CHAPTER 9

COMMUNICATION SYSTEMS
9. Communication Systems

Communication system design is typically a highly complex process. The telecommunications industry is technologically dynamic, with new technologies and enhancement of existing technologies constantly evolving. This chapter sets forth some basic information on communication systems in general. Emphasis is placed on communication conduit infrastructure and wireless spread spectrum design issues. Most applications involving the design of wire line or wireless communication systems will require additional information that is not currently found in this manual. However, for the design of basic communication infrastructure, such as conduit systems or spread spectrum infrastructure, this chapter provides the designer with fundamental guidelines to use in the design of these systems.

Prior to final design of communication system elements, a strategic communication plan must be developed for the region, indicating uses, communication types, configuration, topology, equipment, and other issues beyond the scope of this document. This strategic plan will provide the blueprint for how the overall system communicates, and will provide direction to the designer when implementing various types of communication infrastructure.

Aside from the basic physical components of a communication system (such as cable, modems, etc.), “how” an intelligent transportation system communicates between various components revolves around issues such as element protocols and formats. Older systems may have strict communications protocol guidelines (as defined by existing system software) that must be followed. Newer systems require communication design following “NTCIP” standards. NTCIP stands for the National Transportation Communications for ITS Protocol. It establishes an array of standards that provides:

- the rules for communicating (called protocols), and
- the vocabulary (called objects) necessary to allow electronic traffic control equipment from different manufacturers to operate with each other as a system.

The NTCIP is the first set of standards for the transportation industry that allows traffic control systems to be built using a “mix and match” approach with equipment from different manufacturers. Therefore, NTCIP standards reduce the need for reliance on specific equipment vendors and customized one-of-a-kind software. Bringing together representatives from equipment manufacturers and system users, 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).

9.1. Introduction and Usage

An intelligent transportation system is comprised of many different elements — field components such as variable message signs, detector stations, ramp meters, and CCTV cameras; central equipment such as computers, workstations and monitors; and the human element (i.e., system operators and maintenance personnel). For the system to function properly, it will be necessary for each of these components to exchange information with other system elements. It is the communications network that provides the connecting link for this information.
The communications network is an integral part of any ITS design in that it will affect (and be affected by) system architecture, configuration, and the operational strategies. Moreover, if thought of as a single expense, the communications network will likely be the costliest item in the vast majority of ITS related systems.

The most important consideration in designing a large communications network is that it must provide reliable service for 10 – 20 years or more to ensure economic viability. At this period in the communications industry and continuing into the foreseeable future, the extent of technological change and market restructuring presents both difficulties and opportunities. The difficulties are in the real possibility of equipment obsolescence. As with computers, the communications industry is going through a rapid evolution of available equipment. The opportunities may involve partnering with the many new communications companies that the deregulated environment is producing.

Although the design of the communication elements within individual projects may not involve system assessments and large scale concepts as indicated above, it is important that individual designers be aware of potential changes in communications network equipment and structure brought about by either of the above difficulties and/or opportunities.

9.2. Communication System Types & Fundamentals

Communication network equipment for intelligent transportation systems can be divided into two different categories: analog and digital. Analog technology conveys data as electronic signals of varying frequency or amplitude that are added to carrier waves of a given frequency. Broadcast and phone transmission has conventionally used analog technology. Digital describes electronic technology that generates, stores, and processes data in terms of two states: positive and non-positive. Positive is expressed or represented by the number 1 and non-positive by the number 0. Thus, data transmitted or stored with digital technology is expressed as a string of 0’s and 1’s. Each of these state digits is referred to as a binary digit, or “bit” in short. A string of bits that a computer can address individually as a group is a byte.

Within each of these categories are Voice – typically radio communications, but can include PBX telephone type systems between centers, Data - elements from system detector stations, ramp meters, dynamic trailblazer assemblies, and variable message signs, which do not require large bandwidth (i.e., small packages of data). Video - elements require transmission of full-motion video for incident verification and traffic surveillance, such as closed-circuit television cameras or local agency video (large bandwidth/transmission requirements). The majority of ITS equipment requires data or video transmission requirements. Hence, these communication system elements will be the primary focus of this chapter.

There are numerous types of carrier technologies. This ranges from regular telephone service, one of the most basic forms of communication, to optical carrier (OCx) levels up to OC-48. A sampling of various communication types, data rates, and media are discussed in this section and summarized in Figure 9-1. In discussions of “carrier systems”, the following definitions are presented:
• **T-Carrier** - The T-carrier system, introduced by the Bell System in the U.S. in the 1960s, was the first successful system that supported digitized voice transmission. The original transmission rate (1.544 Mbps) in the T-1 line is in common use today in Internet service provider connections to the Internet. Internet service providers also commonly use another level, the T-3 line, providing 44.736 Mbps. Another commonly installed service is a fractional T-1, which is the rental of some portion of the 24 channels in a T-1 line, with the other channels going unused. The T-carrier system is entirely digital, using pulse code modulation and Time-Division Multiplexing. The system uses four wires and provides duplex capability (two wires for receiving and two for sending at the same time). The T-1 digital stream consists of 24 64-Kbps channel that are multiplexing. (The standardized 64 Kbps channel is based on the bandwidth required for a voice conversation.) The four wires were originally a pair of twisted pair copper wires, but can now also include coaxial cable, optical fiber, digital microwave, and other media. A number of variations on the number and use of channels are possible.

