and digital worlds.

While it is good background knowledge to understand how color information is represented, the end device (i.e., a camera) usually handles the details internally and presents the end user with a simple cable connection for receiving the video.

3.10.2. Video Encoding

As previously discussed, there are two types of signals in the world, analog and digital. The typical video application in the ITS arena, cameras on the roadway, are predominantly analog in nature. Analog video can be provided in one of three forms, including:

- composite – also known as National Television Systems Committee (NTSC);

- S-video – a signal type which carries the brightness and color components of the signal on separate wires; and
- component – the use of two or more separate signals, such as red, green, and blue to provide color information.

The largest installed base is cameras that provide a composite signal on a single wire, such as a coaxial cable as seen in Chapter 2. Digital video cameras, while available, do not have a prevalent installed base as of the writing of this guidebook.

Video can be transmitted between the field and traffic management center using either analog or digital formats. An analog video typically looks the best, but each video stream takes an enormous amount of information and therefore bandwidth. Analog transmission of video is often done on dedicated fiber connections, one per camera, because of the bandwidth requirements.

By comparison, digital transmissions can take much less bandwidth because of the encoding (also known as compression) techniques utilized to reduce the amount of information that is necessary to recreate the picture.

Video encoding is the process of altering a video signal in some manner. Video encoding is used, for example, to stream live video over the Internet. The original video signal is much too large for this to be possible. A video encoding algorithm can make the video stream much smaller, and it can then be sent and viewed at other locations. Once the encoded stream reaches its destination(s) it must be decoded, returning it to its original format. Encoding and decoding the video introduces some level of quality loss to the signal depending on the algorithm used.

There are several popular methods of converting analog video streams to digital data packets for distribution over computer networks. Four of the most common are listed below:

- Motion JPEG (Joint Photographic Experts Group),
- MPEG-1 (Moving Pictures Experts Group),
- MPEG-2, and
- MPEG-4.

3.10.2.1. Motion JPEG

In motion JPEG, still images are compressed into smaller sizes using the JPEG compression method. This method removes color change information from a still picture that the human eye normally cannot see. This trimming of nonuseful information allows storage of the still picture using fewer bytes than the original image. Motion JPEG takes advantage of these compression savings by encoding individual video frames into JPEG frames and then sending the sequence of JPEG frames as a video stream.

The advantage of Motion JPEG is that it requires the least amount of equipment complexity to encode and decode. Therefore, Motion JPEG equipment tends to cost less than other types of video encoding equipment.

The disadvantage of Motion JPEG is that it does not compress video as well as the other MPEG routines and it requires the most bandwidth to transmit a video stream.

3.10.2.2. MPEG-1

MPEG-1 takes the compression savings provided by Motion JPEG a step further by introducing compression techniques that eliminate redundant picture information between adjacent frames in a video sequence.

The advantage of MPEG-1 is that it is well established as a standard. More products can decode and use an MPEG-1 stream than any other standard mentioned here.

The disadvantage is that MPEG-1 does not have a large variety of options compared to other MPEG standards. Additionally, because MPEG-1 is designed to compress progressive-scan video, interlaced television signals are difficult to compress using MPEG-1. It does not easily encode higher quality video streams such as HDTV.

3.10.2.3. MPEG-2

MPEG-2 inherited the benefits of Motion JPEG and MPEG-1, but went further to correct the functional limitations of MPEG-1.

The advantage of MPEG-2 is that it is scalable and allows better picture quality than MPEG-1. It supports interlaced video encoding by design. It is used in many applications including digital video disks (DVDs), HDTV, satellite television distribution, and personal video recorders such as TiVo®.

The disadvantage of MPEG-2 video streams is that they require more central processing unit (CPU) power to decompress than MPEG-1. When encoding video at lower resolutions, the MPEG-2 standard has little advantage over MPEG-1.

3.10.2.4. MPEG-4

MPEG-4 is the newest standard, and commercial products that use it are just now populating the market. MPEG-4 is designed to deliver close to MPEG-2 quality video at lower data rates yet use smaller file sizes. Where previous MPEG development was aimed at television and HDTV encoding, MPEG-4 was developed in response to industry demands to deliver quality video streams over a variety of devices ranging from bandwidth-limited cell phones to broadband video providers.

The main advantage of MPEG-4 is that it was designed to handle low-bandwidth video. If a network suffers from bandwidth limitation, more parallel MPEG-4 streams can be placed on that network than other MPEG methods.

The current disadvantage of MPEG-4 is that fewer products support MPEG-4 than MPEG-2 or MPEG-1. Additionally, MPEG-4 encoders and decoders are more expensive because of their relative newness in the market. These disadvantages will likely disappear over time. Another disadvantage inherent in the standard is that MPEG-4 video stream decompression is slower because of the techniques in the standard. This could lead to latency in the video stream compared to the other MPEG methods.

Table 3-1 provides an overview of the typical digital video encoding standards in use as of the writing of this guidebook.

Table 3-1. Overview of Major Digital Video Encoding Standards. (Compiled from References 2 - 6)

Standard	Minimum Specifications	Characteristics	Bandwidth Range
MJPEG	352 × 240 pixels @ 30 frames per second.	Least amount of equipment complexity to encode and decode	1 Mbit/s to 29 Mbit/s
MPEG-1	352 × 240 pixels @ 30 frames per second. Includes 8 Kbit/s audio.	Improves upon MJPEG by eliminating redundant picture information	1.5 Mbit/s to 4 Mbit/s
MPEG-2	352 × 240 pixels @ 30 frames per second. Includes 8 Kbit/s audio.	Improved and expanded MPEG-1 standard	1 Mbit/s to 1 Gbit/s
MPEG-4	144 × 176 pixels @ 30 frames per second. Includes 6 Kbit/s audio.	Newest standard on the market, close to MPEG-2 quality but less bandwidth consumption	5 Kbit/s to 1 Gbit/s

The equipment used to encode or compress video is called a codec, which stands for COmpression-DECcompression. Codecs can be purchased for any encoding standard. Codecs are typically purchased as either an encoder or a decoder. An encoder resides in the field, compressing video information from the camera using a standard such as in Table 3-1 and delivering it to the transmission mechanism. A decoder resides at the traffic management center, receiving the transmitted information and assembling it back into a video image for display.

It is important to note that the use of encoding standards and codec equipment is typically not a situation where there is complete interoperability between vendors. A codec from Vendor A will typically not interoperate with a codec from Vendor B, even though they may both utilize the same encoding standard, such as MPEG-4. While the level of interoperability is improving, it is by no means common, and readers are urged to consider purchasing decisions carefully to ensure the maximum possible level of video interoperability. This is an especially important consideration if video is to be shared among multiple agencies. As of the writing of this guidebook, it is a critical design decision that the agencies employ the same brand or vendor of video codecs for maximum interoperability and video sharing.

3.10.3. Video Transmission

Previous sections of this chapter introduced the concept of protocols as a standardized method of breaking information up into discrete units that can be sent along a transmission media. Protocols are used to transport all types of information, including video.

By far, the most common protocol in use for transporting video information digitally is TCP/IP. In large part, this is due to the universal acceptance of the protocol and the fact that it can function across disparate networks.

There are two important mechanisms for transmitting video via TCP/IP. The first is known as unicasting, while the second is known as multicasting. Each has distinct advantages and disadvantages, as outlined below.

3.10.3.1. Unicasting

The principal aspect of unicasting video transmission is that it represents a one-to-one scenario. In this arrangement, an encoder in the field sends a video stream to only one other location, a decoder, located somewhere else. Another name for this arrangement is point-to-point. While a system can have more encoders in the field than decoders in the management center, each encoder can send to only one decoder at a time. This distinction is critical when designing a video system that needs to be shared between multiple locations or agencies. Using a unicast video scenario, Agency A can not simultaneously receive the same video as Agency B.

Figure 3-15 shows an illustration of a unicast video system. The video image from each encoder is transmitted through the network and can be received by a maximum of one decoder. Note that it is not necessary that all video streams be received simultaneously. Decoders can be switched between the video streams that are available in the field, which may decrease the equipment costs at the management center.

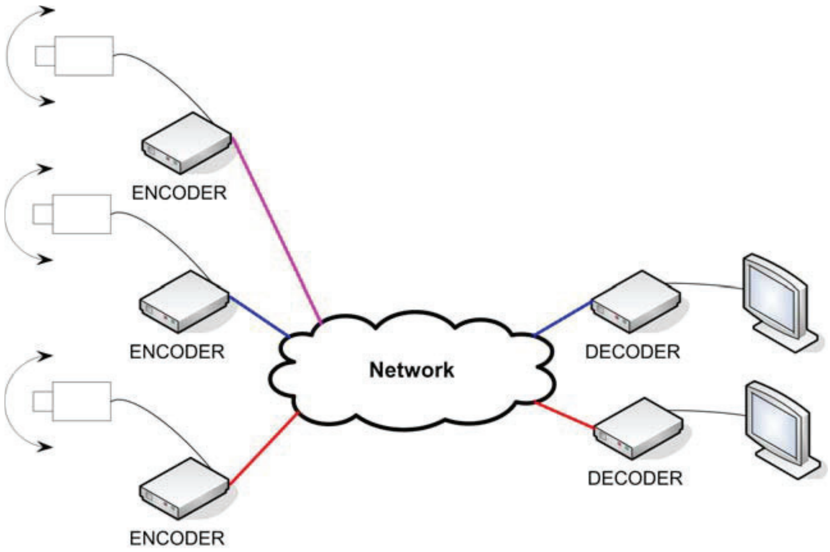


Figure 3-15. Example of a Unicast Video System.

A work-around for the limitation of this point-to-point setup is the use of multiple encoders at the same location. Typically, video from a camera source is split and fed into multiple encoders at the field site. Each encoder has a one-to-one connection with a decoder at a different agency. If five agencies wished to receive the video simultaneously, five encoders would be needed in the field.

The tremendous disadvantage to this system is the cost. While encoders continue to drop in price, having multiple encoders at each location can be a substantial cost component for system implementation. A second disadvantage to this system is the increased bandwidth that is necessary to field sites. In the scenario above, 5× the bandwidth would be required, which can also have a substantial impact on the cost of any system implementation.

One technique used to get around bandwidth limitations is to put a single encoder at each field location, transmit all video back to a central location, then retransmit the video from that central location. This relocates the heavy bandwidth need to the office location, where it is typically more feasible to provide it. The disadvantage to this setup is that the delivery of video to other agencies is then delayed, as multiple encoding and decoding operations must take place. Depending on the level of codec equipment and the encoding format in use, this delay could be several seconds.

3.10.3.2. Multicasting

Multicasting is a completely different scenario than unicasting. The principle is perhaps best illustrated in Figure 3-16, which

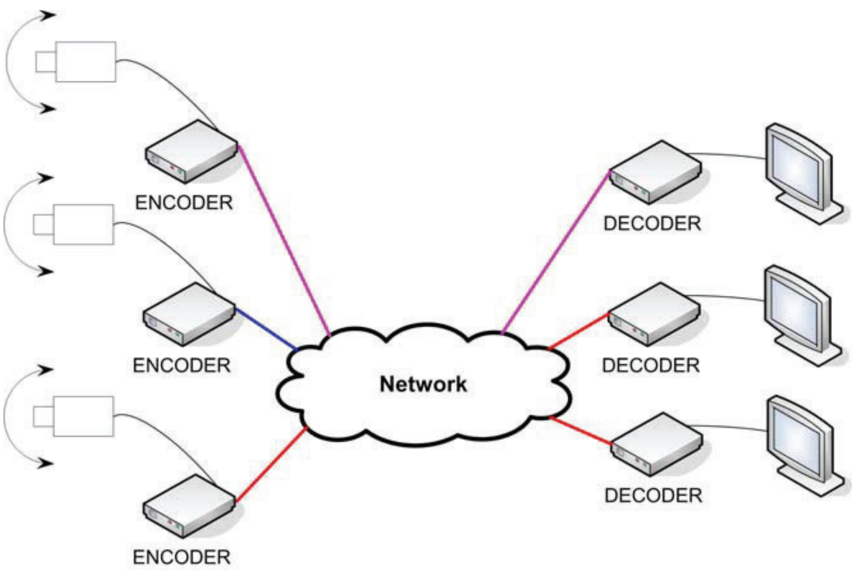


Figure 3-16. Example of a Multicast Video System.

shows a one-to-many or point-to-multipoint arrangement. Multicast is advantageous from the standpoint that multiple decoders can simultaneously receive a single encoder source. This makes an ideal video transmission system for a multiagency operation.

The disadvantage to multicast is that the design of the transmission network is more complex and requires additional expertise that may not be common. Also, vendor support of multicast operations, while increasing, is not yet universal. Significant cost savings can be realized from the perspective of equipment purchases, but agencies must be willing to invest in the design and operation of the network to provide the level of operations required for multicast video systems.

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4. TECHNOLOGY CHOICES

4.1. Introduction

Chapter 2 of this guidebook illustrated some basic concepts concerning communications and introduced the types of wiring used in today's communications systems. Chapter 3 introduced the concepts of protocols and provided an overview of the major protocols employed in ITS solutions. The chapter also illustrated some basic network design concepts and highlighted some special topics that warrant additional consideration in the ITS arena.

Chapter 4 brings these separate concepts together. In reality, the choice of a protocol and, in some cases, a type of wiring, results in a technology choice. Understanding and learning about these technology choices is the sole focus of the following information.

For each technology choice, a brief history is presented as well as a listing of the capabilities and considerations for use. When available, typical cost information is provided, as well as a listing of the protocols that can be used in conjunction with the technology.

4.2. Serial Communication (RS-232, RS-422, RS-485)

4.2.1. Introduction

Serial communication provides a dedicated low-speed data connection between two places. The connection can take place on a single pair of wires and has been the standard of device communications for decades.

4.2.2. History

Serial communication was developed in the 1960s to connect communications equipment. The original protocol, RS-232, provided a mechanism to use electrical signals to transmit data between devices. In addition to the data transfer rules, the protocol also specified an interface. The original interface was a 25-pin connector, in which 22 pins were utilized for various functions. Two pins were reserved for testing, and 1 pin was reserved for future expansion.

Over time, the protocol has been extended and updated. Additional interfaces have been defined that have dropped or eliminated many of the specialty functions of the protocol. The most common interface is now a 9-pin connector. In reality, however, raw serial communication only needs three wires: transmit, receive, and ground.

In addition to the other interfaces for RS-232, additional serial protocols have been created to address some of the limitations of the RS-232 protocol. The other serial protocols commonly used in transportation are RS-422 and RS-485.

4.2.3. Capabilities

RS-232 is suited for short distances in environments with low noise or interference. The type of noise to consider is electrical noise. By standards, RS-232 communications are only supported up to 100 feet.

RS-422 was developed for much longer distances than RS-232. The standard supports distances up to 4000 feet. The signaling mechanism of the standard was also changed to provide higher immunity from electrical interference. The increased distance and noninterference capabilities of RS-422 make it an ideal platform for supporting low-speed data communications in an ITS environment. One of the most common applications of RS-422 is for pan, tilt, and zoom (PTZ) camera control. The RS-422 communication takes place between the receiver, typically located in a cabinet or enclosure, and the actual camera pedestal or base, which is typically mounted on a pole at an intersection or along a highway.

RS-485 is an extension of the RS-422 standard. The main addition is multidrop capabilities. Multidrop allows more than one device to be connected to the same communications link, although typically only one device can transmit at any given time.

Table 4-1 lists the advantages and disadvantages of the most common types of serial communications used in ITS applications.

Table 4-1. Pros and Cons of Typical Types of Serial Communications.

Protocol	Pros	Cons
RS-232	Low cost Widely supported	Very short distances (<100 ft) Prone to interference
RS-422	Less prone to interference Longer distances (up to 4000 ft)	May require additional isolation
RS-485	Less prone to interference Longer distances (up to 4000 ft) Multidrop capability	May require additional isolation

4.2.4. Typical Deployment

A serial connection can be established in many ways. Figure 4-1 illustrates two possible methods. In the first, a master device communicates with multiple field devices, each on an individual serial connection. This is the common connection utilized for RS-232 or RS-422 communications.

In the second illustration in Figure 4-1, the master device communicates with multiple devices across a multidrop connection. This utilizes a single communications link, as would be deployed for RS-485 communications. Both situations are suitable only for short distances, as highlighted in Table 4-1.

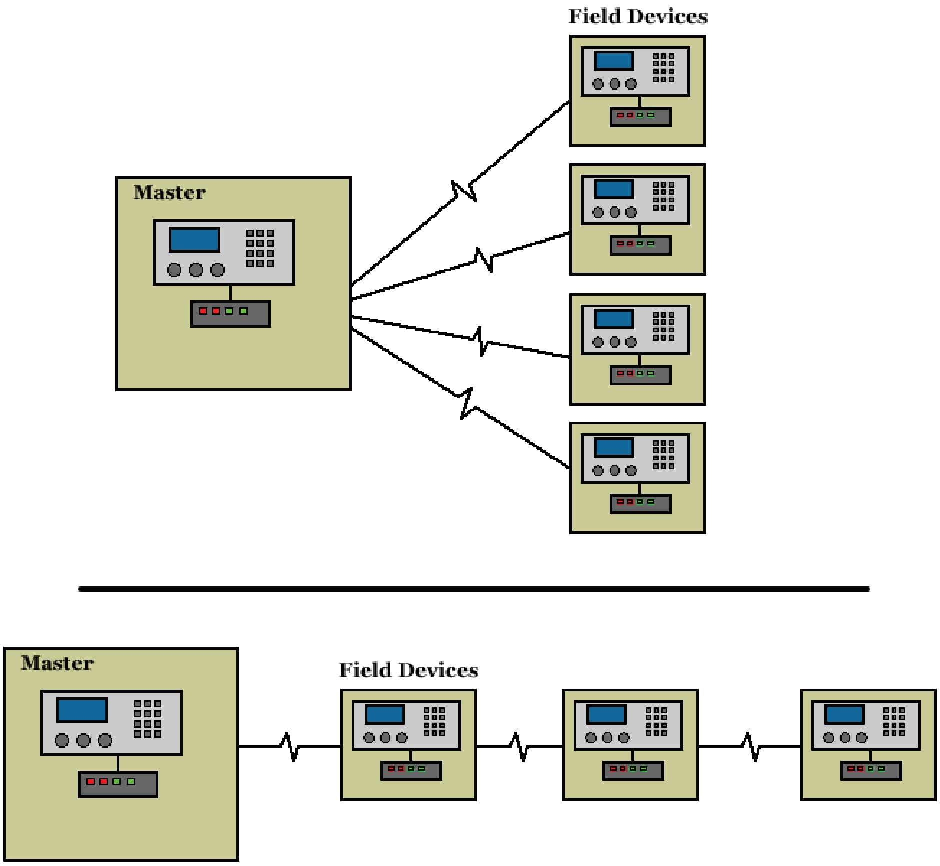

Figure 4-1. Typical Serial Connections.

4.2.5. Considerations for Serial Solutions

As with any technology, there are numerous items to keep in mind when using serial communications for ITS deployments. The list below identifies several of these items.

- Cabling requires at least three wires (transmit/receive/ground).
- Category 5 or above cabling usually is an excellent choice.
- RS-232 is only suitable for short distances (<100 ft).
- RS-422/RS-485 is suitable for longer distances (up to 4000 ft).
- Multidrop operations are best suited for an RS-485 system.
- All serial communications are prone to some level of ground (electrical) interference.
- Serial communications are typically installed and maintained by the operating agency.
- Serial communications links can be allocated from a larger leased line communications system.

4.2.6. Cost

In essence, there are no operating costs for serial connections. These are typically short-run solutions installed by the agency that will utilize them. They are typically not purchased services.

4.2.7. Supported Protocols

Chapter 3 of the guidebook introduced the concept of protocols. Many technologies can support multiple protocols. The list below identifies what protocols run on serial communications.

- RS-232
- RS-422
- RS-485

4.3. Plain Old Telephone Service (POTS)

4.3.1. Introduction

POTS is the standard telephone service that has been around for decades. POTS can carry both analog and digital signals. Although the technologies for carrying calls over long distances have changed, little has changed for what is known as the “last mile,” which is the final connection between the central office and a home or business. This last mile connection is almost always analog. A typical telephone connection uses a single twisted pair.

4.3.2. History

In many ways, the mechanics of telephone service have remained the same for more than 100 years, although there has been a rich history of invention and continued innovation. Invented by Alexander Graham Bell in 1876 and put into commercial use in 1878, the telephone revolutionized communications. By 1885, long-distance calls were made possible by operators making connections at switchboards. Automatic switchboards were invented in 1891, and by 1924, the first commercial fax transmission had taken place, sending photographs of political conventions to hometown newspapers for printing.

What has changed dramatically over the years in the telephone industry has been the operating environment. At the beginning of the telephone era, nearly 2000 telephone companies existed. Monopoly power and lawsuits eventually put them out of business. Then deregulation changed the operating environment of the industry again. Today, the operating environment of the telephone system is a complex arena of partnerships, shared lines, competition, regulated access, and more. However, to the end-users and, most often, even to engineers using the telephone as a solution for a communications need, this complexity is all behind the scenes.

Telephone lines have long been used to carry data in addition to voice. Indeed, the first connected computer systems used phone lines with private protocols. Because the bandwidth of the telephone system is geared to carry voice conversations, there are limitations on how much data can be carried on a single phone line. Although telephone lines can carry up to 64 Kbps of information, they are typically limited to 56 Kbps. In addition, the federal agency responsible for oversight of the industry has limited data communications to 53 Kbps. The true advantage to phone line data transmission is that it is not a distance-sensitive technology.

When used for data communications, telephone lines require a modem, a device that translates the digital information to an analog format for transmission over the line. At the other end, the modem works in reverse, translating the analog signal to digital.

4.3.3. Capabilities

Because of limitations on the amount of information that can be transmitted, POTS is mainly suitable for low-bandwidth applications. The speed of the modem is the primary factor in how fast information can be transferred. Table 4-2 lists the upload and download speeds that can be achieved across a phone line with typical modems.

Table 4-2. Modem Operating Limitations.

Standard Modem Speeds (Kbps)	Download		Upload	
	Max (Kbps)	Nominal (Kbps)	Max (Kbps)	Nominal (Kbps)
28.8	28.8	28	28.8	28
33.6	33.6	33	33.6	31
56	53	43	33.6	31

In practice, the bandwidths in Table 4-2 mean that for data applications, a phone line can accomplish many of the typical ITS data transfer needs. For example, a dynamic message sign (DMS) message is typically around 1000 bytes, or 1 Kb. That transmission can easily be handled by a phone line.

However, video applications are not well suited for transmission across phone lines. Because the amount of information that has to be transferred in video applications is far larger than data applications, most phone line solutions can only handle, at best, 1–2 frames of video per second. In reality, a more typical expectation would be 1–2 seconds per frame. The exact capabilities vary widely depending on the size of the video, the encoding mechanism, and the quality of the phone line.

4.3.4. Typical Deployment

A phone line connection can be used in two ways. As shown in Figure 4-2, two phone lines can call each other and establish a direct connection. The figure shows a field device establishing a direct connection to the traffic management center (TMC). This requires a phone line and a modem at either end. Typically, there are no connection time charges for this connection unless the two locations are in different area codes. The advantages of this type of configuration are:

- The connection can be active all the time.
- There are minimal security issues with a direct connection.
- This is the lowest cost situation.

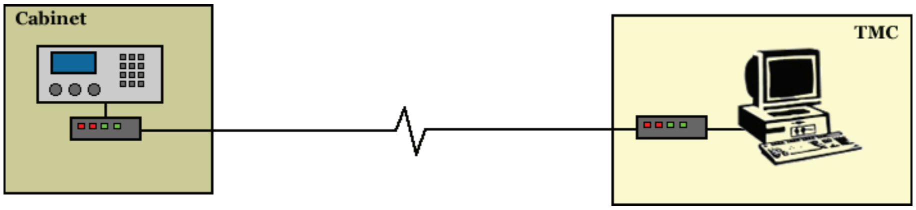

Figure 4-2. Typical Phone Line Direct Connection.

Figure 4-3 shows another model of connectivity that can be used for phone lines. The figure shows a field device establishing an Internet connection and communicating across the Internet to the TMC, which also has an established Internet connection. At a minimum, this requires a phone line and a modem at either end as well as the capability to establish an Internet connection with an Internet Service Provider (ISP).

One advantage of the Internet model of connectivity is that the TMC can have a different (higher speed) connectivity solution than the field. While the two locations are still exchanging information, they are doing so through the 'cloud' of the Internet and via the ISP. It is not a direct connection. An additional advantage of this second configuration is an increased connectivity capability at the field site. One phone line with an Internet connection can serve as a communications gateway for several devices. The Internet model, however, has additional monthly fees for connectivity. There is the potential for security concerns with the Internet model, as it is not a direct, and therefore controlled, connection.

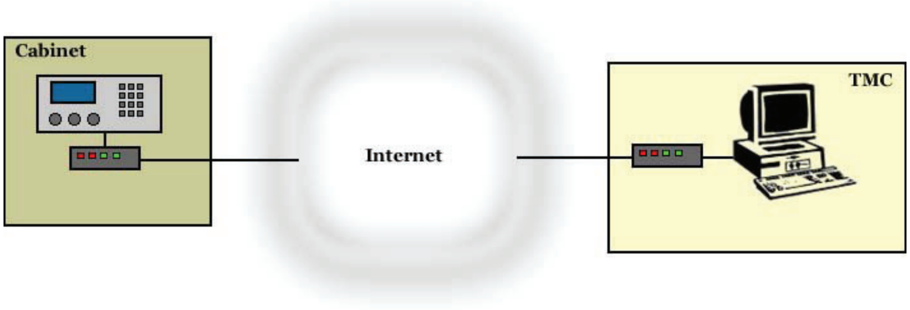

Figure 4-3. Typical Phone Line Internet Connection.

4.3.5. Considerations for Phone Line Solutions

As with any technology, there are numerous items to keep in mind when using POTS for ITS solutions. The list below identifies several of these items.

- Requires a standard phone line.
- Requires a phone line connection at both sending and receiving end.
- Requires a modem for data communications.
- There is typically a 15 to 30 second connect time.
- ITS deployments utilizing phone lines can be point-to-point or connect via an ISP for full Internet connectivity.
- Phone lines are typically not an "always on" connection, although special arrangements and pricing can typically be made for this capability.
- Most connections made through an ISP will time out if no data are being transmitted or received.
- Modem and other powered devices require an external power source.
- Phone connections are fairly reliable, although highly dependent on the quality of the phone service.
- Data connections are almost always available anywhere a phone line is available.
- Phone and data communications over phone lines do not have distance limitations.
- Phone lines are fairly resistant to interference from other local equipment.
- POTS is repaired and maintained by the phone company.

4.3.6. Cost

Typical costs for phone line connections are listed below. Remember that charges apply to both ends.

- Approximately $20 per month for the connection from the local phone company.
- An additional $10 per month for a dial-up connection to an ISP if using Internet connectivity.
- Typical cost for a modem, depending on brand and speed, is $50 to $75.

Data transfer across phone lines may be established without an ISP by calling the modem on the other end and establishing a direct connection.

4.3.7. Supported Protocols

Chapter 3 of the guidebook introduced the concept of protocols. Many technologies can support multiple protocols. The list below identifies what protocols run on POTS.

- IP for direct connect to Internet through an ISP.
- TCP for direct point-to-point communication.

4.4. Integrated Services Digital Network (ISDN)

4.4.1. Introduction

Another technology that runs on a standard phone line is ISDN. The "integrated" part of ISDN refers to the ability to combine voice and data services over the same phone wire. Although the physical cabling is the same as that for POTS, the infrastructure that supports it at either end and at the phone company is substantially different. The main advantage of ISDN is that it is an all-digital system. This increases the available bandwidth because there is no analog conversion process.

4.4.2. History

The early phone system was a largely manual system of interconnected wires. Over time, packet switching protocols were employed to create a much more efficient, capable, and cost-efficient core infrastructure. However, the last mile never saw the same level of improvement as the core.

In the early 1980s, the International Telephone and Telegraph Consultative Committee (CCITT) made recommendations for improvements to many aspects of the phone system. These recommendations included the initial guidelines for ISDN. The service was initially envisioned as a business solution for creating high-speed connections between corporate networks. Prior to this time, many networks were connected using POTS. As network traffic increased in both volume and size, the analog modem became a serious bottleneck to network traffic. The all-digital ISDN service was designed to be purchased at any data rate desired.

Although forward looking, in practice, ISDN never truly succeeded for a number of reasons. Local telephone systems were slow to implement ISDN. One reason for that delay was attributed to the manufacturers of phone equipment, which created different implementations of the CCITT standards. This required compatible equipment across the entire system, which could be tricky if more than one telephone company was involved. Another problem related to the telephone companies' delay in agreeing on standards was a delay in minimizing the knowledge the end-user needed in order to purchase and set up the right equipment.

Combined with the troublesome nature of the service, the above problems resulted in a service that never really became a force in the marketplace. Today, at least in the home computer networking market, ISDN service has largely been displaced by broadband Internet services, such as DSL and cable modem. However, ISDN has its place as a backup to dedicated lines and in locations where broadband service is not yet available. Many ITS deployments utilize ISDN as a technology for transporting video from remote sites. The technology is not capable of providing sufficient bandwidth to provide full-motion high-quality video.

4.4.3. Capabilities

An ISDN connection transmits digital information on a single telephone twisted pair. The connection provides a raw data rate of 144 Kbps. To better suit its use for voice applications, the 144-Kbps channel is generally partitioned into three channels. Two of the channels are 64 Kbps and are labeled B, for *bearer*. The third channel is 16 Kbps and is labeled D, for *data*.

Generally, the D-channel is unavailable for an end-user to transmit data. This channel is used for administrative and call control data that the phone companies transmit; however, each B-channel can carry a separate telephone call and usually has its own telephone number. Through a process called bonding, the two B-channels can be merged together to form a single 128-Kbps channel for end-user use.

There are two types of ISDN:

Basic Rate Interface (BRI) – BRI is the basic ISDN configuration as described above, with two B-channels at a rate of 64 Kbps and one D-channel at a rate of 16 Kbps, which carries call-control information.

Primary Rate Interface (PRI) – PRI is a type of ISDN service designed for larger organizations. PRI includes 23 B-channels and one D-channel.

Table 4-3 summarizes the different configurations available in ISDN as well as the total bandwidth available. One item to note is that unlike a phone line, where only certain speeds are allowed and/or typically achieved, there are no such limitations on ISDN, so the maximum and expected or nominal bandwidths are the same. The reason the maximum bandwidth can be obtained on ISDN is because the D-channel handles the negotiations and overhead.

Table 4-3. ISDN Parameters.

ISDN Type	Data Configuration	Download		Upload	
		Max	Nominal	Max	Nominal
BRI	64 Kbps × 2 B-channels = 128 Kbps total	128 Kbps	128 Kbps	128 Kbps	128 Kbps
PRI	64 Kbps × 23 B-channels = 1.544 Mbps total	1.544 Mbps	1.544 Mbps	1.544 Mbps	1.544 Mbps

4.4.4. Typical Deployment

An ISDN connection can be used in two ways. As shown in Figure 4-4, two ISDN locations can call each other and establish a direct connection. The figure shows a field device establishing a direct connection to the TMC. This requires an ISDN line and modem at either end. Typically, there would be no connection time charges for this connection, unless the two locations are in different area codes. The advantages of this type of configuration are:

- The connection can be active all the time.
- There are minimal security issues with a direct connection.
- This is the lowest cost situation.

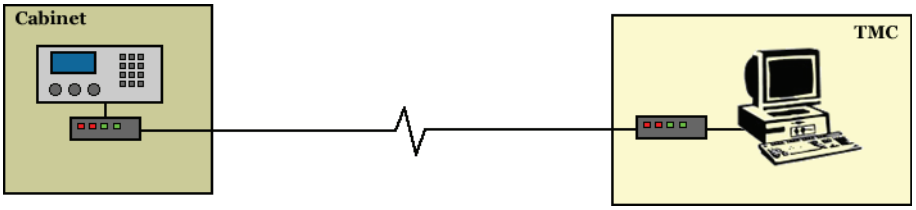

Figure 4-4. Typical ISDN Direct Connection.

Figure 4-5 shows another model of connectivity that can be used for ISDN lines. The figure shows a field device establishing an Internet connection and communicating across the Internet to the TMC, which also has an established Internet connection. At minimum, this requires an ISDN line and a modem at either end as well as the capability for establishing an Internet connection with an ISP.

One advantage of the Internet model of connectivity is that the TMC can have a different (higher speed) connectivity solution than the field. While the two locations are still exchanging information, they are doing so through the ‘cloud’ of the Internet and via the ISP. It is not a direct connection.

An additional advantage of this second configuration is an increased connectivity capability at the field site. One ISDN line with an Internet connection can serve as a communications gateway for several devices. The Internet model, however, comes with additional monthly fees for the connectivity. There is also the potential for security concerns with the Internet model, as it is not a direct, and therefore controlled, connection. Finally, bonding the two ISDN lines together to form a single higher speed connection is only possible using the Internet type of configuration.

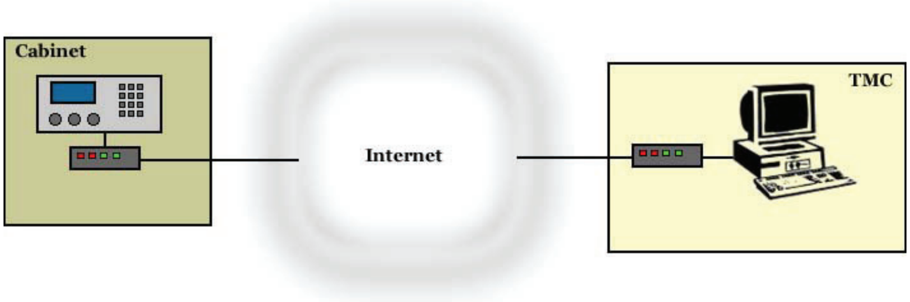

Figure 4-5. Typical ISDN Internet Connection.

4.4.5. Considerations for ISDN Solutions

As with any technology, there are numerous items to keep in mind when using ISDN for ITS solutions. The list below identifies several of these items.

- ISDN lines with BRI configuration require a standard phone line.
- ISDN lines with PRI configuration require two or more pairs, depending on the specific equipment used.
- ISDN capabilities are not available everywhere.
- Availability depends on the central office location and the existing phone network.
- ISDN may need to have line conditioners installed on the phone line to condition the line (increase quality and decrease noise).
- ISDN is distance limited to approximately 18,000 feet from the central office.
- An ISDN BRI connection is not an “always on” connection.

- ISDN connection/startup times are very quick compared to analog modems – 3 second connect time.
- ISDN connections with ISP will eventually time out if no data are being transmitted or received.
- The 144-Kbps channel is partitioned into subchannels: two 64-Kbps B (for *bearer*) channels and one 16-Kbps D (for *data*) channel.
- Each B-channel can carry a separate telephone call and usually has its own telephone number.
- Bonding is the process of combining the two 64-Kbit channels to form one 128-Kbps channel for upload and download.
- The B-channels carry customer voice or data signals.
- The D-channel carries signals between local ISDN equipment and the phone company's central office.
- ISDN is different than an analog modem connection as the upload and download speeds can run at or near the maximum line speed rating.
- ISDN is resistant to interference from other local equipment.
- ISDN is more difficult for the phone company to maintain or set up than an analog modem connection.
- ISDN connections require modems and terminal adapters.
- Most modern ISDN modems have a terminal adaptor built in.
- ISDN connections can be used between networks for data communications.

4.4.6. Costs

Typical costs for ISDN connections are listed below. Remember that charges apply to both ends.

- Approximately $20 a month for a BRI connection ($10 for each 64-Kbps line).
- Telephone company BRI connection is approximately $60 per month.
- BRI connections require a modem on either end (approximately $100).
- Approximately $595 to $1000 a month for a PRI ISDN connection.
- PRI cost can vary greatly depending on the distance from the central office.
- PRI typically needs a router as well as a terminal adaptor.

4.4.7. Supported Protocols

Chapter 3 of the guidebook introduced the concept of protocols. Many technologies can support multiple protocols. The list below identifies what protocols run on standard ISDN.

- IP for direct connect to Internet through an ISP.
- TCP for direct point-to-point communication.

4.5. Digital Subscriber Line (DSL)

4.5.1. Introduction

DSL is a technology for bringing high-bandwidth capabilities to homes and small businesses over ordinary copper telephone lines. Numerous implementations of DSL provide different upload and download speeds. Collectively, these technologies are referred to as xDSL.

4.5.2. History

DSL is an outgrowth of ISDN. Whereas ISDN transmits both voice and data on the phone network, DSL was designed for transmitting data only. Although DSL uses the same phone lines (copper twisted pair cabling), the encoding of the data is very different than ISDN. This different encoding scheme causes less interference, allows more efficient data transfers, and reduces the cost of equipment. These advances were made in the 1980s.

In the 1990s and beyond, DSL was continually innovated. In particular, market offerings or products developed had multiple speeds of DSL. While some were symmetric, meaning that the upload and download speeds were the same, others were asymmetric, meaning that the speeds of the upload and download links were not the same. Many of the asymmetric products were aimed at a home-user or small office situation, where the theory was that most of the information flow would be coming into the home or office, not flowing out.

DSL installation began in 1998 and will continue at a greatly increased pace through the next decade in a number of communities in the United States and elsewhere. DSL has been well received in the home computer networking environment and has been utilized in many ITS deployments in favor of ISDN.

4.5.3. Capabilities

There are many different types of DSL service, with the main difference being speed. Like ISDN, xDSL services are distance limited. Table 4-4 lists the most common types of DSL implementations, the associated speeds, and distance limitations. A main advantage of xDSL over ISDN is that the connection is always on and there are no dial-up connections to establish and maintain. Additionally, DSL service is typically easier to configure and install.

Table 4-4. Rates for Various DSL Technologies.

DSL Type	Data Rate		Distance Limit	Typical Application
	Download	Upload		
IDSL (ISDN DSL)	128 Kbps	128 Kbps	18,000 feet	Home Internet usage; similar to the ISDN BRI service but for data only
G.Lite (Universal ADSL)	1.544 Mbps	Up to 512 Kbps upload	Greater than 18,000 feet	G.Lite has opened up DSL service beyond the traditional 18,000 foot limitation
HDSL (High bit-rate DSL)	1.544–2.048 Mbps	Same	12,000 feet	T-1 service
SDSL (Symmetric DSL)	1.544 Mbps	1.544 Mbps	12,000 feet	Same as HDSL but requires only one line of twisted-pair
ADSL (Asymmetric DSL)	1.544–8.5 Mbps	16–640 Kbps	Varies by distance from central office	Used for Internet and web access, motion video, video on demand, remote LAN access
RADSL (Rate-Adaptive DSL)	Adapted to the line, 640 Kbps to 2.2 Mbps download	272 Kbps to 1.088 Mbps upload	Varies	Similar to ADSL
VDSL (Very high DSL)	12.9–52.8 Mbps download	1.5–2.3 Mbps upload	Varies by distance from central office	ATM networks; fiber to the neighborhood

4.5.4. Typical Deployment

Figure 4-6 shows how a DSL deployment is typically installed. The figure shows a field device establishing an Internet connection and communicating across the Internet to the TMC, which also has an established Internet connection. At minimum, this requires a DSL connection at the field side. One advantage of the Internet model of connectivity is that the TMC can have a different (higher speed) connectivity solution than the field.

In direct contrast to how POTS and ISDN are sold, a DSL connection is sold as a data service and Internet connectivity is part of the service. The DSL modem is also typically part of the service. As shown in the figure, while the two locations are still exchanging information, they are doing so through the ‘cloud’ of the Internet. It is not a direct connection. It should be noted that one DSL can typically serve as a communications gateway for several devices at the same location.

The main advantage of a DSL solution is the speeds that can be achieved, although as shown in Table 4-4, download speeds are typically faster than upload speeds. Utilizing a DSL for a remote camera connection may require special provisioning to provide a higher upload capability.

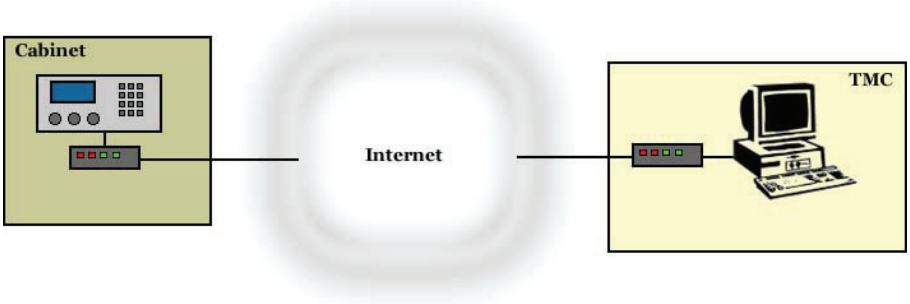

Figure 4-6. Typical DSL Connection.

4.5.5. Considerations for DSL Solutions

As with any technology, there are numerous items to keep in mind when using DSL services. The information below identifies a number of specific items to keep in mind regarding DSL.

- Some DSL services work by sending digital pulses in the high-frequency area of telephone wires and cannot operate simultaneously with voice connections over the same wires.
- A DSL modem specific to the type of DSL service is generally required.
- Not all DSL services are available in all areas. Distance limitations from the central office of the telephone company may greatly slow availability.
- Once the connection is at the central office, DSL lines typically are aggregated to higher speed services. This means that it is a shared communications bandwidth and can be subject to oversubscription.
- xDSL services are not as secure as dedicated connections.

4.5.6. Costs

Typical costs for DSL services are listed below. Costs are highly variable depending on the distance, data rates, type of DSL service, local competition, and more.

- DSL consumer services starts at about $50 per month.
- DSL business service starts at about $80 and can be as high as $500 monthly.

4.5.7. Supported Protocols

Chapter 3 of the guidebook introduced the concept of protocols. Many technologies can support multiple protocols. The list below identifies what protocols run on standard DSL service. This list is by no means inclusive of every protocol that can run on DSL. Keep in mind that other protocols that run on top of ATM or TCP/IP, such as HTTP, FTP, and others, will also run on DSL.

- ATM
- TCP/IP

4.6. Cable Modem

4.6.1. Introduction

The term "cable modem" is actually an abbreviation of two words. Cable is short for Cable TV Network (CATV) and modem is modulator-demodulator. A cable modem is an end-user device for sending and receiving data over the infrastructure originally designed and installed for cable television. The term modem is somewhat of a misnomer because there is no dialing or connection time involved in cable modem service. Cable modem connections are constantly on.

4.6.2. History

Cable TV networks were originally designed and built to deliver television services beyond the standard network channels broadcast over the public airwaves. Some of the impetus behind providing this capability was to serve inner city locations where TV reception was poor due to interference from buildings. In addition, in many places, geographical conditions made it impractical for each building to have its own aerial to receive broadcast TV signals. Additionally, from a practical point of view, it was more efficient to have a TV signal delivered to a central location in a building or a community and then passed to individual TV sets than to have each TV set connected to its own external aerial.

Cable companies typically operate by obtaining a license or franchise for a specific geographic location and sell access for a monthly subscription. Initially, cable companies rebroadcast signals from the major TV networks and did not provide any of their own content. Today, there are hundreds of cable television companies offering programming for virtually any taste, and cable companies have also expanded into the market of providing data services to homes and businesses.

The market for data services was appealing, as the potential customer base was millions of customers. Additionally, these data services utilized the same coaxial cable infrastructure already in place. Today, cable modem service is a well-known technology, serving millions of households by providing relatively inexpensive access to high-speed data services. Many ITS deployments have utilized cable modem service as a method of providing inexpensive, relatively high speed connections to remote locations.

Perhaps the most significant limitation to cable modem service is that the available bandwidth is shared among all users. In effect, all of these users are on the same network of computers. Because of this, even though there is a target rate for upload and download speeds, the actual speed may vary depending on what others on the network are doing.

4.6.3. Capabilities

Cable modem service is not distance limited like DSL and ISDN technologies. It is therefore typically available to a wider customer base. However, the upload and download speeds can be widely variable, as they depend on many factors. Typical speeds are shown below.

- Download – Rates range from 1 to 5 Mbps.
- Upload – Rates range from 128 Kbps to 1 Mbps.

Cable modem service is typically targeted at either home or business use. Business use may have additional features such as a guarantee of minimum levels of service and bandwidth. The business class of service almost always costs more than the home use.

4.6.4. Typical Deployment

Figure 4-7 shows how a cable modem deployment is typically installed. The figure shows a field device establishing an Internet connection, via the cable modem service, and communicating across the Internet to the TMC, which also has an established Internet connection. At minimum, this requires a cable modem connection at the field side. One advantage of the Internet model of connectivity is that the TMC can have a different (higher speed) connectivity solution than the field.

Cable modem service is sold as a data service and Internet connectivity is part of the service. The cable modem may also be part of the package, or you may be required to purchase your own cable modem for the field site. A cautionary note is that most cable modems are not thermally or environmentally hardened.

As shown Figure 4-7, while the two locations are still exchanging information, they are doing so through the ‘cloud’ of the Internet. It is not a direct connection. It should be noted that one cable modem can typically serve as a communications gateway for several devices at the same location.

The main advantage of a cable modem solution is the speed that can be achieved. Utilizing a cable modem connection for a remote camera connection may require special provisioning to provide a higher upload capability.

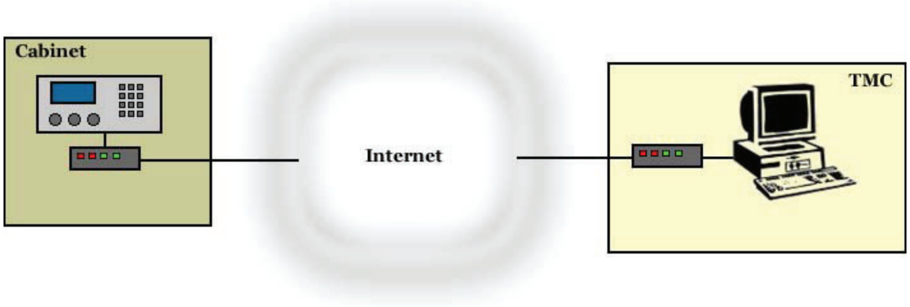

Figure 4-7. Typical Cable Modem Connection.

4.6.5. Considerations for Cable Modem Solutions

As with any technology, there are numerous items to keep in mind when using cable modem services. The list below identifies a number of specific items to consider regarding cable modem solutions.

- Must have coaxial cable run to desired location.
- Technology is not distance limited.
- Historically, achievable speed rates have been inconsistent.
- The more users of the network, the slower everyone becomes.
- May not be as reliable for uploads or downloads as a dedicated connection.
- May not be a secure network.
- On newer systems, all traffic may be encrypted to ensure privacy and security.

4.6.6. Costs

Typical costs for cable modem services are listed below. Costs are highly variable, depending on the data rates and whether it is a home or business account. Keep in mind in addition to the cost of the service, there may be rental fees associated with the cable modem itself, although many companies are now encouraging users to purchase their own equipment from a list of qualified products. Typically, business class is required for advanced services.

- Home User – Typical costs range from $30 to $60 per month.
- Business User – Typical costs range from $100 to $200 per month.

4.6.7. Supported Protocols

Chapter 3 of the guidebook introduced the concept of protocols. Many technologies can support multiple protocols. The list below identifies what protocols run on a cable modem service. This list is by no means inclusive of every protocol that can run on cable modems. Keep in mind that other protocols that run on top of TCP/IP, such as HTTP, FTP, and others, will also run on cable modems.

- TCP/IP

4.7. T-1/T-3 Services

4.7.1. Introduction

T-1 (or Trunk Level 1) is a digital transmission link with a total signaling speed of 1.544 Mbps. Since the development of T-1, it has become the building block of dedicated voice and data service in North America. T-1 is also known as Digital Signal 1 (DS-1).

T-1 service can be delivered to the end-user in either a channelized format or an unchannelized raw bit stream. North American carriers typically deliver T-1 service split into twenty-four 64-Kbps channels. Each channel is often referred to as a DS-0 and can be used to transmit voice (typically one conversation per channel) or data across a network. The provision of T-1 alone provides no specific services to a location, only a means of transmitting data or voice services from a network into the office.

T-3/DS-3 is a higher multiple of T-1/DS-1 that has been joined (also known as bonded or multiplexed). A T-3/DS-3 is composed of 28 individual T-1/DS-1 lines.

4.7.2. History

The T-1 was developed by AT&T in 1957 and implemented in the early 1960s to support long-haul pulse-code modulation (PCM) voice transmission. The primary innovation of T-1 was to introduce "digitized" voice and to create a network fully capable of digitally representing what was, up until then, a fully analog telephone system.

In 1988 Advanced Network Systems, which conducted research into high-speed networking, came up with the concept of T-3. The National Science Foundation (NSF) adopted the new network standard, and by the end of 1991 all of its sites were connected by this new backbone. Since then, T-1 lines have been used extensively in many ITS deployments because of their reliable service and the added capability of providing multidrop communications to field devices.

4.7.3. Capabilities

T-1/T-3 services are not distance limited. Both services can be provided over twisted pair copper wiring or fiber optic wiring. The list below details some of the typical capabilities of these services.

- T-1/T-3 services can be broken out into channels – voice and data can run side by side on the same circuit, but different channels.
- DS-0 = 64 Kbps = 1 channel.
- T-1/DS-1 = 1.544 Mbps = 24 channels.
- T-3/DS-3 = 44.736 Mbps = 28 DS-1/T-1 = 672 channels.
- Each channel can be used for data services or a single phone call.
- Fractional T-1 service is available in some areas, with standard rates of 256, 384, 512, and 768 Kbps.

4.7.4. Typical Deployment

T-1/T-3 service can be used in two ways. As shown in Figure 4-8, a direct connection between two locations can be made using T-1/T-3 service. The figure shows a direct connection between a field location and the TMC. While this type of connection typically requires some equipment at either end, there are no connection charges. The advantages of this type of configuration are:

- The connection can be active all the time.
- There are minimal security issues with a direct connection.
- This may be a lower cost configuration than the Internet model for T-1/T-3 services.
- T-1/T-3 service can be configured as a multidrop deployment to serve multiple locations.

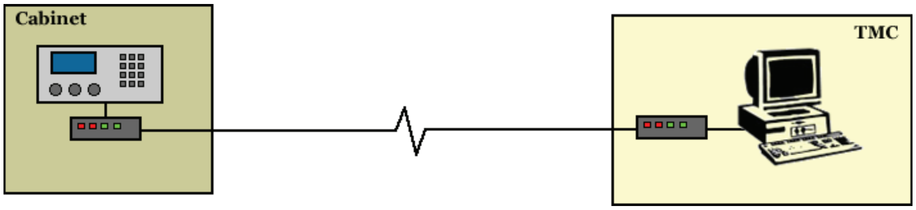

Figure 4-8. Typical T-1/T-3 Direct Connection.

The disadvantage of T-1/T-3 services, especially in a direct connection situation, is that maintenance and configuration of the equipment may reside with the purchasing agency. This typically requires some level of expertise.

Figure 4-9 shows another model of connectivity that can be used for T-1/T-3 lines. In this case, the field location has an Internet connection via the T-1/T-3 service and communicates to the TMC, which also has an Internet connection, across the Internet. This requires T-1/T-3 connection equipment at the field location, as well as the purchased service of an Internet connection with an ISP.

One advantage of the Internet model of connectivity is that the TMC can have a different (higher speed) connectivity solution than the field. While the two locations are still exchanging information, they are doing so through the 'cloud' of the Internet and via the ISP. It is not a direct connection. An additional advantage of this second configuration is an increased connectivity capability at the field site. One T-1/T-3 with an Internet connection can serve as a communications gateway for several devices. The Internet model, however, comes with additional monthly fees for the connectivity. There is the potential for security concerns with the Internet model, as it is not a direct, and therefore controlled, connection.

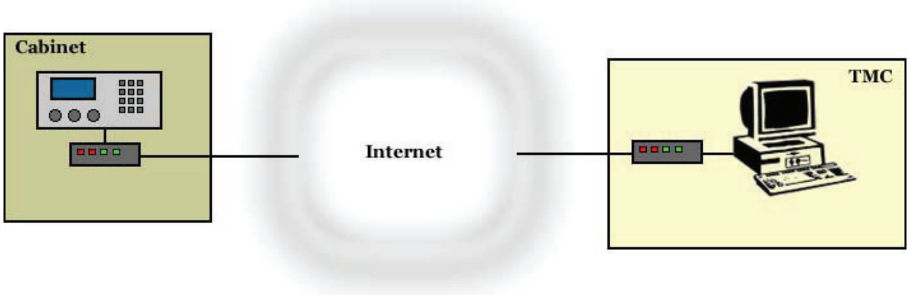

Figure 4-9. Typical T-1/T-3 Internet Connection.

4.7.5. Considerations for T-1/T-3 Services

T-1 or T-3 services can be very costly. In addition to the monthly charges, the service requires equipment at the customer end. This equipment is also costly and can take a high level of knowledge to set up and properly configure. Items to keep in mind regarding T-1/T-3 services include:

- Costly services.
- Service requires connection equipment at termination point.

- Use of service for voice traffic will require equipment to construct a private branch exchange (PBX).
- T-3/DS-3 lines are typically used by ISPs, or large companies, for connecting to the Internet backbone and for the backbone itself.
- The Frame Relay protocol implemented across a T-1/T-3 line may not be the best choice for multimedia networks, as these applications require a constant and consistent delivery of information to avoid ‘choppy’ and freezing video.

4.7.6. Costs

Typical costs for T-1/T-3 services are listed below. Costs are highly variable depending on the location and data rate.

- T-1/DS-1 – $150–$1000 per month.
- T-3/DS-3 – $1500–$9500 per month.
- Installations require connection equipment at termination point, which may be an additional cost.

4.7.7. Supported Protocols

Chapter 3 of the guidebook introduced the concept of protocols. Many technologies can support multiple protocols. The list below identifies what protocols run on T-1/T-3 communications. Keep in mind that other protocols that run on top of TCP/IP, such as HTTP, FTP, and others, will also run on T-1/T-3 services.

- Frame Relay
- TCP/IP

4.8. ATM

4.8.1. Introduction

Asynchronous Transfer Mode is a high-bandwidth, low-delay technology that is capable of very high transmission rates. ATM is a packet switching technology that uses a fixed packet size. Along with a fixed packet size, ATM has long provided for the concept of Quality of Service, which is the guaranteed delivery of packets in the right order, without delay. In the initial days of ATM, these characteristics provided significant advantages to applications requiring continuous streams of data, such as video. Today, other technologies can often provide the same reliability at a fraction of the cost.

4.8.2. History

The research behind ATM started around 1980, when researchers began to investigate ways to increase the speed and reliability of the existing technologies. The challenges were significant. Companies did not want to pay for bandwidth that was generally idle, but the bandwidth needed to be available when a burst of information was ready to be sent. In addition, networks were needed that could carry all forms of information including data, voice, and video and do so while providing the best service.

ATM is the result of a compromise to find a single common denominator that was best for all types of data. In ATM, a stream of information is broken into discrete packets or cells, each of which has a header indicating its path and other worthwhile information. If the cell size is made small and the overall throughput of the circuit is high, traffic that is sensitive to delay can be successfully carried at the same time as nonsensitive data.

In 1989, the cell size of ATM was standardized at 53 bytes. This was small enough to allow fast and efficient switching to ensure timely delivery of time-sensitive data, while at the same time large enough to provide good throughput for large data communications. Everyone therefore gets what they need from the data link. Voice and video transfer without glitches, and data customers can get bandwidth on demand.

4.8.3. Capabilities

ATM services are not distance limited. ATM service is provided over fiber optic wiring. The list below details some of the typical capabilities of ATM.

- ATM is a packet switching technology that divides upper-level data units into 53-byte cells for transmission over the physical medium.
- Each individual ATM cell consists of a 5-byte cell header and 48 bytes of information encapsulated within its payload.
- ATM is a connection-oriented technology, which means it requires establishment of a channel between the sender and receiver before any messages are transmitted.
- ATM creates these pathways, called virtual circuits.
- ATM can allocate bandwidth on demand as services requirements change.
- ATM can interface with SONET and Ethernet technologies.

- Typical ATM bandwidth is 1.54 to 622 Mbps.
- ATM features characteristics such as low delay and quality of service, which is a guaranteed delivery feature.

4.8.4. Typical Deployment

An ATM network is usually not a service that would be purchased from a provider. An ATM network would typically be constructed, operated, and maintained by an agency with total control over the equipment and infrastructure. With established infrastructure, building your own network can reduce operating costs and provide maximum bandwidth. However, the ongoing maintenance and operation of the network is a factor that must be considered in the decision process.

Figure 4-10 shows a typical ATM network that could be constructed for an ITS deployment. Although the figure shows a ring topology, any other topology could also be utilized. An ATM network simply provides the means to transport information from point A to point B. Additional equipment, such as codecs, are still necessary to encode video signals and place them into the network for transport. The same situation holds true for data communications such as connecting to traffic controllers, dynamic message signs, or other field devices.

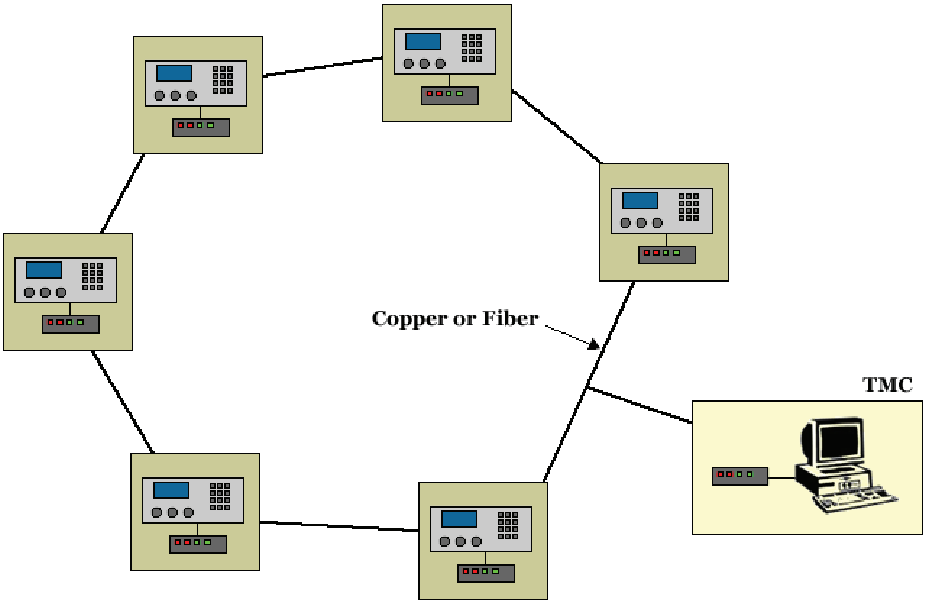

Figure 4-10. Typical ATM Network Construction.

4.8.5. Considerations for ATM

The decision to utilize ATM implies that the agency is going to construct a network system incorporating field devices and connecting to the TMC. ATM equipment is costly and can take a high level of knowledge to set up and properly configure. In addition, all the advantages that were previously unique to ATM are now present in other technologies. Items to keep in mind regarding ATM networks include:

- ATM equipment can be significantly more expensive than other technologies.
- ATM requires a significant learning curve and management overhead.
- Market penetration of ATM to the desktop or device level has not been significant, increasing costs and the need for specialized knowledge.
- ATM is currently thought of as more of a backbone or WAN technology.

4.8.6. Costs

Prices for ATM installations can vary widely, depending on the desired bandwidth, the equipment used, and the services provided. At the backbone level, prices to connect each individual device can run from $1,000 to $10,000. At the desktop level, ATM typically runs several hundred dollars per port or device, which includes the device interface and cabling costs.

4.8.7. Supported Protocols

Chapter 3 of the guidebook introduced the concept of protocols. Many technologies can support multiple protocols. The list below identifies what protocols run on an ATM service. This list is by no means inclusive of every protocol. Keep in mind that other protocols that run on top of TCP/IP, such as HTTP, FTP, and others, can also run on ATM.

- SONET
- TCP/IP

4.9. SONET

4.9.1. Introduction

Synchronous optical network (SONET) is a standard for optical telecommunications transport formulated by the Exchange Carriers Standards Association (ECSA) for ANSI, which sets industry standards in the United States for telecommunications and other industries.

4.9.2. History

SONET was really developed out of necessity and as a replacement for copper-based transmissions. As communication demands grew, copper ceased to be economical to carry the vast number of calls being made nationwide. Copper also had practical limitations, since it is prone to electrical spikes from storms and other interference.

With the advent of fiber optic cabling, a single cable can handle thousands of calls. Lines that once required hundreds of copper cables could be replaced by a single glass fiber. An assembly of fiber optic cabling can handle millions of voice calls and do so more reliably than copper. Long-distance phone carriers rapidly embraced this technology. Unfortunately, the equipment manufacturers created a multitude of techniques to transmit traffic through these tiny strands of glass. Most of these systems were proprietary and interoperability was difficult, if not impossible.

The driving force behind the creation of SONET was to create a standard for manufacturers to build fiber optic gear and ensure operability with other fiber optic equipment. This also allowed users the opportunity to construct multivendor networks without being forced to use a single vendor.

4.9.3. Capabilities

SONET can provide bandwidths from 51.84 Mbps to 39.812 Gbps. Each level of SONET is called OC, for Optical Carrier. Table 4-5 lists the typical OC levels that can be obtained in SONET installation.

Table 4-5. Optical Carrier Rates.

Optical Carrier Level	Data Rate
OC-1	51.84 Mbps
OC-3	155.52 Mbps
OC-12	622.08 Mbps
OC-24	1.244 Gbps
OC-48	2.488 Gbps
OC-192	10 Gbps
OC-256	13.271 Gbps
OC-768	39.812 Gbps

In addition to providing the extremely high bandwidths detailed above, SONET has the following capabilities:

- Provides flexibility to transport many different digital signals.
- Provides an optical interface standard that allows for interoperability of transmissions products from multiple vendors.
- Provides the capability to breakout bandwidth at the T-1 (1.544 Mbps) level.

4.9.4. Typical Deployment

A SONET network is usually not a service that would be purchased from a provider. A SONET network would typically be constructed, operated, and maintained by an agency with total control over the equipment and infrastructure. With established infrastructure, building your own network can reduce operating costs and provide maximum bandwidth. However, the ongoing maintenance and operation of the network is a factor that must be considered in the decision process.

Figure 4-11 shows a typical SONET network that could be constructed for an ITS deployment. The figure illustrates a ring topology. A SONET network simply provides the means to transport information from point A to point B. Additional equipment, such as codecs, would still be necessary to encode video signals and place them into the network for transport. The same situation holds true for data communications such as connecting to traffic controllers, dynamic message signs, or other field devices.

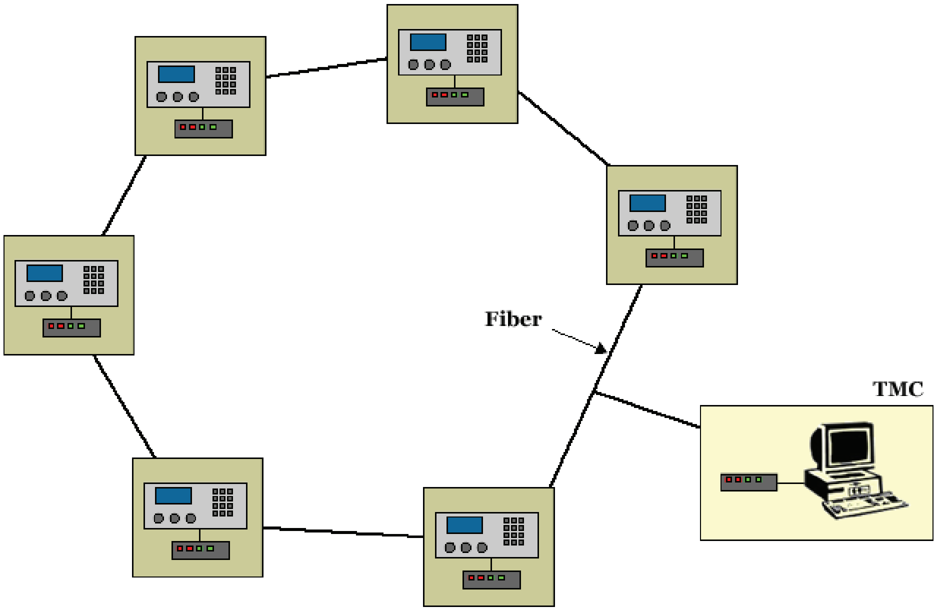

Figure 4-11. Typical SONET Network Construction.

4.9.5. Considerations for SONET

The decision to utilize SONET implies that the agency is going to construct a network system incorporating field devices and connecting to the TMC. SONET equipment is very costly, and while it can provide the ultimate amount of bandwidth, it can take a high level of knowledge to set up and properly configure. Items to keep in mind regarding SONET networks include:

- SONET provides much greater bandwidth than ATM.
- SONET has networking advantages over ATM, most notably speed.
- SONET equipment is expensive.
- A great deal of SONET equipment is field hardened.
- SONET is an ideal backbone or WAN technology due to its high speed.

4.9.6. Costs

Although SONET provides the highest speeds, it also costs more than any other technology choice. A typical installation of SONET created from dark fiber can cost as much as $50,000 per endpoint or drop. A SONET link purchased from a service provider for a backbone typically costs $5,000 to $10,000 per month, depending on the speed.

4.9.7. Supported Protocols

Chapter 3 of the guidebook introduced the concept of protocols. Many technologies can support multiple protocols. The list below identifies what protocols typically run on a SONET service. This list is by no means inclusive of every protocol. Keep in mind that other protocols that run on top of TCP/IP, such as HTTP, FTP, and others, can also run on SONET. Because SONET is more of a backbone technology, an end-user will not have to do anything at their level to operate within a SONET environment.

- SONET
- ATM
- IP

4.10. Ethernet

4.10.1. Introduction

Ethernet was invented as a project to connect computers, printers, and workstations within a small area. Ethernet is a Layer 2 protocol. Other protocols, such as TCP/IP, run on top of Ethernet and provide additional features and capabilities.

4.10.2. History

The first Ethernet network was designed and built in 1973 by Bob Metcalfe, who was with the Xerox Corporation. The term ‘Ethernet’ was a registered trademark of Xerox Corporation. The second generation of Ethernet was often called DIX after the corporate sponsors of Digital, Intel, and Xerox. As the holder of the trademark, Xerox established and published the standards.

Having a U.S.-based corporation hold, develop, and publish standards did not sit well with the international community, who saw Ethernet as a viable networking technology. The international organization Institute of Electrical and Electronics Engineers (IEEE) was assigned the task of developing formal international standards for all local-area network (LAN) technologies. It formed the “802” committee to examine Ethernet, as well as other technologies, such as token ring or fiber optics. The objective of the project was not just to standardize each LAN individually, but also to establish rules that would be global to all types of LANs so that data could easily move from Ethernet to token ring or fiber optics.

This larger view created conflicts with the existing practice under the old Xerox DIX system. IEEE was careful to separate the new and old rules. It recognized that there would be a period when old DIX messages and new IEEE 802 messages would have to coexist on the same wire. It published a set of standards called 802.3, which were immediately adopted by all the hardware vendors. Today, all Ethernet devices conform to this standard.

These standards did cause changes in many other standards to ensure interoperability. Apple, Digital Equipment Corporation, and Novell were several companies that had to alter their proprietary standards to embrace the development of Ethernet.

4.10.3. Capabilities

Ethernet has evolved more rapidly than perhaps any other technology. From simple beginnings with low speeds just 30 years ago, Ethernet now boasts speeds of 10 Gbps and features such as Quality of Service.

It is estimated that 85–90 percent of all networks are Ethernet-based networks. Table 4-6 lists the current levels of Ethernet and their usable capacity.

Table 4-6. Standard Ethernet Speeds.

Name	Speed (Mbps)	Usable Capacity (%)
Ethernet	10	Approx 30–50
Fast Ethernet	100	Approx 50
Gigabit Ethernet	1000	Approx 80
10 Gigabit Ethernet	10,000 (10 Gbps)	Approx 80

It is important to recognize that the line speed of Ethernet may never truly be realized, as it is a technology based on random transmission of data. This means that collisions will occur and that they will occur more frequently as more data reside on the network. The standards have improved the signaling and transmission methods of Ethernet over time, so Table 4-6 shows an increase in the usable capacity of the wire.

It is also important to recognize that the design of Ethernet networks has changed considerably since the inception of the protocol. In the first implementations, the Ethernet “wire” or media was truly a shared communications backbone among multiple nodes. Figure 4-12 illustrates this type of design.

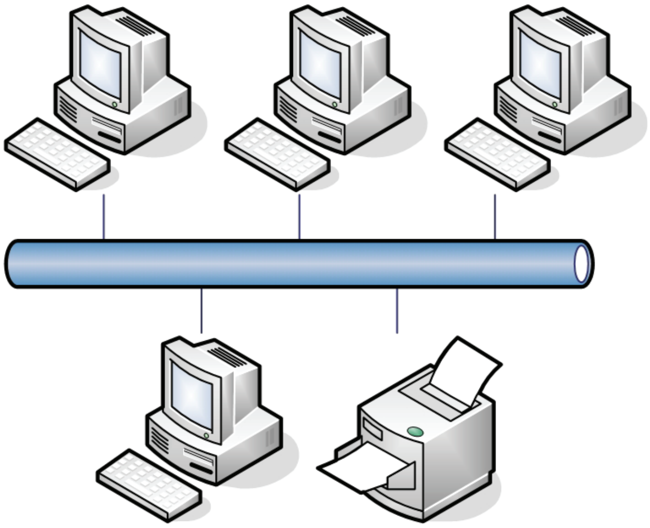

Figure 4-12. First Implementations of Ethernet.

Because multiple devices were on the same media, the CSMA/CD algorithm (explained in Chapter 3 of this guidebook) was utilized to detect collisions between packets of information and to provide rules for retransmitting the information to ensure that all packets got through the "wire."

Each "wire," as shown in Figure 4-12, was called a network segment. Network segments were typically joined by hubs or switches. The number and layout of the devices on the "wire" determined what was called a collision domain. A collision domain was the extent of the network devices which would conflict with one another when trying to send and receive information. If the collision domain was too large, the number of collisions would greatly increase and performance would suffer. Special design considerations were employed to reduce the extent of the collision domain, usually by reducing the number of devices on any particular network segment.

Over time, as Ethernet advanced in capabilities, equipment, and design, the design situation shown in Figure 4-12 became outdated. Virtually all Ethernet implementations today are known as full-duplex switched Ethernet.

Figure 4-13 shows an illustration of a full-duplex switched Ethernet design. Because each device has its own "wire" back to the switch, there is no longer conflict with other devices, since there is no more sharing of that particular wire. The switch essentially segregates each device from the other devices, only permitting packet flow if they are trying to communicate to each other. These improvements in both hardware and design have helped to greatly advance the performance of Ethernet.

Although the full-duplex switched Ethernet in use today is far more advanced in design and application than early Ethernet applications, designing an Ethernet network can still be a challenge. Typical networks today have multiple switches, each communicating to a central location, be it another switch or router. Available bandwidth is a significant consideration in this design. Even though individual devices may not exceed the available bandwidth from an individual port on a switch, the cumulative bandwidth may be an issue. Other concerns include items such as the packet forwarding performance of the network switching and routing equipment—basically, whether the equipment can keep up with the end devices generating the packets. Standards for items such as transmission distance should still be observed to reduce problems and optimize performance.

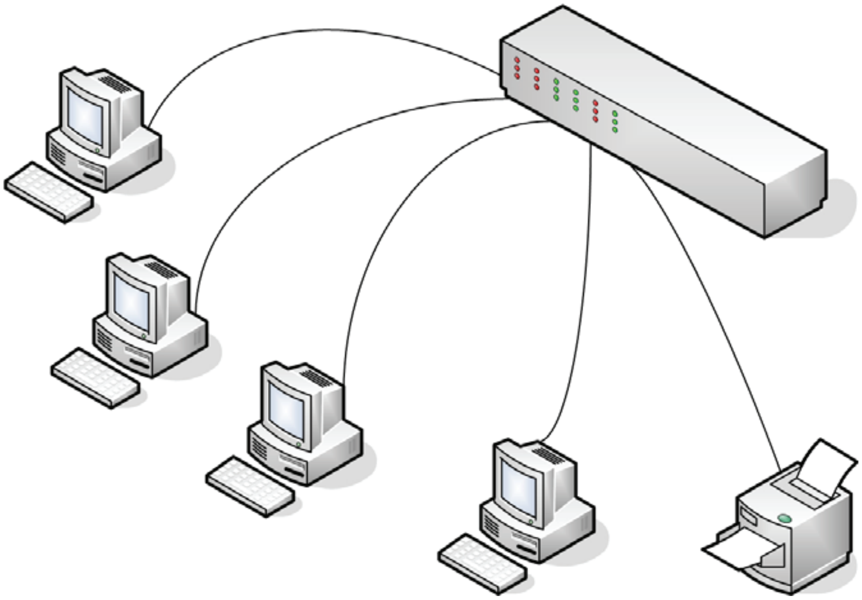

Figure 4-13. Full-Duplex Switched Ethernet.

The above items are of critical importance when designing a multicast video network. Although the use of multicast video can significantly decrease the cost of field deployments, particularly in multiagency situations, the demands placed upon the network require increased performance, which translates to additional design considerations.

In general, Ethernet has the following capabilities:

- Supports all wiring types.
- Can achieve speeds up to 10,000 Mbps (10 Gbps).
- Supports redundancy with alternate paths to destination.
- Supports high-end features such as Quality of Service.
- Hardened field equipment is available.
- Basic implementations are highly scalable and robust and have the lowest cost point of any network solution.

4.10.4. Typical Deployment

An Ethernet network is usually not a service that would be purchased from a provider. An Ethernet network would typically be constructed, operated, and maintained by an agency with total control over the equipment and infrastructure. With established infrastructure, building your own network can reduce operating costs and provide maximum bandwidth. However, the ongoing maintenance and operation of the network is a factor that must be considered in the decision process.

Figure 4-14 shows a typical Ethernet network that could be constructed for an ITS deployment. Although the figure shows a ring topology, any topology could be utilized. An Ethernet network simply provides the means to transport information from point A to point B. Additional equipment, such as codecs, are still necessary to encode video signals and place them into the network for transport. The same situation holds true for data communications such as connecting to traffic controllers, dynamic message signs, or other field devices.

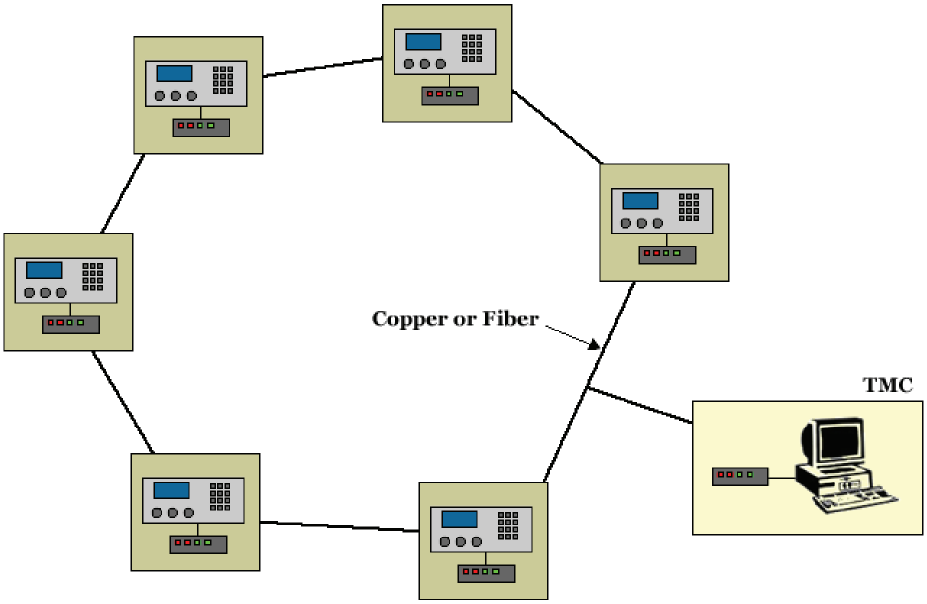

Figure 4-14. Typical Ethernet Network Construction.

4.10.5. Considerations for Ethernet

The decision to utilize Ethernet implies that the agency is going to construct a network system incorporating field devices and connecting to the TMC. Ethernet equipment is the least costly of any of the "network" level solutions and can provide significant bandwidth. A tremendous advantage of Ethernet is that it is a well-known networking technology and is understood and utilized by a vast majority of the companies and agencies utilizing networks. Ethernet equipment that is thermally and environmentally hardened is increasingly available and affordable.

- Expensive for full Gigabit or 10-Gbps Ethernet.
- Prices per port drop rapidly as new innovations or speed improvements are released.
- Supports computer to computer (with a cross-connect cable).
- Supports LANs.
- Supports WANs.

- Equipment cost is low to moderate for LAN systems.
- Equipment cost is moderate to high for WAN systems.
- Efficiency: 50–80 percent on average.

4.10.6. Costs

Ethernet is the lowest cost and most flexible of all of the networking technologies. Items to keep in mind concerning Ethernet costs include:

- 10/100 Ethernet can be purchased for as little as $5 to $10 per port.
- Gigabit Ethernet is less than $100 per port at the desktop level.
- Switching level installations cost more.
- Hardened equipment adds additional expense.

4.10.7. Supported Protocols

Chapter 3 of the guidebook introduced the concept of protocols. Many technologies can support multiple protocols. The list below identifies what protocols run on Ethernet. This list is by no means inclusive of every protocol. Keep in mind that other protocols that run on top of TCP/IP, such as HTTP, FTP, and others, can also run on Ethernet.

- Ethernet
- TCP/IP
- PPP (Point-to-Point Protocol—employed in dial-up connections)
- ATM (with additional equipment)

4.11. Cross Technology Tabulations

Perhaps the most important outcome of learning all the information in Chapter 4 is being able to quickly compare the technology choices. By examining one characteristic at a time across all the options, rapid decisions can be made regarding the applicability of the technology to the current application or need.

4.11.1. Bandwidth

Bandwidth is a parameter that will most likely reduce the available options quickly, since several of the solutions do not have the capability of supporting multiple video streams simultaneously. However, careful consideration of the network topology is warranted, in conjunction with bandwidth, as some topologies make more use of shared bandwidth than others. Table 4-7 shows the nine technology choices discussed in this chapter and details the bandwidth for each choice. The table shows both a theoretical and typical or usable bandwidth, as many technologies have overhead or constraints that limit the availability of the full theoretical bandwidth.

Table 4-7. Bandwidth for Technology Choices.

Technology	**Bandwidth**			
	Theoretical		**Typical (Usable)**	
Serial	Up to 115.2 Kbps		19.2 Kbps	
POTS	56 Kbps		40–45 Kbps	
ISDN	BRI – 128 Kbps PRI – 1.544 Mbps		BRI – 128 Kbps PRI – 1.544 Mbps	
DSL	Download	1.544–52.8 Mbps	Download	1–8 Mbps
	Upload	128 Kbps – 4 Mbps	Upload	128 Kbps – 1 Mbps
Cable Modem	Download	1–8 Mbps	Download	1–4 Mbps
	Upload	128 Kbps – 4 Mbps	Upload	128 Kbps – 1 Mbps
T-1/T-3	1.544–44.736 Mbps		1.544–44.736 Mbps	
ATM	1.54–622 Mbps		Up to 500 Mbps	
Ethernet	10 Mbps		4–5 Mbps	
	100 Mbps		40–50 Mbps	
	1000 Mbps		800 Mbps	
	10,000 Mbps		8000 Mbps	
SONET	51.84 Mbps – 39.812 Gbps		51.84 Mbps – 39.812 Gbps	

4.11.2. Wiring

One of the fundamental concepts of this guidebook is that there are limited wiring choices available to implement the current technology choices. Table 4-8 shows the wiring choices that are supported by each of the various technologies.

Table 4-8. Wiring Supported by Technology Choices.

Technology	Wire Type
Serial	Twisted Pair (1–2 pairs plus ground)
POTS	Twisted Pair
ISDN	Twisted Pair
DSL	Twisted Pair
Cable Modem	Coaxial Cable
T-1/T-3	Twisted Pair, Fiber
ATM	Twisted Pair, Fiber
Ethernet	Coaxial Cable (seldom used), Twisted Pair, Fiber
SONET	Fiber

4.11.3. Typical Deployment Method

The technologies discussed in Chapter 4 use multiple methods of deployment. Table 4-9 details the deployment methods typically used for each of the technologies. Some technologies, such as POTS, show more than one type of deployment method, indicating that there is more than one method of using the technology to provide communications for ITS deployment.

Table 4-9. Typical Deployment Method for Technology Choices.

Technology	Direct Connection	Internet Connection	Network
Serial	✓		
POTS	✓	✓	
ISDN	✓	✓	
DSL		✓	
Cable Modem		✓	
T-1/T-3	✓	✓	
ATM			✓
Ethernet			✓
SONET			✓

4.11.4. Distance

Many of the technology choices have some sort of distance limitation associated. In some cases, the limitation is specific to the media employed by the technology. For example, longer distances can often be achieved by using fiber instead of copper. Table 4-10 shows the typical distances associated with each technology choice discussed in Chapter 4.

Be aware that specific vendor implementations may have longer distances than what are shown in Table 4-10, which are based on the approved standards. While vendor specific implementations may have increased capabilities, other considerations, such as interoperability, support, longevity, open standards, and more, should be carefully considered in the decision-making process.

Table 4-10. Distance Limitations for Technology Choices.

<table>
<tr><th>Technology</th><th>Distance Limitations</th></tr>
<tr><td>Serial</td><td>Depends on protocol:
<table>
<tr><td>RS-232</td><td>RS-422</td><td>RS-485</td></tr>
<tr><td>100 feet</td><td>4000 feet</td><td>4000 feet</td></tr>
</table></td></tr>
<tr><td>POTS</td><td>None</td></tr>
<tr><td>ISDN</td><td>18,000 feet from central office</td></tr>
<tr><td>DSL</td><td>18,000–30,000 feet; generally less than 18,000 feet</td></tr>
<tr><td>Cable Modem</td><td>Up to 75 miles maximum</td></tr>
<tr><td>T-1/T-3</td><td>None</td></tr>
<tr><td>ATM</td><td>Depends on physical media and speed:
<table>
<tr><td>Speed (Mbps)</td><td>Multimode Distance</td><td>Single-mode Distance</td></tr>
<tr><td>52</td><td>3000 m
(10,000 ft)</td><td>15,000 m
(50,000 ft)</td></tr>
<tr><td>155</td><td>1000–2000 m
(3000 to 6500 ft)</td><td>15,000 m
(50,000 ft)</td></tr>
<tr><td>622</td><td>300–500 m
(1000 to 1600 ft)</td><td>15,000 m
(50,000 ft)</td></tr>
</table></td></tr>
<tr><td>Ethernet</td><td>Depends on physical media:
Category 5/5e/6 – Up to 100 m (328 ft)
Multimode fiber – up to 550 m (1804 ft)
Single-mode fiber – up to 5 km (3.1 miles)</td></tr>
<tr><td>SONET</td><td>Depends on physical media:
Multimode fiber – up to 550 m (1804 ft)
Single-mode fiber – up to 60 km (37.3 miles)</td></tr>
</table>

4.11.5. Cost

The costs of the various technology choices vary greatly, from a few dollars a month to tens of thousands of dollars for a single piece of equipment. Obviously, increased capability comes with increased costs. Table 4-11 identifies some of the typical costs associated with the technologies discussed in Chapter 4.

Note that many of the technologies that are a service provided by another company have pricing that is per connection or endpoint. A typical application may have two endpoints (field and central office), resulting in double the costs. An exception would be if there are multiple field locations and only one office location. Either way, count the number of endpoint installations to determine your approximate costs.

It should also be noted that the costs listed in Table 4-11 are typical and may vary by location and provider.

Table 4-11. Typical Costs for Technology Choices.

Technology	Approximate Cost
Serial	$0
POTS	Costs are per end (connection): $30 per month
ISDN	Costs are per end (connection): BRI – $60 per month PRI – $600–$100 per month
DSL	Costs are per end (connection): Home User – $50 per month Business User – $80–$100 per month
Cable Modem	Costs are per end (connection): Home User –$30–$60 per month. Business User –$100–$200 per month
T-1/T-3	T-1 – $150–$1000 per month. T-3 – $1500–$9500 per month.
ATM	$1000 and up per port
Ethernet	Cost depends on speed: 10 Mbps – $5–$10 per port 100 Mbps – $100 per port 1000 Mbps – $1000 per port
SONET	Cost depends on speed: $5,000–$50,000 per port

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5. SYSTEM DESIGN/EVALUATION

5.1. Focus of This Chapter

Chapters 5 and 6 introduce and explain a stepwise procedure for evaluating communication needs.

Chapters 1 through 4 provided both an introduction to communications and a primer on many of the underlying concepts. By now, the reader should have a basic understanding of the choices in wireline media, the concept and use of protocols, and an overview of the typical solutions employed in the ITS arena. In addition, concepts such as topologies, video encoding, information transfer rates, and more, have been presented as important concepts related to ITS deployments.

This chapter applies that fundamental knowledge base to the typical needs of TxDOT. Those needs consist of either designing a new system/deployment or evaluating an existing system/deployment. By providing a stepwise procedure to assess communications needs, the decision of which technologies to consider can be significantly narrowed.

A procedure can only narrow down the potential choices.

It can not provide THE right answer.

There is more than one right answer.

No procedure can examine all of the choices and provide a single answer of "this" technology for "that" situation. Although communications is a science, building communications systems is more of an art. Multiple solutions could be built for any given scenario, but they would all have different strengths and weaknesses. The final solution of decision depends on many deployment specific items, such as cost, scalability, available expertise, and more.

Instead, the goal of these procedures is to narrow the wide range of choices into a subset of best options. The reader must then utilize his or her individual knowledge and experience to pick a final solution for the particular deployment situation.

5.2. Terminology

Prior to looking at the procedures, several terms should be identified and discussed, as they are critical components of the procedures that follow.

5.2.1. Bandwidth

Bandwidth is the amount of information that can be transmitted in a certain amount of time.

Chapter 2 discussed information transfer rates and the concept of bandwidth. As a review, bandwidth refers to the amount of information that can be transmitted in a certain amount of time and is usually expressed in bits per second. The various sections in Chapter 4 illustrated that each technology has a different bandwidth. Table 4-7 tabulated the theoretical and usable bandwidth for each technology.

When used for design or evaluation, the term bandwidth has a slightly different connotation. We know, of course, that every device needs to transmit or send information. In order for the device to work properly it must be able to transmit information at some rate. Every device, therefore, has a bandwidth. In this instance, however, it is a required bandwidth.

As you will see in subsequent sections of this chapter, one of the key factors in determining an appropriate communications solution is to determine the sum of the required bandwidths for all of the devices that will be on the system and compare it to the usable bandwidths for each technology.

5.2.2. Latency

Latency is the delay between two points in the system.

In communications, latency is a synonym for delay. Simply put, latency is a measure of the amount of time it takes a piece of information to get from one designated point to another. Every device and communications solution has latency. Latency is typically measured in milliseconds or thousandths of a second.

Latency is typically expressed in thousandths of a second.

An important concept to understand is that each link in a communications system has an associated latency. A codec takes a certain amount of time to encode a video stream. A switch takes a certain amount of time to process each piece of information and send it to the next device. The physical medium itself has transmission latency from one end to the other. The sum of all of these time components is the total latency in the system. Most high-speed communications systems minimize latency. By most considerations, a delay of 1000 milliseconds, or 1 second, would be considered excessive.

Latency is important to consider from the standpoint of the application. In telephone conversations, a large amount of delay would make communications very difficult. However, in other applications, a large amount of delay may not affect the outcome at all. Consider, for example, posting a message to a DMS. In many situations, the amount of time that it takes for the message to arrive at the sign would not be considered critical. Whether it takes 250 or 1250 milliseconds, the message would still get there. The 1 second of difference is not likely to have any significant effect on drivers using the information posted on the sign.

In contrast to that situation, however, are applications like video. Many video applications become unstable when a high degree of latency is present. When the video information does not arrive at the decoder in the correct amount of time, it tends to get out of sequence. This results in information being dropped or displayed out of time. The video appears jerky, may experience stop and go motion, or may even show black screens or other manifestations of incorrect timing.

5.2.3. System Design Scenarios

Chapter 3 of this guidebook presented the concept of network topologies, or how devices are arranged in a communications system. One of the other aspects of communications is not only how devices are arranged, but how they 'talk' to other devices.

Communications systems can be built to be either 'unicast' or 'multicast.'

Let's return to our ongoing example of a telephone call. In a typical telephone call, two people are involved and communication (information) flows between the two ends of the connection. In the terminology associated with network communications, that is said to be unicast, or point-to-point communications.

The other possibility for a telephone call is to have a conference call. In this situation, many people are connected and each person can both hear and talk to the other people. When one person talks, every other person on the telephone call can hear them. This is called multicast communications.

In one sense, multicast communications are easier, since the same conversation does not have to be repeated individually to each person in the conference call. It is more efficient to simply say it once and have everyone hear it. On the other hand, arranging a multiperson conference call every time you need to pick up the telephone can be cumbersome and time consuming. Many conversations do not need to be multicast.

These same trade-offs exist in the design of a communications system. Because unicast is a point-to-point scenario, it is not well suited to a situation where the same information has to be received at multiple locations. In fact, for video communications, this may impose significant additional costs for extra equipment. However, multicast networks are more difficult to set up and maintain and may require more significant expertise to achieve stable operations. The methodology presented in this chapter provides significant guidance on the best design situation (unicast or multicast) for any particular situation by asking a few questions and using accepted communications system design principles.

5.3. Data Communications

By nature, data communications do not typically require extensive bandwidth. In fact, if no video information is being transmitted, even a basic solution such as a telephone line can transfer a significant amount of information.

One of the primary issues related to data communications is the speed at which information is transmitted. While latency has been discussed, the speed of transmitting the data must also be considered.

Consider an example where a sensor on the roadway transfers information to a central location. Furthermore, assume that the size of the information is 150 KB, or 1200 Kb. For this example, we'll assume that a phone line (POTS) is in place for the data transfer.

From Table 4–7, we know that a typical phone line solution will transfer information at approximately 40 Kbps. Therefore, the time it will take to transfer this amount of data over the phone line will be:

$$1200\ Kb \div 40\ Kbps = 30\ seconds$$

If the data are needed for real-time operations, a 30-second delay may not provide a feasible solution.

Now consider the same scenario, but the communications connection has been switched to a DSL line. If the connection speed on the uploading side is relatively low, say 128 Kbps, the time to transfer the information will be:

$$1200\ Kb \div 128\ Kbps = 9.4\ seconds$$

This is significantly better than 30 seconds, but still may not be fast enough for "real-time" purposes.

If the upload speed of the DSL connection was a more robust 1 Mbps, the time to transfer the information would be:

$$1200\ Kb \div 1000\ Kbps = 1.2\ seconds$$

As you can see, the information transfer for data can be accomplished in multiple ways, but the speed at which it is accomplished may prove to be a critical factor in the design.

Unfortunately, it is difficult, if not impossible, to capture this type of need internal to a design and evaluation process. The designer must often utilize personal knowledge and experience to produce the best solution for the given scenario.

5.4. Data Communications Design/Evaluation Methodology

The process presented in this guidebook for designing or evaluating data communications solutions is illustrated in the flow chart in Figure 5-1. The figure shows the seven parts of the methodology. Each part of the methodology is referenced to a section in this chapter where detailed information is provided. A worksheet that covers the entire process can be found in Chapter 6.

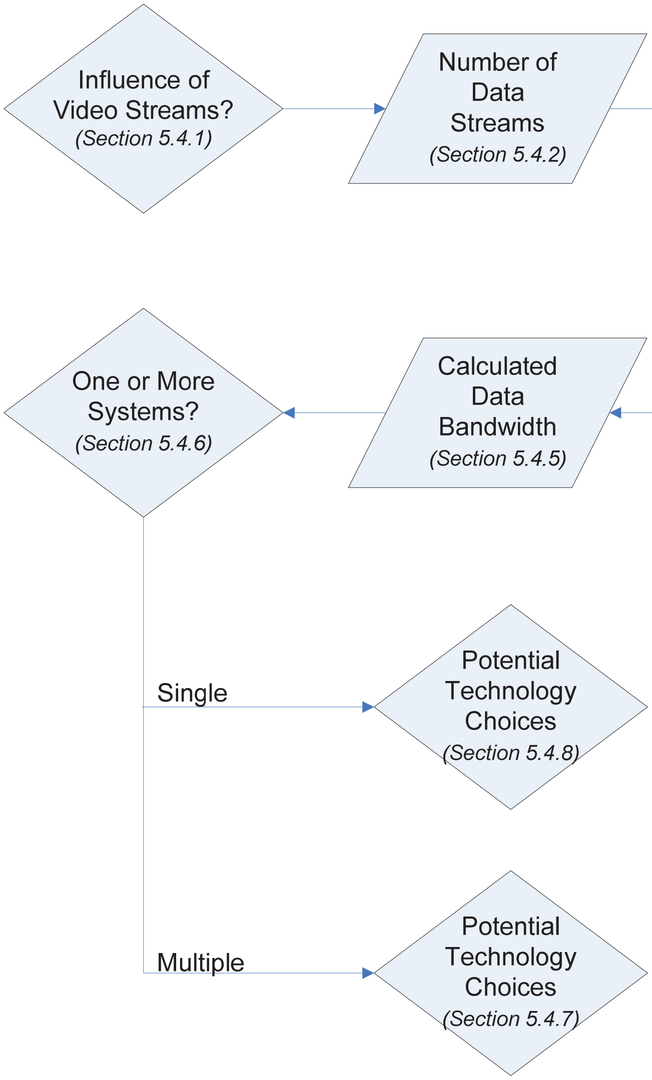


Figure 5-1. Flowchart for Data System Design/Evaluation.

One of the interesting design aspects of data communications is that they are often a start/stop type of communication, as opposed to video, which is always on. Consider, for example, a DMS that displays a message only periodically, say, once a day. Most of the time, the DMS will have little to no data communication needs, as no information is being exchanged.

However, as we know, bandwidth is defined as an amount of information transferred over a set unit of time. In this case, the DMS has bandwidth needs for only a few minutes of the day. One method of calculating the proper bandwidth requirement is to convert the total bandwidth used during DMS transmissions to an equivalent usage per second, the typical time frame used for bandwidth.

Consider the following example. A DMS message is 1 KB in size and that device acknowledges a transmission with a return message of the same size. Furthermore, this transfer takes place in a total of 5 seconds. The equivalent bandwidth used is:

$$2\ KB \div 5 \text{ seconds} = 0.4\ KBps = 3.2 Kbps$$

However, that value is misleading, because that need is only present for a total of 5 seconds. In addition, it would be tedious at best to tabulate the periodic communications needs of every device and determine an equivalent bandwidth need.

An alternative approach would be to simply break down every device's communications on a per-second basis across a single day. In this case, the DMS would require the following equivalent bandwidth:

$$2\ KB \div 86{,}400 \text{ seconds} = 0.000023\ KBps = 0.000185\ Kbps$$

Although this may be numerically correct, this procedure doesn't take into account the timing of the various needs. If a design is implemented that provides communications needs via a phone line, that phone line may perform adequately for quite some time. However, if several devices need to communicate at the same time, the bandwidth needs will quickly accumulate. As seen in the previous examples in Section 5.3, this could cause a significant increase in the time it takes to transmit data. This could cause several problems, as data would not be received on time and events that need to take place in real time would be late.

As a result of the above issues, the design methodology presented in the following sections assumes that all data communications are constant. In other words, all devices are constantly transmitting information at their maximum rate. While this errs on the side of designing for an increased bandwidth need, it removes much of the tedious work and inaccuracies of trying to pinpoint when and how often a device communicates.

5.4.1. Influence of Video Streams

The first two questions in the data methodology inquire about the presence of video streams. While this may be somewhat puzzling at first glance, video takes a considerably greater amount bandwidth than data communications. If video will share the same communications system, the appropriate methodology to use is the video design methodology presented in Section 5.6

If video will be present and the data will be on a separate communications system, the designer must perform both a data analysis and a video analysis. Using current communications design philosophy, this is a relatively rare design situation. Table 5-1 shows questions from the data communications worksheet that determine the appropriate design situation: data or video.

Table 5-1. Questions 1 and 2 from Data Communications Worksheet.

Data Communications Design Worksheet				
Presence of Video Streams *(Section 5.4.1)*	1.	Are video streams in use now or will they be in the future? ☐ YES ☐ NO If 'NO,' proceed to Question 3.	1.	▨
	2.	Are the video streams and data being transmitted together over the same communications system in the field? ☐ YES ☐ NO If 'YES,' you do not need this worksheet, you need the Digital Video Communications Design Worksheet. If 'NO,' proceed to Question 3.		▨

5.4.2. Number of Devices

The third question in the procedure asks you to identify both the type and number of the various devices that are present in the system today and that must be accommodated in the future.

The breakdown by type of device is provided simply to help the designer identify different data sources. Other than the bandwidth in use, there is no inherent difference in the data stream from one type of device to another.

Table 5-2 shows the question from the data communications worksheet. The total number of data streams you are designing for is contained in Line 3m of the table, which is the summation of current plus future needs.

Table 5-2. Question 3 from Data Communications Worksheet.

Number of Devices *(Section 5.4.2)*

3\. How many of the following devices do you have?

		Number of Devices	
	Device Type	**Current**	**Future**
3a.	Dynamic Message Signs		
3b.	Vehicle/Roadway Detectors		
3c.	TxDOT LCU		
3d.	TxDOT SCU		
3e.	RWIS		
3f.	Weather Stations		
3g.	Ramp Meters		
3h	PTZ Camera		
3i	Traffic Controllers		
3j.	Other		
3k.	***Subtotals***		
3l.	***TOTAL NUMBER OF DATA STREAMS (Add 3k CURRENT + 3k FUTURE)***		

TOTAL NUMBER OF DEVICES 3m.

5.4.3. Determine Raw Data Bandwidth

The fourth question in the data communications procedure aims to identify the bandwidth that will be used by each device. If average bandwidth numbers are not known, the procedure suggests using 9.6 Kbps. This is in accordance with accepted designed principles. As discussed in the introduction to this section, this procedure assumes that all devices are on and transmitting at all times.

Table 5-3 shows Question 4 from the procedure. Enter device rates in the first column. Enter the number of devices using that rate in the second column.

The Bandwidth column is the product of the rate and the number of streams at that rate. The total bandwidth is then obtained by adding the column and entering the result in line 3d.

Note that the total number of devices in the column titled ‘Number’ should match line 3m.

Table 5-3. Question 4 from Data Communications Worksheet.

<table>
<tr>
<td>Raw Data Bandwidth
(Section 5.4.3)</td>
<td>4.</td>
<td>
FOR ALL DEVICES, ASSUME CONSTANT TRANSMISSION
<table>
<tr><th></th><th></th><th>Rate</th><th>Number</th><th>Bandwidth</th></tr>
<tr><td>4a.</td><td>**Known Data Bandwidth Calculation**
For devices with known rates enter the rate and number.</td><td></td><td></td><td></td></tr>
<tr><td>4b.</td><td>**Unknown Data Bandwidth Calculation**
For devices with unknown rates use 9.6 Kbps.</td><td></td><td></td><td></td></tr>
<tr><td>4c.</td><td colspan="2">**Total Bandwidth**
Total number should match line 3m.</td><td></td><td></td></tr>
</table>
TOTAL RAW DATA BANDWIDTH (Kbps)
</td>
<td>4d.</td>
<td></td>
</tr>
</table>

5.4.4. Adjustment for Latency

As was discussed earlier, latency is the delay between any two points in the system. Latency is a fairly important consideration in the design or evaluation of communications systems because it can have a significant effect on the final result.

As presented in Table 5-9, Question 5 in the procedure asks if an acceptable latency value is known. This may be determined from previous experience, by adding the delays between various points, or from the specifications of various equipment manufacturers.

Table 5-4. Question 5 from Data Communications Worksheet.

Acceptable Latency *(Section 5.4.4)*	5.	Do you know what your acceptable latency is? ☐ YES ☐ NO If 'YES,' enter the value on Line 5. If 'NO,' assume 0.25 seconds and enter it on Line 5.	5.	

The procedure suggests that if a value is not known, a value of 250 milliseconds or 0.25 seconds should be assumed. This is a reasonable expectation based upon standard practices and design procedures.

5.4.5. Determine Calculated Data Bandwidth

In Question 6 of the procedure (presented in Table 5-5), the designer essentially inflates the design bandwidth to account for inherent delays in the system. Although delays through the communications equipment and system will always occur, they will be more problematic at lower bandwidths. Using latency to inflate the bandwidth to a higher number essentially acts as a safety factor, ensuring that the design situation is not exceeded and that overall system delays have a negligible impact on the operations of the communications system.

The equation to use for calculating the required bandwidth is below. Latency is expressed in units of seconds. The formula works over a range of 0 to 1 seconds or 0 to 1000 milliseconds. Design latencies above that range would be a very unusual design situation.

$$Raw\ Bandwidth \div \{1 - Latency\} = Calculated\ \ Bandwidth$$

Table 5-5. Question 6 from Data Communications Worksheet.

<table>
<tr><td>Calculated
Data
Bandwidth
<i>(Section 5.4.5)</i></td><td>6.</td><td>
<table>
<tr><td>6a.</td><td>Raw Data Bandwidth, Kbps (from Line 4d)</td><td></td></tr>
<tr><td>6b.</td><td>Acceptable Latency, in seconds (from Line 5)</td><td></td></tr>
<tr><td>6c.</td><td>Calculated Data Bandwidth, Kbps
Calculate using: $Line\ 6a \div \{1 - Line\ 6b\}$</td><td></td></tr>
</table>
CALCULATED DATA BANDWIDTH (Kbps)</td><td>6d.</td><td></td></tr>
</table>

5.4.6. Examine the Use of Single or Multiple Systems

Question 7 of the procedure, illustrated in Table 5-6, is a critical juncture in the data communications design process. The question asks if all of the data streams will be aggregated in one communications system in the field. If the answer is 'NO,' the design situation changes dramatically.

Rather than designing for a single comprehensive solution, an answer of 'NO' indicates you are designing for more of a stand-alone solution for each individual device or cluster of devices. This reduces the aggregate bandwidth necessary and orients the possible solutions toward multiple communications systems with smaller bandwidths.

If the answer to question 7 is 'NO,' the worksheet directs you to skip to Question 9. If the answer to question 6 is 'YES,' you should continue to progress through the worksheet and go to Question 8.

Table 5-6. Question 7 from Data Communications Worksheet.

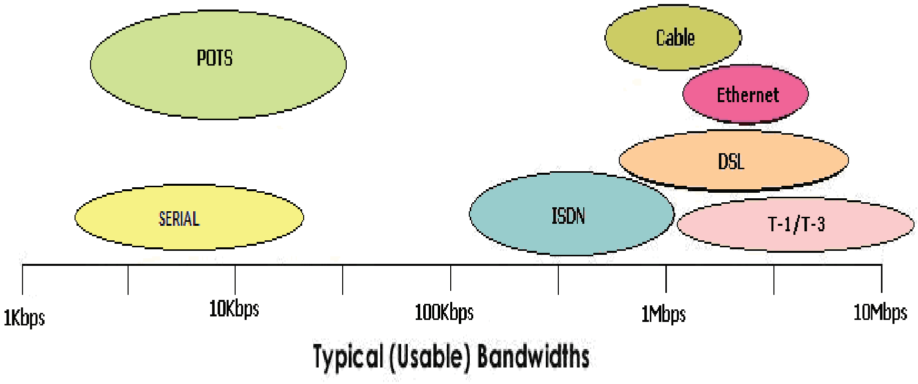
Single or Multiple Systems *(Section 5.4.6)*	7.	Will all of the data streams be aggregated together on one communications system in the field? ☐ YES ☐ NO If the answer is "NO," please go to Question 9.	7.	▨

5.4.7. Multiple Systems – Potential Technology Choices

Question 9 is the final step in the design situation if there will be multiple field communications systems deployed, rather than a single comprehensive system. As Table 5-7 illustrates, at this step of the procedure, the designer determines the potential technology choices for these smaller deployments.

Table 5-7 illustrates a graphic that shows the typical usable bandwidths associated with each of the technology choices. The directions state to draw a vertical line through the graphic for the bandwidth needed at each location. This is an important point to clarify. If one location has a single device, the necessary bandwidth would be the rate for that device. Likewise, if there will be multiple devices tied to a single communications link at one location, enter the figure in Question 9 with the aggregate bandwidth of that location. If you have to recalculate bandwidths at a particular location, do not forget to include the adjustment for latency to provide a factor of safety for that communications link.

Table 5-7. Question 9 from Data Communications Worksheet.

Multiple Systems – Define Potential Technology Choices *(Section 5.4.7)*	9.	Design information provided suggests that multiple communication links will be utilized. Identify potential communication solutions for <u>*EACH*</u> field link by drawing a vertical line through the figure below with a typical (per location) bandwidth need (refer to Question 3). The choices immediately surrounding that line that represent purchased services (Ex: POTS, ISDN, DSL, T-1/T-3, Cable) should be investigated for their applicability.  *After completing this question, please proceed to "Data System Summary."*	9.	

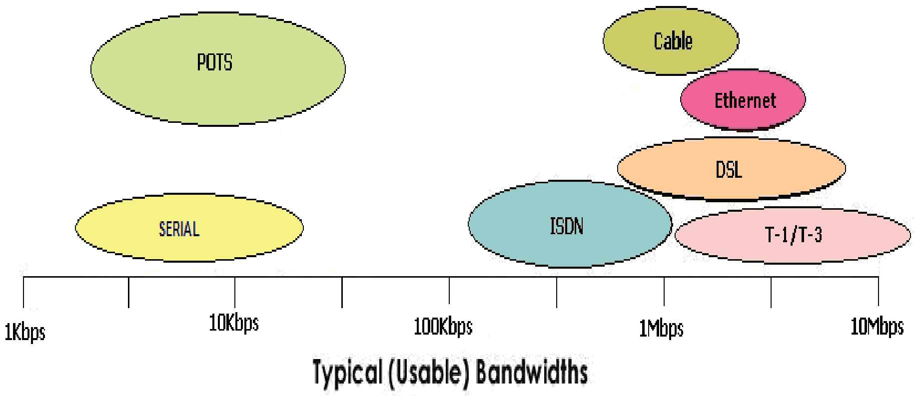
5.4.8. Single System – Potential Technology Choices

Question 8 is the next step in the process if the answer to Question 7 was 'YES,' that there will be a single comprehensive communications system.

As shown in Table 5-16, the question utilizes a graphic that shows the typical usable bandwidths associated with each of the technology choices. The directions state to draw a vertical line through the graphic for the calculated bandwidth from Question 6d.

Anything to the right of that vertical line will be a potential technology choice. Since the vertical line through the diagram represents the *minimum* bandwidth necessary for the video streams, solutions to the right represent technologies that can supply the necessary bandwidth or more.

Table 5-8. Question 8 from Data Communications Worksheet.

Single System – Define Potential Technology Choices *(Section 5.4.8)*	8.	The figure below shows the broad range of technology solutions that are available. The scale is logarithmic. Using the value from Line 6d, draw a vertical line through the graph representing the bandwidth you need. All of the choices to the *RIGHT* of the vertical line are potential choices.  *After completing this question, please proceed to "Data System Summary."*	8.	

5.4.9. Data Communications – Conclusion of Procedure

With the procedure complete and many of the larger issues determined for a data communications solution, the designer should now focus on some of the other issues associated with communications solutions. These issues, which are additional items to consider in any design, are detailed in Section 5.7.

5.5. Video Communications

Video communications require significantly more bandwidth than data communications. The main reason, of course, is that the amount of information required to produce a picture is far greater than the amount of information required to, as an example, display a message on a DMS. In addition, because the camera views a scene that is constantly changing, the flow of information is constant. By comparison, a DMS can be told what message to display and no additional information is necessary.

There are three main factors to understand with regard to video communications: frame rate, resolution, and color depth. Together, these three factors determine the uncompressed bandwidth needed for a video signal.

Frame rate is how many times the picture refreshes in a certain amount of time. The typical measure is frames per second (fps). The standard is 30 fps, relating back to the beginning of the television era. Many video solutions in use today have frame rates as high as 60 fps. The relation to video bandwidth is that the higher the frame rate, the more bandwidth is required.

Resolution is basically the size of the picture, which is typically measured in pixels. A pixel is an abbreviation for the term Picture Element. One pixel is one point or individual dot of light. Resolution is specified by telling the number of pixels horizontally and then the number of pixels vertically.

As an example, a typical computer screen resolution is 1024 × 768, meaning there are 1024 pixels horizontally and 768 pixels vertically. One frame at that resolution has to convey information about 786,432 individual points of light. The larger the resolution, the more bandwidth required to transmit the information. Some common video resolutions are 176 × 144 (QCIF), 352 × 288 (CIF), and 720 × 576 (D1).

The last factor pertaining to video is the color depth. This refers to how much information it is necessary to convey about each individual pixel. Computers often use 24-bit color. Since we know that 8 bits equals 1 byte, it takes 3 bytes to convey information about each pixel.

The total bandwidth of a video stream can then be calculated as the product of the resolution, frame rate, and color depth. As can be seen from the example calculation below, a single stream of uncompressed video to a computer screen would take nearly 71 Mbps.

$$1 \textit{ frame at } 1024 \textit{ x } 768 \textit{ resolution} = 786{,}432 \textit{ pixels per frame}$$

$$786{,}432 \textit{ pixels x } 3 \textit{ bytes per pixel color depth} = 2{,}359{,}296 \textit{ bytes per frame}$$

$$2{,}359{,}296 \textit{ bytes per frame x } 30 \textit{ frames per second} = 70{,}778{,}880 \textit{ bytes per second}$$

$$70{,}778{,}880 \textit{ bytes per second} = 70.8 \textit{ MBps} = 566 \textit{ Mbps}$$

Although the example above pertains to computers, the bandwidth of a single video stream from a camera is also significant. Consider the case of a video stream operating at D-1 resolution.

$$1 \textit{ frame at } 720 \textit{ x } 576 \textit{ resolution} = 414{,}720 \textit{ pixels per frame}$$

$$414{,}720 \textit{ pixels x } 3 \textit{ bytes per pixel color depth} = 1{,}244{,}160 \textit{ bytes per frame}$$

$$1{,}244{,}160 \textit{ bytes per frame x } 30 \textit{ frames per second} = 37{,}324{,}800 \textit{ bytes per second}$$

$$37{,}324{,}800 \textit{ bytes per second} = 37.3 \textit{ MBps} = 298.4 \textit{ Mbps}$$

A single uncompressed video stream can consume nearly 300 Mbps bandwidth!

The guidebook materials identify a number of solutions that could meet this bandwidth requirement, but the associated cost for even a single camera would be very significant. A small system of 10 cameras could potentially cost several million dollars per year to transmit the video streams. The guidebook materials discuss the use of techniques to reduce the amount of video bandwidth, including the use of encoding. This allows the video stream to be transported using a much smaller amount of bandwidth and, typically, reduced operating cost for the communications technology.

One way to decrease the amount of bandwidth is to decrease the resolution but keep the frame rate the same. Alternatively, many video deployments drop the frame rate to something less than 30 fps but keep the resolution the same.

While the above trade-offs help to reduce the total bandwidth, it is still substantial. Most video streams utilize compression to help decrease the required bandwidth. Compression is the process of encoding the video information to reduce the amount of information that has to be transmitted for each frame of video. Several standard video encoding algorithms were discussed in Chapter 3 of this guidebook. The trade-off to increased compression is a loss in quality of the video stream.

5.6. Video Design/Evaluation Methodology

The process presented in this guidebook for designing or evaluating video solutions is illustrated in the flow chart in Figure 5-2. The figure shows the eight parts of the methodology. Each part of the methodology is referenced to a section in this chapter, where detailed information is provided. A worksheet that covers the entire process can be found in Chapter 6.

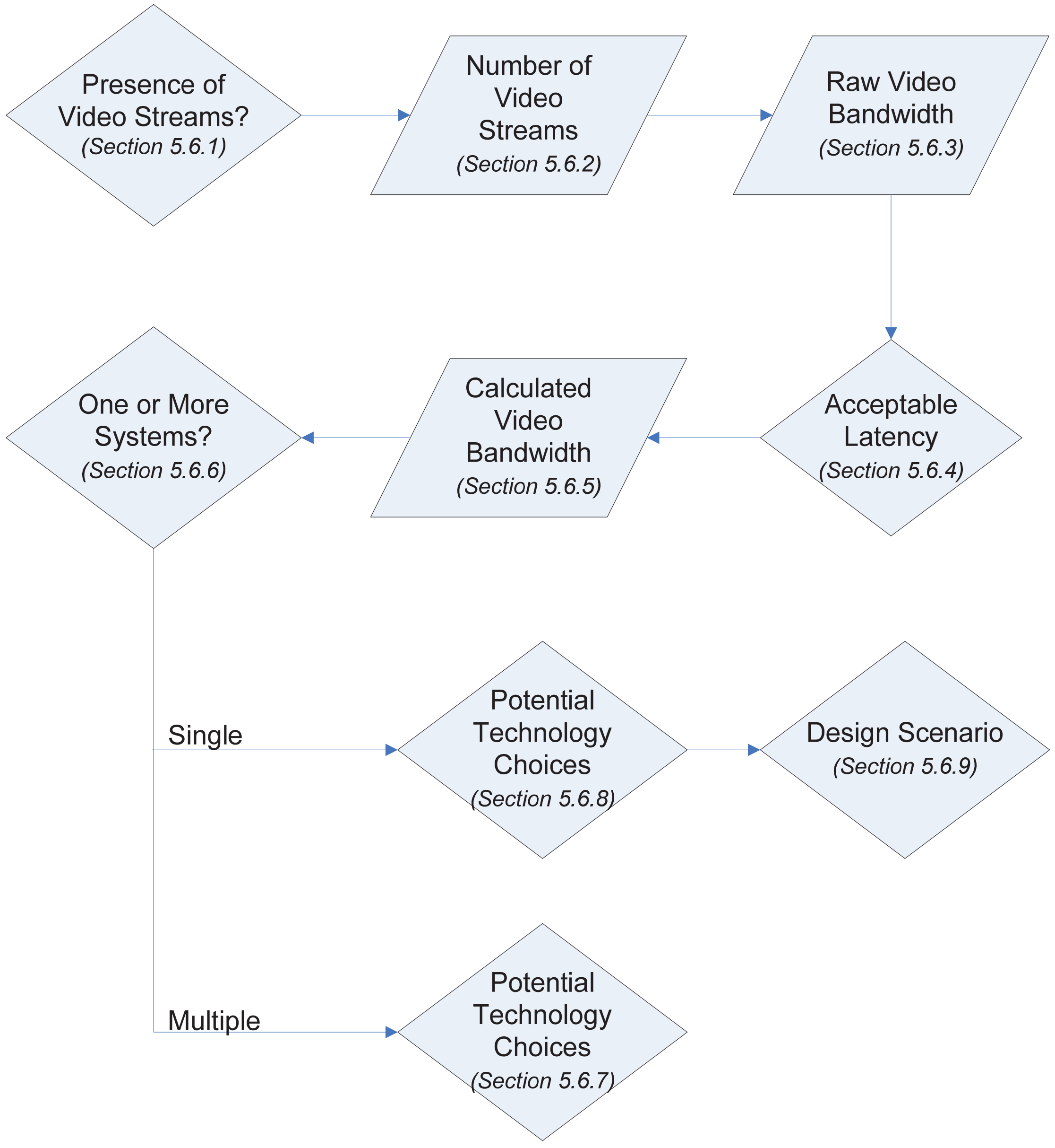


Figure 5-2. Flowchart for Video System Design/Evaluation.

5.6.1. Presence of Video Streams

The first question in the methodology is asked to determine if video streams will be a part of the design requirements. An answer of 'YES' tells the user to proceed through the worksheet and determine their needs and potential solutions. An answer of 'NO' indicates that video will not be a part of the design requirements and that this worksheet is not needed. Table 5-9 shows the question from the video design and evaluation worksheet.

Table 5-9. Question 1 from Video Communications Worksheet.

Presence of Video Streams *(Section 5.6.1)*	1.	Are video streams in use now or will they be in the future? ☐ YES ☐ NO If 'YES,' proceed with Question 2. If 'NO,' you do not need this worksheet.	1.	▨

5.6.2. Number of Video Streams

The second question in the procedure asks you to identify both the type and number of video streams that are present in the system today and that must be accommodated in the future. The breakdown of video streams by type is provided simply to help the designer identify different camera sources. Other than the bandwidth in use, there is no inherent difference in the video stream from one type of camera to another.

Table 5-10 shows the question from the video design and evaluation worksheet. The total number of video streams you are designing for is contained in Line 2h of the table, which is the summation of current plus future needs.

Table 5-10. Question 2 from Video Communications Worksheet.

<table>
<tr>
<td>Number of Video Streams <i>(Section 5.6.2)</i></td>
<td>2.</td>
<td>How many video streams?
<table>
<tr><th></th><th></th><th colspan="2">Number of Streams</th></tr>
<tr><th></th><th>Type of Video Streams</th><th>Current</th><th>Future</th></tr>
<tr><td>2a.</td><td>PTZ Color Video Streams</td><td></td><td></td></tr>
<tr><td>2b.</td><td>PTZ B/W Video Streams</td><td></td><td></td></tr>
<tr><td>2c.</td><td>Static Color Video Streams</td><td></td><td></td></tr>
<tr><td>2d.</td><td>Static B/W Video Streams</td><td></td><td></td></tr>
<tr><td>2e.</td><td>Intersection Detection Cameras</td><td></td><td></td></tr>
<tr><td>2f.</td><td><i>Subtotals</i></td><td></td><td></td></tr>
<tr><td>2g.</td><td><i>TOTAL NUMBER OF VIDEO STREAMS (Add 2f CURRENT + 2f FUTURE)</i></td><td colspan="2"></td></tr>
</table>
TOTAL NUMBER OF VIDEO STREAMS</td>
<td>2h.</td>
<td></td>
</tr>
</table>

5.6.3. Determine Raw Video Bandwidth

The third question in the procedure aims to identify the bandwidth that will be used by each video stream. It is important to understand that this question assumes the use of standard compression techniques to reduce the amount of bandwidth. It would be uncommon for video to be transmitted at its full uncompressed bandwidth.

If average bandwidth numbers are not known, the procedure suggests some for use. A low-bandwidth video stream is suggested to be 0.5 Mbps, a medium stream 2.0 Mbps, and a high-bandwidth stream 6.0 Mbps. The higher bandwidths reflect less compression and therefore a higher quality picture at the receiving end. It should be noted that video is inherently a subjective media. What looks great to one person may look poor to another. There are no predefined limits or bandwidth rates that have been found to represent the majority of the population and how they perceive video quality.

Table 5-11 shows Question 3 from the video design and evaluation worksheet. If you know the bandwidth rate that you intend to use for each type of camera deployment, the procedure allows you to enter your own numbers. Enter the rates in the first column.

The second column, titled "Number," is the total number of video streams that will be run at that particular rate. The sum of the number column in line 3d should equal the total number of streams identified in Question 2.

The third column, titled "Bandwidth," is the product of the rate and the number of streams at that rate. The total bandwidth is then obtained by adding the column and entering the result in line 3d.

Table 5-11. Question 3 from Video Communications Worksheet.

<table>
<tr>
<td>Raw Video Bandwidth
(Section 5.6.3)</td>
<td>3.</td>
<td>
<table>
<tr><th></th><th>Type of Video Stream</th><th>Rate</th><th>Number</th><th>Bandwidth</th></tr>
<tr><td>**3a.**</td><td>**Low-Speed Video Stream**
If rate unknown, use 0.5 Mbps.</td><td></td><td></td><td></td></tr>
<tr><td>**3b.**</td><td>**Medium-Speed Video Stream**
If rate unknown, use 2.0 Mbps.</td><td></td><td></td><td></td></tr>
<tr><td>**3c.**</td><td>**High-Speed Video Stream**
If rate unknown, use 6 Mbps.</td><td></td><td></td><td></td></tr>
<tr><td>**3d**</td><td colspan="2">***TOTALS (Add sum of 3a through 3c)***
CHECK: Total Number of Streams should match Line 2h</td><td></td><td></td></tr>
</table>
TOTAL RAW VIDEO STREAM BANDWIDTH (Mbps)
</td>
<td>3e.</td>
<td></td>
</tr>
</table>

5.6.4. Adjustment for Latency

As was discussed earlier, latency is the delay between any two points in the system. Latency is a fairly important consideration in the design or evaluation of communications systems because it can have a significant effect on the final result.

As presented in Table 5-12, Question 4 in the procedure asks if an acceptable latency value is known. This may be determined from previous experience, by adding the delays between various points, or from the specifications of various equipment manufacturers.

Table 5-12. Question 4 from Video Communications Worksheet.

Acceptable Latency *(Section 5.6.4)*	4.	Do you know what your acceptable latency is? ☐ YES ☐ NO If 'YES,' enter the value on Line 4. If 'NO,' assume 0.25 seconds and enter it on Line 4	4.	

The procedure suggests that if latency is not known, a value of 250 milliseconds, or 0.25 seconds should be assumed. This is a reasonable expectation based upon standard practices and design procedures.

5.6.5. Determine Calculated Video Bandwidth

In Question 5 of the procedure (presented in Table 5-13), the designer essentially inflates the design bandwidth to account for inherent delays in the system. Although delays through the communications equipment and system will always occur, they will be more problematic at lower bandwidths. Using latency to inflate the bandwidth essentially acts as a safety factor, ensuring that the design situation is not exceeded and that overall system delays have a negligible impact on the operations of the communications system.

The equation to use for calculating the required bandwidth is below. Latency is expressed in units of seconds. The formula works over a range of 0 to 1 seconds or 0 to 1000 milliseconds. Design latencies above that range would be a very unusual design situation.

$$Raw\ Bandwidth \div \{1 - Latency\} = Calculated\ \ Bandwidth$$

Table 5-13. Question 5 from Video Communications Worksheet.

<table>
<tr>
<td>Calculated Video Bandwidth <i>(Section 5.6.5)</i></td>
<td>5.</td>
<td>
<table>
<tr><td>5a.</td><td>Raw Video Bandwidth, Mbps (from Line 3e)</td><td></td></tr>
<tr><td>5b.</td><td>Acceptable Latency, in seconds (from Line 4)</td><td></td></tr>
<tr><td>5c.</td><td>Calculated Video Bandwidth, Mbps
Calculate using: $Line\ 5a \div \{1 - Line\ 5b\}$</td><td></td></tr>
</table>
CALCULATED VIDEO STREAM BANDWIDTH (Mbps)
</td>
<td>5d.</td>
<td></td>
</tr>
</table>

5.6.6. Examine the Use of Single or Multiple Systems

Question 6 of the procedure, illustrated in Table 5-14, is a critical juncture in the design process. The question asks if all of the video streams will be aggregated in one communications system in the field. If the answer is 'NO,' the design situation changes dramatically.

Rather than designing for a single comprehensive solution, you are designing for more of a stand-alone solution for each individual camera or cluster of video streams. This reduces the aggregate bandwidth necessary and orients the possible solutions toward multiple communications systems with smaller bandwidths.

If the answer to Question 6 is 'NO,' the worksheet directs you to skip to Question 13. If the answer to Question 6 is 'YES,' you should continue to progress through the worksheet and go to Question 7.

Table 5-14. Question 6 from Video Communications Worksheet.

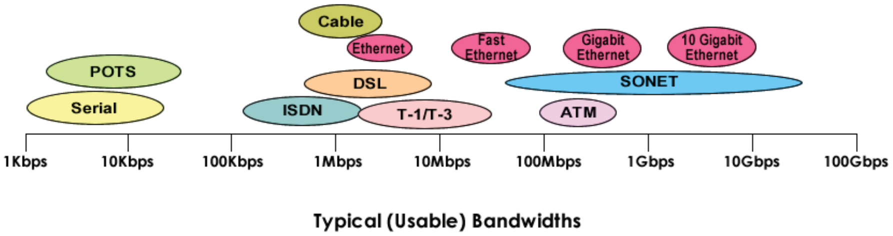
Single or Multiple Systems *(Section 5.6.6)*	6.	Will all of the video streams be aggregated together on one communications system in the field? ☐ YES ☐ NO If the answer is "NO,' please go to Question 13.	6.	▨

5.6.7. Multiple Systems – Potential Technology Choices

Question 13 is the final step in the design situation if there will be multiple field communications systems deployed, rather than creating a single comprehensive system. As Table 5-15 illustrates, at this step of the procedure, the designer determines the potential technology choices for these smaller deployments.

Table 5-15 illustrates a graphic that shows the typical usable bandwidths associated with each of the technology choices. The directions state to draw a vertical line through the graphic for the bandwidth needed at each location. This is an important point to clarify. If one location has a single camera, the necessary bandwidth would be the rate for that single camera. However, don't forget to include the adjustment for latency to provide a factor of safety for that communications link.

Table 5-15. Question 13 from Video Communications Worksheet.

Multiple Systems – Define Potential Technology Choices *(Section 5.6.7)*	13.	Design information provided suggests that multiple communication links will be utilized. Identify potential communication solutions for *EACH* field link by drawing a vertical line through the figure below with a typical (per location) bandwidth need (refer to Question 3). The choices immediately surrounding that line that represent purchased services (Ex: POTS, ISDN, DSL, T-1/T-3, Cable) should be investigated for their applicability.  *After completing this question, please proceed to "Video System Summary."*	13.	

If the location in question will have more than one camera, the aggregate bandwidth for all devices at that location should be used to determine the appropriate technology choices. Again, don't forget to include the adjustment for latency to provide a factor of safety.

The choice to use multiple communications links indicates that the appropriate solutions will likely be purchased services, such as ISDN, DSL, cable modem, or T-1. It would be highly unlikely that a constructed communications system such as Ethernet, ATM, or SONET would be built as multiple individual systems.

The graphic in Question 13 should be utilized for as many individual deployment locations that you will have. Refer to Chapter 4 for details and typical information pertaining to each of the technology choices identified as a possible solution. The final decision may depend on local availability, future scalability, cost, available expertise, and more.

At the conclusion of the worksheet a small summary table is provided to record the main results of your analysis. This provides a quick way to run through multiple scenarios and summarize the information from each alternative.

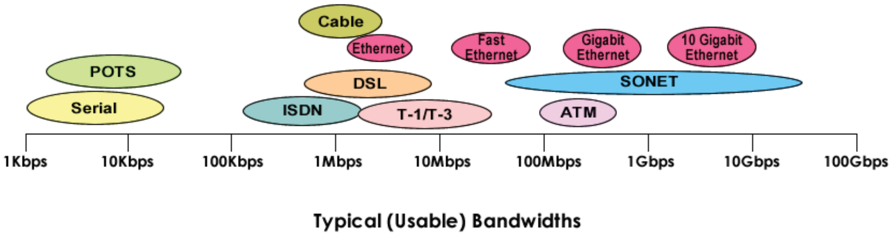
5.6.8. Single System – Potential Technology Choices

Question 7 is the next step in the process if the answer to Questions 6 was ‘YES,’ that there will be a single comprehensive communications system.

As shown in Table 5-16, the question utilizes a graphic that shows the typical usable bandwidths associated with each of the technology choices. The directions state to draw a vertical line through the graphic for the calculated bandwidth from Question 5d.

Anything to the right of that vertical line will be a potential technology choice. Since the vertical line through the diagram represents the *minimum* bandwidth necessary for the video streams, solutions to the right represent technologies that can supply the necessary bandwidth or more.

Table 5-16. Question 7 from Video Communications Worksheet.

Single System – Define Potential Technology Choices *(Section 5.6.8)*	7.	The figure below shows the broad range of technology solutions that are available. The scale is logarithmic. Using the value from Line 5d, draw a vertical line through the graph representing the bandwidth you need. All of the choices to the *RIGHT* of the vertical line are potential choices.  	7.	

5.6.9. Single System – Design Situation

The final step in the design process is to determine the most applicable design situation for the communications system. These situations were identified in Section 5.2.3 as being either unicast or multicast.

Table 5-17 illustrates Question 8 from the procedure. The critical point behind Question 8 is ownership. If an agency does not own and operate 100 percent of the system, including the media and all of the equipment, multicast is not the preferred design scenario. As mentioned previously, multicast takes a considerable amount of expertise to set up, operate, and maintain. While multicast can be a far more efficient use of resources, many agencies are not experienced with its use. In fact, many agencies that share communications networks do not allow the use of multicast systems because they lack the available expertise.

Table 5-17. Question 8 from Video Communications Worksheet.

Single System – Most Appropriate Design Scenario *(Section 5.6.9*	8.	Will you be able to own, operate, and maintain 100% of your communications network internal to your agency? ☐ YES ☐ NO If the answer is 'YES,' please proceed to Question 9. If the answer is 'NO,' you should design for Unicast operations *After completing this question, please proceed to "Video System Summary."*	8.	▨

If the answer to Question 8 is 'NO,' that an agency does not own, operate, and maintain 100 percent of the communications network, the appropriate design scenario is unicast operations.

If the answer to Question 8 is 'YES,' that an agency does own, operate, and maintain 100 percent of the communications network, the appropriate design scenario is still open for consideration and the designer should proceed to Questions 9–12.

Table 5-18 illustrates Questions 9–12 of the procedure. Questions 9 through 11 each ask a basic question pertaining to how the communications system is envisioned to be used.

Question 9 asks if the video streams need to be received at more than one location. An answer of 'YES' heavily favors a multicast design scenario, as it will be the most efficient in terms of equipment and cost.

Table 5-18. Questions 9–12 from Video Communications Worksheet.

<table>
<tr><td rowspan="4">Single System – Most Appropriate Design Scenario
(Section 5.6.9)</td><td>9.</td><td>Does the same video stream need to be received at more than one location?
☐ YES ☐ NO</td><td>9.</td><td>▨</td></tr>
<tr><td>10.</td><td>Are you willing to manually reconfigure video streams?
☐ YES ☐ NO</td><td>10.</td><td>▨</td></tr>
<tr><td>11.</td><td>What is the PRIMARY design constraint? (Please select one)
☐ Simplicity (S) ☐ Cost (C) ☐ Bandwidth (B)</td><td>11.</td><td>▨</td></tr>
<tr><td>12.</td><td>What design situation is most applicable to your situation?

Enter the table below with the results from Questions 9 through 11 to find the most appropriate design for your situation.
<table>
<tr><td>Q9</td><td>Y</td><td>Y</td><td>Y</td><td>Y</td><td>Y</td><td>Y</td><td>N</td><td>N</td><td>N</td><td>N</td><td>N</td><td>N</td></tr>
<tr><td>Q10</td><td>Y</td><td>Y</td><td>Y</td><td>N</td><td>N</td><td>N</td><td>Y</td><td>Y</td><td>Y</td><td>N</td><td>N</td><td>N</td></tr>
<tr><td>Q11</td><td>S</td><td>B</td><td>C</td><td>S</td><td>B</td><td>C</td><td>S</td><td>B</td><td>C</td><td>S</td><td>B</td><td>C</td></tr>
<tr><td><i>Design for</i></td><td>(a)</td><td>Multicast</td><td>Multicast</td><td>Unicast</td><td>(a)</td><td>(b)</td><td>Unicast</td><td>Multicast</td><td>Multicast</td><td>Unicast</td><td>Unicast</td><td>Unicast</td></tr>
</table>
(a) Design goals are somewhat at odds. Multicast is favored.
(b) Design goals are somewhat at odds. Unicast is favored.

After completing this question, please proceed to “Video System Summary.”</td><td>12.</td><td></td></tr>
</table>

Question 10 seeks to determine if your agency or operators are equipped to change parameters on the various types of hardware found in the system. Many deployments typically have more cameras in the field than they have the capability to view at any given time. While many system software solutions can easily change video streams operating in a unicast scenario, the state-of-the-practice is not as advanced in the multicast scenario. Enterprise-level solutions that change all of the parameters necessary for switching multicast streams are in their infancy. If employees are not familiar with changing equipment parameters and are not comfortable operating in that environment, multicast would not be the preferred design option.

Question 11 asks what the primary constraint is in building the communications system. The three possible choices are simplicity, cost, and bandwidth. Cost and bandwidth both favor the use of a multicast design scenario, while simplicity favors the use of a unicast design scenario.

Question 12 consists of a matrix of answers from Questions 9 through 11. Entering the matrix and identifying the answers chosen for Questions 9 through 11 yields a preferred design scenario most of the time.

In a small percentage of cases, the responses from Questions 9 through 11 may prove to be at odds with each other. An example might be that video streams need to be received at multiple locations, employees are not comfortable with the concept of reconfiguration equipment, and the primary design constraint is bandwidth. The result from the matrix indicates that multicast is favored, but it is not a clear consensus choice. While the employee's concerns are warranted, the need to minimize bandwidth and provide video streams at multiple locations may preempt the desire to not change equipment settings.

5.6.10. Video Communications – Conclusion of Procedure

With the video design procedure complete and many of the larger issues determined for a communications solution, the designer should now focus on some of the other issues discussed in Section 5.7 to ensure a comprehensive communications solution.

5.7. Other Design Considerations

As has been discussed previously, the design of a communications solution is often more of an art than an exact science. Multiple solutions can be created for nearly every need. While the methodology used for data and video communications solutions in this guidebook covers numerous technologies and implementations, it cannot cover every design situation.

Table 5-19 lists several areas of any communications system that warrant additional consideration. These areas include items such as funding. One of the critical issues that face ITS deployments is a lack of funding for ongoing operations and maintenance. It is entirely conceivable that a communications system choice might be made on the basis of long-term funding availability.

Another critical area identified in the table across several categories is training. The implementation of advanced communications systems may require significant additional expertise at all levels of the organization. Staff may need training in proper maintenance of equipment. Operators and managers may need training to understand the capabilities of new deployments and how these fit into the normal activities.

The prudent designer should take items such as those identified in Table 5-19 into consideration before a final design decision is made.

Table 5-19. Additional Considerations for All Deployments.

Deployment Locations	• Field cabinets? • Traffic management centers (TMCs)? • Controlled access areas? • Hardened equipment will cost more. • Additional security may be necessary to protect equipment.
Project Funding	• What is included in the system cost? • What other equipment is necessary? • Is training required? • Are funds available for maintenance? • Is there a budget for monthly operating cost if using purchased services?
	• Is this a budgeted item? • Is this a one-time purchase? • Are there provisions that have to be met?
Construction Timeline	• Purchased services can be installed more quickly. • Can some installation be done in-house? • Does construction have to take place within the bid process?
Ease of Implementation	• Can some work be done in-house? • Can some equipment be pre-configured? • Can equipment be standardized with other deployments?
System Expansion Capability	• Can the system be expanded in the future? • Will equipment have to be added or replaced? • How compatible will future equipment be (changing standards)?
Staff Expertise	• How much expertise is needed? • Can staff on hand do the job? • Are new hires necessary? • How will staff training be paid for?
System Managers	• Are system managers knowledgeable enough to integrate new deployments and resources? • How much training is necessary? • Are new hires necessary?
System Maintainers	• Is specialized communications training necessary? • Who will pay for training costs? • If training is available, who is eligible to receive it? • Are new hires necessary?

6. DESIGN/EVALUATION METHODOLOGIES

6.1. Data Communications Methodology

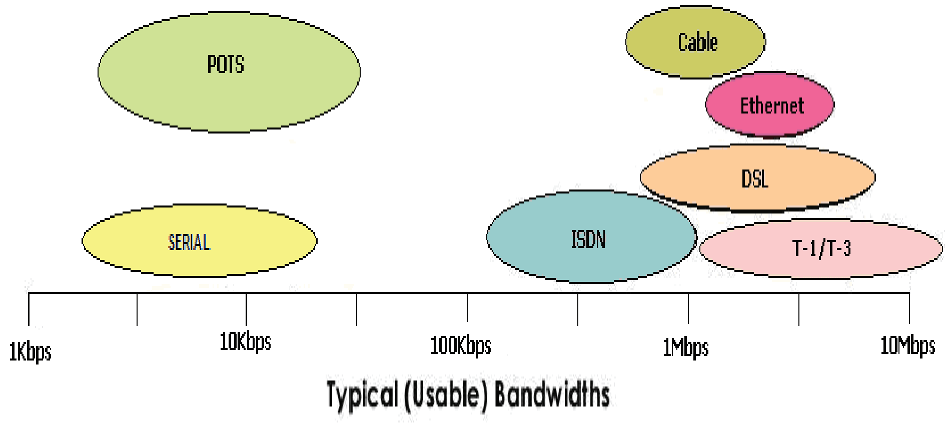
This section contains the worksheets for performing a comprehensive evaluation of the data communications for ITS deployments. The methodology is applicable to new deployments or an evaluation of an existing system or design.

This section contains blank worksheets for future use. The reader is encouraged to make copies of the following pages and use them for their design and evaluation needs. The worksheets in this book should be left blank to ensure an available source of clean copies.

Chapter 5 details each step in the data communications procedure and provides both explanation and analysis. Chapter 7 contains case studies utilizing the procedures contained in this chapter.

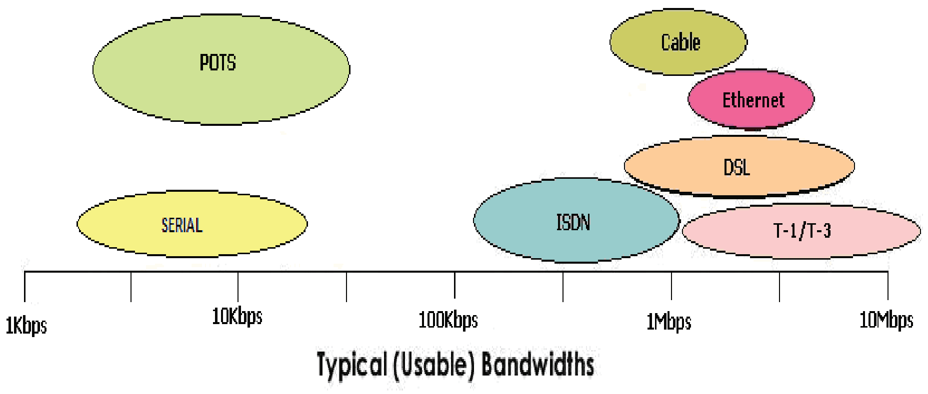
Table 6-1. Data Communications Design/Evaluation Worksheet.

<table>
<tr><th colspan="5">Data Communications Design Worksheet</th></tr>
<tr><td rowspan="2">Presence of Video Streams <i>(Section 5.4.1)</i></td><td>1.</td><td>Are video streams in use now or will they be in the future?
☐ YES ☐ NO
If 'NO,' proceed to Question 3.</td><td>1.</td><td>▨</td></tr>
<tr><td>2.</td><td>Are the video streams and data being transmitted together over the same communications system in the field?
☐ YES ☐ NO
If 'YES,' you do not need this worksheet, you need the Digital Video Communications Design Worksheet.
If 'NO,' proceed to Question 3.</td><td>2.</td><td>▨</td></tr>
<tr><td>Number of Devices <i>(Section 5.4.2)</i></td><td>3.</td><td>How many of the following devices do you have?
<table>
<tr><th></th><th></th><th colspan="2">Number of Devices</th></tr>
<tr><th></th><th>Device Type</th><th>Current</th><th>Future</th></tr>
<tr><td>3a.</td><td>Dynamic Message Signs</td><td></td><td></td></tr>
<tr><td>3b.</td><td>Vehicle/Roadway Detectors</td><td></td><td></td></tr>
<tr><td>3c.</td><td>TxDOT LCU</td><td></td><td></td></tr>
<tr><td>3d.</td><td>TxDOT SCU</td><td></td><td></td></tr>
<tr><td>3e.</td><td>RWIS</td><td></td><td></td></tr>
<tr><td>3f.</td><td>Weather Stations</td><td></td><td></td></tr>
<tr><td>3g.</td><td>Ramp Meters</td><td></td><td></td></tr>
<tr><td>3h</td><td>PTZ Camera</td><td></td><td></td></tr>
<tr><td>3i</td><td>Traffic Controllers</td><td></td><td></td></tr>
<tr><td>3j.</td><td>Other</td><td></td><td></td></tr>
<tr><td>3k.</td><td><i>Subtotals</i></td><td></td><td></td></tr>
<tr><td>3l.</td><td><i>TOTAL NUMBER OF DATA STREAMS (Add 3k CURRENT + 3k FUTURE)</i></td><td colspan="2"></td></tr>
</table>
TOTAL NUMBER OF DEVICES</td><td>3m.</td><td></td></tr>
<tr><td>Raw Data Bandwidth <i>(Section 5.4.3)</i></td><td>4.</td><td>FOR ALL DEVICES, ASSUME CONSTANT TRANSMISSION
<table>
<tr><th></th><th></th><th>Rate</th><th>Number</th><th>Bandwidth</th></tr>
<tr><td>4a.</td><td>Known Data Bandwidth Calculation
<i>For devices with known rates enter the rate and number.</i></td><td></td><td></td><td></td></tr>
<tr><td>4b.</td><td>Unknown Data Bandwidth Calculation
<i>For devices with unknown rates use 9.6 Kbps.</i></td><td></td><td></td><td></td></tr>
<tr><td>4c.</td><td colspan="2">Total Bandwidth
<i>Total number should match line 3m.</i></td><td></td><td></td></tr>
</table>
TOTAL RAW DATA BANDWIDTH (Kbps)</td><td>4d.</td><td></td></tr>
</table>

<table>
<tr><td>Acceptable Latency
(Section 5.4.4)</td><td>5.</td><td>Do you know what your acceptable latency is?
☐ YES ☐ NO
If ‘YES,’ enter the value on Line 5.
If ‘NO,’ assume 0.25 seconds and enter it on Line 5.</td><td>5.</td><td></td></tr>
<tr><td>Calculated Data Bandwidth
(Section 5.4.5)</td><td>6.</td><td><table><tr><td>**6a.**</td><td>**Raw Data Bandwidth, Kbps (from Line 4d)**</td><td></td></tr><tr><td>**6b.**</td><td>**Acceptable Latency, in seconds (from Line 5)**</td><td></td></tr><tr><td>**6c.**</td><td>**Calculated Data Bandwidth, Kbps**
Calculate using: *Line 6a* ÷ {1 – *Line 6b*}</td><td></td></tr></table>
CALCULATED DATA BANDWIDTH (Kbps)</td><td>6d.</td><td></td></tr>
<tr><td>Single or Multiple Systems
(Section 5.4.6)</td><td>7.</td><td>Will all of the data streams be aggregated together on one communications system in the field?
☐ YES ☐ NO
If the answer is ‘NO,’ please go to Question 9.</td><td>7.</td><td>▨</td></tr>
<tr><td>Single System – Define Potential Technology Choices
(Section 5.4.8)</td><td>8.</td><td>The figure below shows the broad range of technology solutions that are available. The scale is logarithmic. Using the value from Line 6d, draw a vertical line through the graph representing the bandwidth you need. All of the choices to the *RIGHT* of the vertical line are potential choices.

After completing this question, please proceed to “Data System Summary.”</td><td>8.</td><td>▨</td></tr>
</table>

<table>
<tr>
<td>Multiple Systems – Define Potential Technology Choices (Section 5.4.7)</td>
<td>9.</td>
<td>

Design information provided suggests that multiple communication links will be utilized. Identify potential communication solutions for <u>EACH</u> field link by drawing a vertical line through the figure below with a typical (per location) bandwidth need (refer to Question 3). The choices immediately surrounding that line that represent purchased services (Ex: POTS, ISDN, DSL, T-1/T-3, Cable) should be investigated for their applicability.



After completing this question, please proceed to "Data System Summary"

</td>
<td>9..</td>
<td></td>
</tr>
</table>

Data System Summary (please record the result of your worksheet analysis)	
Data Bandwidth (from Line 6d)	_______ Kbps
System Type (circle one)	Multiple links Single aggregated network
Technologies under consideration (list top 3 choices)	1. 2. 3.

6.2. Video Communications Methodology

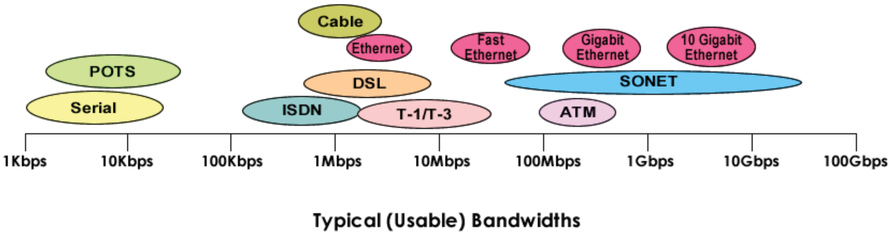
This section contains the worksheets for performing a comprehensive evaluation of digital video communications for ITS deployments. The methodology is applicable to new deployments or an evaluation of an existing system or design.

This section contains blank worksheets for future use. The reader is encouraged to make copies of the following pages and use them for their design and evaluation needs. The worksheets in this book should be left blank to ensure an available source of clean copies.

Chapter 5 details each step in the digital video communications procedure and provides both explanation and analysis. Chapter 7 contains case studies utilizing the procedures contained in this chapter.

Table 6-2. Video Communications Design/Evaluation Worksheet.

<table>
<tr><th colspan="5">Digital Video Communications Design Worksheet</th></tr>
<tr>
<td>Presence of Video Streams
(Section 5.6.1)</td>
<td>1.</td>
<td>Are video streams in use now or will they be in the future?
☐ YES ☐ NO
If ‘YES,’ proceed with Question 2.
If ‘NO,’ you do not need this worksheet.</td>
<td>1.</td>
<td>▨</td>
</tr>
<tr>
<td>Number of Video Streams
(Section 5.6.2)</td>
<td>2.</td>
<td>How many video streams?
<table>
<tr><th></th><th></th><th colspan="2">Number of Streams</th></tr>
<tr><th></th><th>Type of Video Streams</th><th>Current</th><th>Future</th></tr>
<tr><td>2a.</td><td>PTZ Color Video Streams</td><td></td><td></td></tr>
<tr><td>2b.</td><td>PTZ B/W Video Streams</td><td></td><td></td></tr>
<tr><td>2c.</td><td>Static Color Video Streams</td><td></td><td></td></tr>
<tr><td>2d.</td><td>Static B/W Video Streams</td><td></td><td></td></tr>
<tr><td>2e.</td><td>Intersection Detection Cameras</td><td></td><td></td></tr>
<tr><td>2f.</td><td>*Subtotals*</td><td></td><td></td></tr>
<tr><td>2g.</td><td>*TOTAL NUMBER OF VIDEO STREAMS (Add 2f CURRENT + 2f FUTURE)*</td><td colspan="2"></td></tr>
</table>
TOTAL NUMBER OF VIDEO STREAMS</td>
<td>2h.</td>
<td></td>
</tr>
<tr>
<td>Raw Video Bandwidth
(Section 5.6.3)</td>
<td>3.</td>
<td>
<table>
<tr><th></th><th>Type of Video Stream</th><th>Rate</th><th>Number</th><th>Bandwidth</th></tr>
<tr><td>3a.</td><td>**Low-Speed Video Stream**
If rate unknown, use 0.5 Mbps.</td><td></td><td></td><td></td></tr>
<tr><td>3b.</td><td>**Medium-Speed Video Stream**
If rate unknown, use 2.0 Mbps.</td><td></td><td></td><td></td></tr>
<tr><td>3c.</td><td>**High-Speed Video Stream**
If rate unknown, use 6 Mbps.</td><td></td><td></td><td></td></tr>
<tr><td>3d</td><td colspan="2">*TOTALS (Add sum of 3a through 3c)*
CHECK: Total Number of Streams should match Line 2h</td><td></td><td></td></tr>
</table>
TOTAL RAW VIDEO STREAM BANDWIDTH (Mbps)</td>
<td>3e.</td>
<td></td>
</tr>
<tr>
<td>Acceptable Latency
(Section 5.6.4)</td>
<td>4.</td>
<td>Do you know what your acceptable latency is?
☐ YES ☐ NO
If ‘YES,’ enter the value on Line 4.
If ‘NO,’ assume 0.25 seconds and enter it on Line 4.</td>
<td>4.</td>
<td></td>
</tr>
<tr>
<td>Calculated Video Bandwidth
(Section 5.6.5)</td>
<td>5.</td>
<td>
<table>
<tr><td>5a.</td><td>**Raw Video Bandwidth, Mbps (from Line 3e)**</td><td></td></tr>
<tr><td>5b.</td><td>**Acceptable Latency, in seconds (from Line 4)**</td><td></td></tr>
<tr><td>5c.</td><td>**Calculated Video Bandwidth, Mbps**
Calculate using: $Line\ 5a \div \{1 - Line\ 5b\}$</td><td></td></tr>
</table>
CALCULATED VIDEO STREAM BANDWIDTH (Mbps)</td>
<td>5d.</td>
<td></td>
</tr>
</table>

Single or Multiple Systems *(Section 5.6.6)*	6.	Will all of the video streams be aggregated together on one communications system in the field? ☐ YES ☐ NO If the answer is 'NO,' please go to Question 13.	6.	
Single System – Define Potential Technology Choices *(Section 5.6.8)*	7.	The figure below shows the broad range of technology solutions that are available. The scale is logarithmic. Using the value from Line 5d, draw a vertical line through the graph representing the bandwidth you need. All of the choices to the *RIGHT* of the vertical line are potential choices.  	7.	
Single System – Most Appropriate Design Scenario *(Section 5.6.9)*	8.	Will you be able to own, operate, and maintain 100% of your communications network internal to your agency? ☐ YES ☐ NO If the answer is 'YES,' please proceed to Question 9. If the answer is 'NO,' you should design for Unicast operations. *After completing this question, please proceed to "Video System Summary."*	8.	
	9.	Does the same video stream need to be received at more than one location? ☐ YES ☐ NO	9.	
	10.	Are you willing to manually reconfigure video streams? ☐ YES ☐ NO	10.	
	11.	What is the PRIMARY design constraint? (Please select one) ☐ Simplicity (S) ☐ Cost (C) ☐ Bandwidth (B)	11.	

Single System – Most Appropriate Design Scenario *(Section 5.6.9)*

12.

What design situation is most applicable to your situation?

Enter the table below with the results from Question 9 through 11 to find the most appropriate design for your situation.

Q9	Y	Y	Y	Y	Y	Y	N	N	N	N	N	N
Q10	Y	Y	Y	N	N	N	Y	Y	Y	N	N	N
Q11	S	B	C	S	B	C	S	B	C	S	B	C
Design for	**(a)**	**Multicast**	**Multicast**	**Unicast**	**(a)**	**(b)**	**Unicast**	**Multicast**	**Multicast**	**Unicast**	**Unicast**	**Unicast**

(a) Design goals are somewhat at odds. Multicast is favored.

(b) Design goals are somewhat at odds. Unicast is favored.

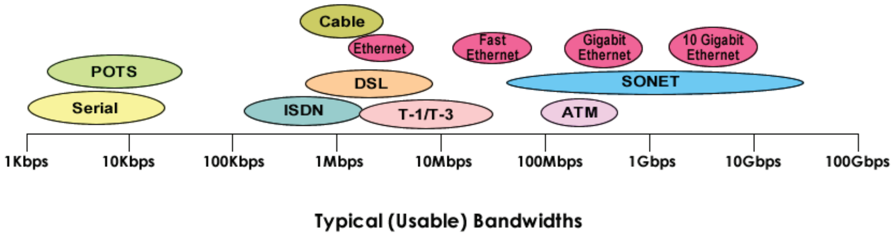
After completing this question, please proceed to "Video System Summary."

12.

Multiple Systems – Define Potential Technology Choices *(Section 5.6.7)*

13.

Design information provided suggests that multiple communication links will be utilized. Identify potential communication solutions for *EACH* field link by drawing a vertical line through the figure below with a typical (per location) bandwidth need (refer to Question 3). The choices immediately surrounding that line that represent purchased services (Ex: POTS, ISDN, DSL, T-1/T-3, Cable) should be investigated for their applicability.



After completing this question, please proceed to "Video System Summary."

13.

Video System Summary (please record the result of your worksheet analysis)	
Video Bandwidth (from Line 5d)	_______ Mbps
System Type (circle one)	Multiple links Single aggregated network
Technologies under consideration (list top 3 choices)	1. 2. 3.
Design Situation (circle one)	Unicast Multicast

7. CASE STUDIES

7.1. Data Case Study

Baker, Texas, a midsize city located in a hilly region, has recently seen a surge in its population. Severe weather conditions often occur on a major roadway near town. The city wishes to alert drivers of these severe conditions as rapidly as possible to promote safer driving and help to reduce accidents.

The design calls for installing loop detectors on both sides of the roadway to measure volumes and speeds. In addition, Baker will install a weather station and two DMSs to warn drivers of impending weather conditions. There is also a new isolated signal installation along the affected stretch of roadway that Baker would like to communicate with as well. It is possible that during adverse conditions, Baker may alter the timing of the light. The combination of all of these countermeasures will help them to protect drivers and the city.

Because Baker is relatively new to these types of deployments, there is no established infrastructure available for communications.

7.1.1. Objectives

Baker would like to install communications infrastructure to support the following:

- Installation of loop detectors along both sides of the roadway to monitor the speed and volume of traffic,
- Installation of two DMSs to relay information to drivers along dangerous sections of road,
- Installation of a weather station near the roadway to detect weather conditions, and
- Communication with the traffic signal at the isolated intersection.

7.1.2. Analysis

The initial question that must be answered is will there be any video streams in the system. For this case there will not be, so we can go from Question 1 to 3. Table 7-1 details the responses from the data communications methodology that address the presence of video streams.

Table 7-1. Case Study 1 – Video Streams.

Data Communications Design Worksheet				
Presence of Video Streams *(Section 5.4.1)*	1.	Are video streams in use now or will they be in the future? _____ YES __X__ NO If 'NO,' proceed to Question 3.	1.	▨
	2.	Are the video streams and data being transmitted together over the same communications system in the field? ______ YES ______ NO If 'YES,' you do not need this worksheet, you need the Digital Video Communications Design Worksheet. If 'NO,' proceed to Question 3.	2.	▨

The system that Baker wants to install includes loop detectors, two DMSs, a traffic signal controller, and a weather station. Table 7-2 details the responses for Question 3 of the data collection methodology, which determines the number of devices that will be in use.

It is important to understand that items such as loop detectors utilize their own communications from their point of installation to a central processing point. Generally, that processing point is within 800–1000 feet. This loop processing device will take the contact closure information from the loops and process it into a serial data stream.

In this example, therefore, Baker needs to design not for eight loop detectors but for one loop processor that outputs a data stream composed of information from all the loops.

Table 7-2. Case Study 1 – Device Accounting.

Number of Devices *(Section 5.4.2)*	3.	How many of the following devices do you have?		

		Number of Devices	
	Device Type	**Current**	**Future**
3a.	Dynamic Message Signs	2	
3b.	Vehicle/Roadway Detectors	1	
3c.	TxDOT LCU		
3d.	TxDOT SCU		
3e.	RWIS		
3f.	Weather Stations	1	
3g.	Ramp Meters		
3h	PTZ Camera		
3i	Traffic Controllers	1	
3j.	Other		
3k.	***Subtotals***	5	
3l.	***TOTAL NUMBER OF DATA STREAMS (Add 3k CURRENT + 3k FUTURE)***	5	

TOTAL NUMBER OF DEVICES	3m.	**5**

Most of the devices that will be used in this deployment have a low transmission rate. For those devices, the default will be used. However, the loop processing device will be reporting information for eight loops every 20–30 seconds. This could take some bandwidth, and we should plan for a higher data transmission rate in the design. (In a real-world application, the necessary data transfer rate would likely be provided by the equipment manufacturer.)

Table 7-3 identifies the bandwidth associated with each device and calculates the raw bandwidth necessary to support this deployment.

Table 7-3. Case Study 1 – Device Bandwidth.

<table>
<tr>
<td>Raw Data Bandwidth
<i>(Section 5.4.3)</i></td>
<td>4.</td>
<td>FOR ALL DEVICES, ASSUME CONSTANT TRANSMISSION
<table>
<tr><th></th><th></th><th>Rate</th><th>Number</th><th>Bandwidth</th></tr>
<tr><td>4a.</td><td>Known Data Bandwidth Calculation
<i>For devices with known rates enter the rate and number.</i></td><td>38.4</td><td>1</td><td>38.4</td></tr>
<tr><td>4b.</td><td>Unknown Data Bandwidth Calculation
<i>For devices with unknown rates use 9.6 Kbps.</i></td><td>9.6 Kbps</td><td>4</td><td>38.4</td></tr>
<tr><td>4c.</td><td colspan="2">Total Bandwidth
<i>Total number should match line 3m.</i></td><td>5</td><td>76.8</td></tr>
</table>
TOTAL RAW DATA BANDWIDTH (Kbps)</td>
<td>4d.</td>
<td>76.8</td>
</tr>
</table>

In the described situation, 250 milliseconds or 0.25 seconds of latency is acceptable. Table 7-4 details the latency expectations of the deployment.

Table 7-4. Case Study 1 – Device Latency.

Acceptable Latency *(Section 5.4.4)*	5.	Do you know what your acceptable latency is? __X__ YES ______ NO If 'YES,' enter the value on Line 5. If 'NO,' assume 0.25 seconds and enter it on Line 5.	5.	**250**

From the previous results, the calculated data bandwidth can now be determined. Table 7-5 identifies the necessary information and shows the calculation of the required bandwidth.

Table 7-5. Case Study 1 – Calculated Data Bandwidth.

<table>
<tr>
<td>Calculated Data Bandwidth
(Section 5.4.5)</td>
<td>6.</td>
<td>
<table>
<tr><td>**6a.**</td><td>**Raw Data Bandwidth, Kbps (from Line 4d)**</td><td>76.8</td></tr>
<tr><td>**6b.**</td><td>**Acceptable Latency, in seconds (from Line 5)**</td><td>0.25 sec</td></tr>
<tr><td>**6c.**</td><td>**Calculated Data Bandwidth, Kbps**
Calculate using: *Line 6a* ÷ {1 – *Line 6b*}</td><td>102.4</td></tr>
</table>
CALCULATED DATA BANDWIDTH (Kbps)
</td>
<td>6d.</td>
<td>**102.4**</td>
</tr>
</table>

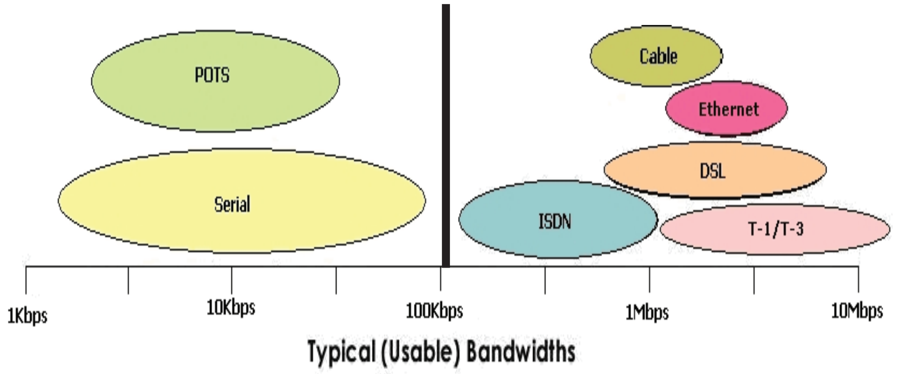
Given that we need approximately 102 Kbps, the next step in the analysis process is identifying the main details of the communications system. An important aspect of the communications systems design is shared or aggregate communications. As defined by the objectives of the case study, all of the devices in this system will share the same communications system. Table 7-6 shows the answer to this question from the data communications methodology. Because the answer was 'YES,' the next determination is to narrow the realm of choices to the most appropriate solutions.

Table 7-6. Case Study 1 – Aggregation of Data Communications.

Single or Multiple Systems *(Section 5.4.6)*	7.	Will all of the data streams be aggregated together on one communications system in the field? __X__ YES ______ NO If the answer is 'NO,' please go to Question 9.	7.	▨

Table 7-7 shows the section of the data communications methodology that deals with a single aggregated solution. Following the instructions, the Baker engineer draws a line representing the necessary calculated bandwidth on the graphic. Anything to the right of the line would be a potential solution. As can be seen on Table 7-7, several possible solutions are identified.

Table 7-7. Case Study 1 – Appropriate Communication Solutions.

Single System – Define Potential Technology Choices *(Section 5.4.8)*	8.	The figure below shows the broad range of technology solutions that are available. The scale is logarithmic. Using the value from Line 6d, draw a vertical line through the graph representing the bandwidth you need. All of the choices to the <u>*RIGHT*</u> of the vertical line are potential choices.  *After completing this question, please proceed to "Data System Summary."*	8.	

At this point in time, other factors come into play to help determine the best possible solution. As has been mentioned previously, it is not possible to cover every aspect of the systems design. For example, the available offerings in the area from communications companies may have an influence if this site is outside the typical ranges. One solution that can be eliminated is serial—although the line shows that the data rates are within the capabilities of serial, higher data rates occur only across very short distances. Since we know this is an isolated area outside of town, it is unlikely that high data rates could be obtained through serial data transfer.

Another factor that could be a significant consideration is security. The cable and DSL solutions are Internet-based technologies, which utilize a different set-up. Baker would have to ensure that field equipment is protected against security problems, such as viruses and hacking attempts. On the other hand, historically, ISDN has not been as reliable as some of the other technologies and may prove to be more problematic.

Table 7-8 shows a summary of the information from this example.

Table 7-8. Case Study 1 – Summary.

Data System Summary (please record the result of your worksheet analysis)	
Data Bandwidth (from Line 6d)	102.4 Kbps
System Type (circle one)	Multiple links [✓ **Single aggregated network**]
Technologies under consideration (list top 3 choices)	1. ISDN 2. CABLE 3. DSL

7.2. Video Case Study

Smallville, Texas, has just finished construction of a new state-of-the-art civic center. The center is located on an intersection on one of two main highways that run through town. During special events, traffic around the new center traffic often becomes congested and police are called to direct traffic.

Smallville would like to install a video monitoring system at the intersection so that the intersection and surrounding traffic can be remotely monitored during these events. The city would like four stationary cameras, each showing one direction at the intersection. They would also like one PTZ camera located at or near the intersection that they can control to see the surrounding area. The video feeds would be viewed from a control center located at the city police station, a few miles away.

The four intersection cameras can be displayed together in a quad view, while the PTZ camera needs a separate stream. The main purpose of the intersection cameras is to show the status of the intersection, not show details of each car passing through. This enables the quad feed to be low-quality streams. The PTZ camera needs to be a medium-quality feed, so that the operator of the monitoring station can focus on details if needed.

The city would also like to obtain traffic counts at the intersection for studies on the impact of these special events on local traffic and the economy. The counts need to contain the number of cars passing through the intersection in each direction, including both straight and turning vehicles. This data must be viewable in real time during an event and must also be stored to a database for further analysis.

7.2.1. Objectives

Smallville, Texas, would like to deploy equipment to:

- Receive video feeds at a central location from an intersection for viewing/monitoring proposes,
- Obtain vehicle count records for all directions of the intersection and store data to a database for future analysis, and
- Enable PTZ for one camera to monitor the intersection and surrounding areas.

7.2.2. Analysis

The initial question that must be answered is are any video streams part of the system. The presence of video streams is the overriding factor in determining the required bandwidth and the overall communications solution. Even a small number of video feeds will have a far greater impact on the bandwidth of a network than many other traffic monitoring devices combined. In the case of Smallville, there are two video streams in the system. Table 7-9 shows the preliminary question from the video evaluation methodology. At this juncture, the designer knows to stay with the video evaluation.

Table 7-9. Case Study 2 – Presence of Video Streams.

Presence of Video Streams *(Section 5.6.1)*	1.	Are video streams in use now or will they be in the future? _X_ YES ___ NO If 'YES,' proceed with Question 2. If 'NO,' you do not need this worksheet.	1.	▨

Smallville needs a total of two video streams for their system. There are five cameras, one PTZ and four intersection cameras. The four intersection cameras will be combined in a quad and transmitted as a single stream. Table 7-10 utilizes the next step in the video evaluation methodology to identify the number and type of video streams that will be in the system.

Table 7-10. Case Study 2 – Number of Video Streams.

Number of Video Streams *(Section 5.6.2)*

2. How many video streams?

		Number of Streams	
	Type of Video Streams	**Current**	**Future**
2a.	PTZ Color Video Streams	--	1
2b.	PTZ B/W Video Streams	--	--
2c.	Static Color Video Streams	--	--
2d.	Static B/W Video Streams	--	--
2e.	Intersection Detection Cameras	--	1
2f.	***Subtotals***	--	2
2g.	***TOTAL NUMBER OF VIDEO STREAMS (Add 2f CURRENT + 2f FUTURE)***	2	

TOTAL NUMBER OF VIDEO STREAMS 2h. **2**

Following the process, Smallville designers now need to identify the bandwidth that will be used by each video stream. Because the intersection detection cameras are envisioned to monitor traffic and not count specific vehicles, the overall quality does not need to be high. However, the PTZ camera should be higher quality and should utilize a higher bandwidth. We will therefore use rates of 1 Mbps and 3 Mbps for the low- and medium-quality streams, respectively. This determination and calculation is show in Table 7-11.

Table 7-11. Case Study 2. – Video Stream Rates.

Raw Video Bandwidth *(Section 5.6.3)*

3.

	Type of Video Stream	**Rate**	**Number**	**Bandwidth**
3a.	**Low-Speed Video Stream** If rate unknown, use 0.5 Mbps.	1	1	1
3b.	**Medium-Speed Video Stream** If rate unknown, use 2.0 Mbps.	3	1	3
3c.	**High-Speed Video Stream** If rate unknown, use 6 Mbps.			
3d	***TOTALS (Add sum of 3a through 3c) CHECK: Total Number of Streams should match Line 2h***		2	4

TOTAL RAW VIDEO STREAM BANDWIDTH (Mbps) 3e. **4**

The next step in the process is the determination of latency. Because the police station is relatively close to the civic center, latency is not expected to be an important factor in this communications system. Table 7-12 shows the use of the default value for latency.

Table 7-12. Case Study 2 – Latency.

Acceptable Latency *(Section 5.6.4)*	4.	Do you know what your acceptable latency is? ___ YES _X_ NO If 'YES,' enter the value on Line 4. If 'NO,' assume 0.25 seconds and enter it on Line 4	4.	**250**

Using the values from the previous steps, the next portion of the process (shown in Table 7-13) shows that a calculated video bandwidth of 5.3 Mbps is necessary. Recall that there is also a data bandwidth that must be accommodated as well, but it is negligible compared to the video requirements.

Table 7-13. Case Study 2 – Calculated Bandwidth Needs.

<table>
<tr>
<td>Calculated Video Bandwidth <i>(Section 5.6.5)</i></td>
<td>5.</td>
<td>
<table>
<tr><td>5a.</td><td>Raw Video Bandwidth, Mbps (from Line 3e)</td><td>4</td></tr>
<tr><td>5b.</td><td>Acceptable Latency, in seconds (from Line 4)</td><td>0.25 sec</td></tr>
<tr><td>5c.</td><td>Calculated Video Bandwidth, Mbps
Calculate using: $Line\ 5a \div \{1 - Line\ 5b\}$</td><td>5.3</td></tr>
</table>
CALCULATED VIDEO STREAM BANDWIDTH (Mbps)
</td>
<td>5d.</td>
<td>5.3</td>
</tr>
</table>

As discussed in Chapter 5 of this guidebook, the determination of the type of communications system that will be utilized is an important stage in the process. For Smallville, it makes the most sense to construct a single economical system for transporting the video to the police station. Table 7-14 highlights Question 6 from the video design methodology and shows a 'YES' answer to the question relating to aggregation of the video streams.

Table 7-14. Case Study 2 – Aggregated Communications.

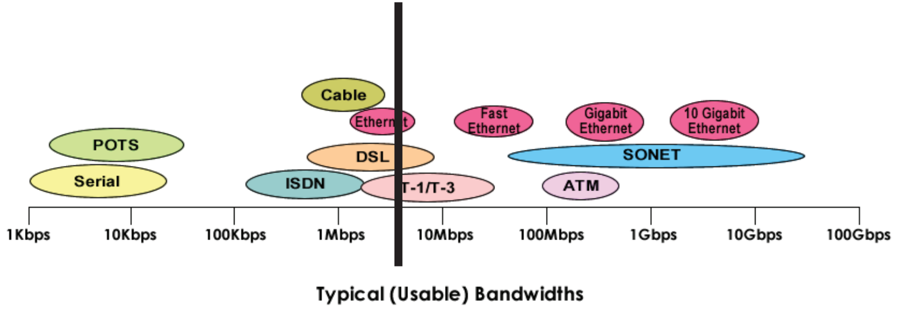
Single or Multiple Systems *(Section 5.6.6)*	6.	Will all of the video streams be aggregated together on one communications system in the field? _X_ YES ___ NO If the answer is 'NO,' please go to Question 13.	6.	▨

For the next step in the process, potential technology choices are identified. By drawing a vertical line at the point on the graph where 5.3 Mbps is located, Smallville designers can readily identify the candidate solutions for their deployment.

Table 7-15 shows that the vertical line passes through Ethernet, DSL, and T-1/T-3. Recall that the bandwidth for a T-1 line is approximately 1.5 Mbps, so the solution indicated would be a T-3 line. However, a T-

3 line has approximately nine times the required bandwidth, so it may prove uneconomical to purchase that much bandwidth. The DSL and Ethernet solutions are the most logical alternatives to explore.

Table 7-15. Case Study 2 – Technology Choices.

Single System – Define Potential Technology Choices *(Section 5.6.8)*	7.	The figure below shows the broad range of technology solutions that are available. The scale is logarithmic. Using the value from Line 5d, draw a vertical line through the graph representing the bandwidth you need. All of the choices to the *RIGHT* of the vertical line are potential choices.  	7.	

As the final portion of the design methodology, Smallville is asked if they can maintain and operate their own communications network (see Table 7-16). In fact, because of its size and budget Smallville cannot afford to operate and maintain its own network. Of the two solutions, Ethernet and DSL, Ethernet would be a stronger candidate if the communications system could be owned and operated in-house.

Table 7-16. Case Study 2 – Design Scenario.

Single System – Most Appropriate Design Scenario *(Section 5.6.9)*	8.	Will you be able to own, operate, and maintain 100% of your communications network internal to your agency? ___ YES _X_ NO If the answer is 'YES,' please proceed to Question 9. If the answer is 'NO,' you should design for Unicast operations. *After completing this question, please proceed to "Video System Summary."*	8.	

That leaves DSL as the most promising solution for Smallville. While this case study resulted in a single answer, the choice is not without some complications. Because DSL is geared for an Internet type of deployment, typically the download speed is very fast and the upload speed is considerably slower. In this situation, the upload speed will need to be significant to accommodate the 5.3 Mbps required bandwidth. This will entail detailed discussions with the local DSL service provider to ensure adequate service. A T-3 line would, however, have sufficient capacity and may be a viable alternative, depending on the cost. Table 7-17 highlights the results of Case Study 2.

Table 7-17. Case Study 2 – Summary.

Video System Summary (please record the result of your worksheet analysis)	
Video Bandwidth (from Line 5d)	5.3 Mbps
System Type (circle one)	Multiple links [✓ **Single aggregated network**]
Technologies under consideration (list top 3 choices)	1. DSL 2. T-1/T-3 3. Ethernet
Design Situation (circle one)	[✓ Unicast] Multicast

7.3. In-Class Exercise

Bigtown, Texas, has just completed the construction of a new 10-mile toll road around the city. To assist with the day-to-day operation of the toll road the city plans to implement a system of traffic monitoring devices along the road. PTZ cameras will be installed along the roadway so that every spot on the toll road is covered by at least one camera. To accomplish this, eight high-resolution PTZ cameras are required.

Two high-resolution static cameras will also be placed at the entrance points to/from the toll road to monitor conditions. The system will also include ramp metering for three ramps that enter along the corridor, as well as the main ramps at the beginning and ending of the toll road. Traffic speeds and occupancy will also be collected using a total of 52 loop detectors and 2 radar detectors. Two weather stations will also be placed along the 10-mile stretch. In order to help relay any important information to travelers, four DMSs will also be placed along the road.

In order to collect the fees, toll collection sites will be located at each entrance/exit ramp along the corridor. Each collection site will have two static high-resolution cameras, one in each direction, for a total of six cameras at the collection sites.

All video streams and data will be monitored at the main toll road offices, located at one end of the roadway. From here an operator will be able to view all cameras, control the PTZ cameras, and display important messages on the dynamic message signs.

7.3.1. Objectives

The toll road operator in Bigtown, Texas, would like to deploy equipment to:

- Monitor traffic conditions on a 10-mile stretch of toll road via video streams,
- Monitor traffic occupancy at locations on the toll road and implement ramp metering strategies based on occupancies,
- Detect toll payment violators at toll booth sites, and
- Update dynamic message signs for current situations, including traffic and weather conditions.

7.3.2. Analysis

This section is left blank for an in-class exercise.

8. GLOSSARY

ADDRESSING – A mechanism used in communication systems to ensure that information gets to the correct destination.

AERIAL CABLE – See Messenger Cable.

ANALOG – A device or system that represents changing values as continuously variable physical quantities.

ARCHITECTURE – A conceptual plan focusing on the relationship of all the components that compose the ITS solution.

ARMORED CABLE – Type of fiber cable that contains a steel jacket surrounding the fiber cables. Armored cable is often used for rodent protection in direct burial applications.

ATM – Asynchronous Transfer Mode – A network technology that transfers data in units of information that are fixed in size, called cells.

BANDWIDTH – The amount of information that is transmitted across a communications system in a certain amount of time. The theoretical bandwidth is the maximum amount of data that can be transmitted across the system.

BIT – BInary digiT **–** The smallest unit of information. A bit has a value of either “0” or “1.”

BNC CONNECTOR – Bayone-Neill-Concelman Connector – The type of connector used for coaxial cabling.

BYTE – A larger level of information, generally considered to consist of 8 bits.

BREAKOUT CABLE – Type of fiber cable where each fiber has its own jacket and aramid strength elements. This makes each fiber extremely strong and rugged.

BRI – Basic-Rate Interface – The basic ISDN configuration, which consists of two B-channels that can carry voice or data at rate of 64 Kbps and one D-channel that carries call-control information.

BUS TOPOLOGY – A type of topology where all the nodes are connected on a single line.

CABLE MODEM – A modem that is specifically designed to operate over coaxial cable TV lines to an Internet Service Provider.

CELL – An assembly of information in ATM networks that is 53 bytes in size.

CENTRAL OFFICE – CO – The central office is what telephone companies call the buildings they own that contain the “other” ends of all the phone lines in their local neighborhoods. Central offices contain computers and machines that connect (or “switch”) phone lines together.

CIF – Common Intermediate Format – A video resolution with a size of 352 × 288 pixels.

COAXIAL CABLING – A single copper wire at the center of the wiring assembly made of a plastic layer surrounded by a metal shield and covered in a rubber sheath.

CODEC – COmpressor / DECompressor – Technology for transferring data including video across communications media by compressing it for sending and then decompressing it at the receiving end.

D-1 – A video resolution with a size of 720 × 576 pixels.

DECODING – The process of converting data between formats.

DIGITAL – A device or system that represents values as either On (a “1”) or Off (a “0”).

DISTRIBUTION CABLE – Type of fiber cable similar to a breakout cable; however, each fiber does not have its own strength element.

DMS – Dynamic Message Sign **–** A roadside device used to convey messages to drivers.

DOWNSTREAM – Terminology used to describe the transmission of data to the current location from a remote location (i.e., data entering the local system).

DS – Digital Signal (level) – A hierarchy of speeds used to classify the bandwidth (capacities) of digital communication lines. The fundamental speed level is DS-0 (64 Kbps, i.e., 64,000 bps), which is the amount of bandwidth used for one voice conversation.

DS-0 – Digital Signal, level 1 – In North America, a DS-0 is a single channel of communications, operating at a signaling rate of 64 Kbps.

DS-1 – Digital Signal, level 1 – In North America, DS-1 translates into T-1, which is the equivalent of 24 DS-0 channels, each operating at a signaling rate of 64 Kbps for a total signaling rate of 1.544 Mbps.

DS-3 – Digital Signal, level 3 – In North America, DS-3 translates into T-3, which is the equivalent of 28 T-1 channels, each operating at total signaling rate of 1.544 Mbps. A DS-3 is also equivalent to 672 DS-0 channels, each operating at a signaling rate of 64 Kbps, for a total signaling rate of 44.73 Mbps.

DSL – Digital Subscriber Line – A communications technology that transmits information over existing phone lines.

ENCAPSULATION – The process of surrounding a piece of data with additional information as it moves from layer to layer in the communications process. This is the opposite of stripping.

ENCODING – The process of converting data between formats.

ETHERNET – A communications technology originally designed to connect computer, printers, and workstations within a small area. Ethernet has exploded in use and is the most common networking communications technology in use today. Ethernet is also known as 10BaseT and has a maximum bandwidth of 10 Mbps.

FAST ETHERNET – A form of Ethernet that has a maximum bandwidth of 100 Mbps. Fast Ethernet is also known as 100BaseT.

FIBER OPTIC CABLING – A type of cabling that transmits light instead of electronic signals.

FRAME – (1) In data communications, a variable-length assembly of data used in packet switching networks. (2) In video communications, one video image.

FRAME RATE – In video communications, the number of times per second that the video image is refreshed. Frame rate is expressed in frames per second (fps).

FRAME RELAY – A communications technology that utilizes the concept of packet switching to transmit information but without error checking.

FTP – File Transfer Protocol – A protocol that defines how to transfer files over the Internet.

GEL FILLED CABLE – Type of fiber cable where color-coded plastic buffer tubes house and protect the optical fibers. The buffer tubes are surrounded by a gel filling which protects from water penetration.

GIGABIT – 1,000,000,000 bits of information. Abbreviated as Gb. When used as a rate of information transfer, abbreviated as Gbps.

GIGABIT ETHERNET – A form of Ethernet that has a maximum bandwidth of 1000 Mbps or 1 Gbps. Gigabit Ethernet may also be referred to as 1000BaseT.

HTTP – Hypertext Transfer Protocol – A protocol that defines how to transmit and display information across networks using a web server and browser.

HYBRID TOPOLOGY – A topology that uses a combination of the other topologies (star, ring, or bus).

HUB – A device for sending and receiving information that works by broadcasting all information to all devices.

HYBRID CABLE – Type of cable that contains different combinations of cables within the outer jacket. Some examples are Fiber/Coax, Fiber/Copper, and Fiber/CAT5 cables.

ISDN – Integrated Services Digital Network – An international communications standard for sending voice, video, and data over normal telephone wires.

ISP – Internet Service Provider – A company that provides communications services (typically an Internet connection) to home and/or business users.

ITS – Intelligent Transportation Systems – The application of technology to enhance or improve the transportation system.

INTERNET – The vast collection of interconnected computers that utilize common protocols for sharing information.

JPEG –Joint Photographic Expert Group – A standard type of picture that uses compression to reduce the size of the file.

KILOBIT – 1000 bits of information. Abbreviated as Kb or kb. When used as a rate of information transfer, abbreviated as Kbps or kbps.

LAN – Local Area Network – A network that typically spans only a small area, such as a building or company.

LATENCY – A communications term for the delay between two points in the system.

LCU – Local Control Unit – A roadside device used to communicate with equipment installed in the roadway, such as loop detectors or ramp meters.

LOSS – The drop is signal level between two points in a network.

MEGABIT – 1,000,000 bits of information. Abbreviated as Mb. When used as a rate of information transfer, abbreviated as Mbps.

MESH TOPOLOGY – A network topology where each device is interconnected to multiple other devices to form multiple redundant paths.

MESSENGER CABLE – Also known as aerial cable. This type of fiber cable has a steel member, separate from the fiber lines, which is used to string and secure the cable in aerial applications.

MODEM – MOdulator-DEModulator – A device that enables the transmission of data over physical wiring.

MJPEG – Motion JPEG – A standard for transmitting video across communication systems by using successive frames of JPEG images.

MPEG – Moving Pictures Experts Group – A set of standards for transmitting video across communications systems.

MULTICAST – A network design situation where each device that transmits information can be received simultaneously by multiple other devices.

MULTIMODE – A type of fiber optic cable that supports the propagation of multiple streams of light at the same time. Multimode fiber has a typical core diameter of 50 or 62.5 µm.

NETWORK – A system of devices linked together via shared communications.

NTP – Network Time Protocol – A protocol used ensure accurate synchronization of clock times in a network of computers and devices

OPTICAL CARRIER – A designation used to identify the bandwidth available in fiber-based communications technologies, such as SONET.

OSI – Open Systems Interconnect – An international standard for communications that uses seven layers to move data from point A to point B.

PACKET – A small assembly of data to be transmitted across a network.

PACKET SWITCHING – A communications technology where every piece of information (packet) has a known origin and destination address.

PIXEL – Picture Element – One point or individual dot of light in a picture.

POINT-TO-POINT TOPOLOGY – A topology that typically uses direct connection between two devices or computers.

POTS – Plain Old Telephone Service – The standard telephone service that most homes and business use.

PRI – Primary-Rate Interface – A type of ISDN service that provides large bandwidth. A PRI includes 23 B-channels and one D-Channel. PRI service is generally transmitted through a T-1 line.

PROTOCOL – A set of formal rules describing how to transmit data between two devices.

QCIF – Quarter Common Intermediate Format – A video resolution with a size of 176 × 144 pixels.

QoS – Quality of Service – The guaranteed delivery of packets in the right order, without delay.

RESOLUTION – The size of a picture, typically expressed in pixels.

RJ-45 CONNECTOR – A typical type of connector used for twisted pair cabling.

RING TOPOLOGY – A topology where every device is connected within a loop system. Rings can be physical or logical.

ROUTER – A device for sending and receiving information between networks.

SC CONNECTOR – Square Connector – A type of fiber optic connector.

SCU – System Control Unit – A device used to talk to multiple LCUs and aggregate their data feeds and information.

SINGLE-MODE – A type of fiber optic cable that supports the propagation of a single stream of light at the same time. Single-mode fiber has a typical core diameter of 9 µm.

SMTP – Simple Mail Transfer Protocol – A protocol for sending electronic mail messages between servers.

SNMP – Simple Network Management Protocol – A set of protocols used to remotely manage networks and devices.

SOAP – Simple Object Access Protocol – A messaging protocol based on the eXtensible markup language (XML) that is used to encode information into a format known as a web service

SONET – Synchronous Optical Network – An optical interface standard designed to allow multiple vendors products to be networked together.

SPANNING TREE – A specialized protocol used to determine the best path for data flows when there is more than one route from point A to point B.

ST CONNECTOR – Straight Tip – A type of fiber optic connector.

STAR TOPOLOGY – A topology where every node in the network is connected to a central server or device.

STRIPPING – The process of removing information that surrounds each piece of data as it moves from layer to layer in the communications process. This is the opposite of encapsulation.

SWITCH – An intelligent device for sending and receiving information between devices, typically within the same network.

10 GIGABIT ETHERNET – A form of Ethernet that has a maximum bandwidth of 10,000 Mbps or 10 Gbps.

T-1 – Trunk Level 1 – A dedicated connection supporting data rates of 1.544 Mbps. A T-1 line actually consists of 24 individual channels, each of which supports 64 Kbps. Each 64 Kbps channel can be configured to carry voice or data traffic. A T-1 line can be delivered across both twisted pair copper and fiber optic cabling.

T-3 – Trunk Level 3 – A dedicated connection supporting a data rate of 44.736 Mbps. A T-3 line actually consists of 672 individual channels, each of which supports 64 Kbps.

TCP/IP – Transmission Control Protocol/Internet Protocol – A low-level protocol used by computers and other hardware to communicate across disparate networks.

TOPOLOGY – The arrangement of computers or devices inside a network. Topologies can be physical or logical.

TUNNELING – A technology that enables data from one network to be sent using a separate, second network.

TWISTED PAIR CABLING – Copper cabling that uses the twisting between pairs to cancel out electrical interference.

UNICAST – A network design situation where each device that transmits information can be only received by one other device.

UPSTREAM – Terminology used to describe the transmission of data from the current location to a remote location (i.e., data leaving the local system).

VIDEO ENCODING – The process of taking a video signal and altering it in some manner for transmission to a remote location.

WAN – Wide Area Network – A large network, usually consisting of a collection of several LANs, that spans a large geographic area.

WIRELINE – The use of a physical cable, or medium, to move information from one point to another.

WORLD WIDE WEB – WWW – A collection of computers that utilize HTTP to share information. The World Wide Web is often referred to as "the web" or even "the Internet," although this last characterization is incorrect.

ZIPCORD – Another name for a fiber optic patch cable.