• **Synchronous Optical Network** - SONET is the U.S. (American National Standards Institute) standard for synchronous data transmission on optical media. The international equivalent of SONET is synchronous digital hierarchy (SDH). Together, they ensure standards so that digital networks can interconnect internationally and that existing conventional transmission systems can take advantage of optical media through tributary attachments. SONET provides standards for a number of line rates up to the maximum line rate of 9.953 gigabits per second (Gbps). Actual line rates approaching 20 gigabits per second are possible. SONET is considered to be the foundation for the physical layer of the broadband ISDN (Broadband Integrated Services Digital Network). SONET defines a base rate of 51.84 Mbps and a set of multiples of the base rate known as "Optical Carrier levels (OCx)." Asynchronous transfer mode (ATM) runs as a layer on top of SONET as well as on top of other technologies.

• **Optical Carrier Levels (OCx)** SONET includes a set of signal rate multiples for transmitting digital signals on optical fiber. The base rate (OC-1) is 51.84 Mbps. OC-2 runs at twice the base rate, OC-3 at three times the base rate, and so forth. Planned rates include OC-1, OC-3 (155.52 Mbps), OC-12 (622.08 Mpbs), and OC-48 (2.488 Gbps). Asynchronous transfer mode (ATM) makes use of some of the Optical Carrier levels.

• **Asynchronous Transfer Mode (ATM)** - ATM is a dedicated-connection switching technology that organizes digital data into 53-byte cell units and transmits them over a physical medium using digital signal technology. Individually, a cell is processed asynchronously relative to other related cells and is queued before being multiplexed over the transmission path. Because ATM is designed for easy implementation by hardware (rather than software), faster processing and switch speeds are possible. The pre-specified bit rates are either 155.520 Mbps or 622.080 Mbps. Speeds on ATM networks can reach 10 Gbps. Along with (SONET) and several other technologies, ATM is a key component of broadband ISDN.
Various communication system mediums (types) are associated with ITS deployment, and include the following:

- **Fiber optic communication** - Fulfills communication requirements for voice, data, or video devices
- **Twisted-pair communication cable** - Typically reserved for communication with voice or data communication only
- **Spread-spectrum radio** - Most applications of spread-spectrum radio are reserved for data devices, however higher bandwidth technologies of spread-spectrum radio may apply to video devices
- **Leased communications** - Depending on the type of leased communication chosen, any of the communication categories may apply. Typically, leased video communication alternatives are substantially higher in cost than those available for data devices.

The overall communications network configuration has a major impact on the design of communications network. Network configuration falls into two main categories: centralized and distributed.

- **Centralized Communications** – All processing is performed at the control center. Communications in this manner are handled directly from trunk lines, and connected directly to each surveillance and control element in the field. This concept allows the greatest control over the system, and permits all communications trouble-shooting and maintenance to be handled at one physical location. Its primary disadvantage is that direct connections between the control center and the ever-expanding amount of field equipment require an extremely complex and expensive communication network. Moreover, the system is slightly more susceptible to wide-area disruptions.

- **Distributed Communications** – This network uses a concept identical to that of the central system, in that most information and control is processed at a single point (i.e., control center). The major difference is that the communications network is distributed to several key locations (i.e., “hubs”) throughout the network. A local distribution network is used for each section of a freeway, and all of the communications for that area are concentrated at the “hub” within the area. At the communications hub, the data are concentrated (i.e., multiplexed) for transmission to the control center over long-haul, high-speed, large bandwidth trunks. Similarly, trunk communications from the control center are split into multiple low-speed channels at the hubs, and then transmitted over the local distribution network to the field devices. (NOTE -
Depending on the distance involved and the data concentrations, a distributed network may include multiple tiers of hubs. For example, at the first level, the data may be concentrated into T-1 or T-3/OC-3 channels and transmitted to a second level node. At this hub, the T-1/T-3/OC-3 channels from several first nodes may be concentrated into higher bandwidth channels (e.g., OC-24 or OC-48); and so on until the data reach the control center.)

The distance requirements of the system area, coupled with cost and reliability considerations, dictate the distributed configuration with one or two tiers of hubs; although higher-level tiers may also be required if the video transmissions are digitized using coder-decoder (otherwise known as CODEC) hardware.

The distributed configuration will require the placement of communication hubs at locations in the field to gather/distribute field data. These hubs divide the network topology into two basic divisions:

- **Trunk circuits** (i.e., “backbone network”) for hub-to-hub and hub-to-control center communications. The data transmissions are high-speed conforming to T-carrier or SONET (synchronous optical network) standards. Analog video communications (if used) will be multiplexed at the hub, providing multiple video images on a single trunk channel. If digital video communications are used, they too will be multiplexed at the hub and combined with the digital data, thereby requiring a larger bandwidth trunk and multiple tiers of hubs.

- **Distribution circuits** are used for the exchange of digital data messages between the hubs and field elements. These are typically low-speed channels (i.e., 1200-9600 baud). The hardware devices are usually aggregated on multi-drop lines in a polled network, both to take advantage of the connectivity economics and to have the system in control of the timing.

Several segments will consist of WisDOT-owned fiber optic and twisted-pair cables -- the fiber optic cable being used for video transmissions and for high-speed data trunks between communication “hubs” and the control center; and the twisted-pair cable being used for low-speed data transmissions between the hubs and the various field components, although fiber or alternate communications methods (wireless) may also be used for this function. The communications cables are all installed in conduit. Additionally, conduit will be necessary for control cables between field components and their respective field devices (e.g., between ramp signals and the ramp meter controller), and for 120 VAC power feeds. This report addresses the configuration of the network’s main trunk line.

Freeway resurfacing / modernization programs offer excellent opportunities for installing the conduits required for the ITS communications networks and for the control cables. Performing this work during freeway rehabilitation work will result in reduced installation costs, as well as minimize disruption to traffic flow. Moreover, given its long life expectancy, conduit can be installed several years before it is actually needed. Assuming that the conduit network is designed and constructed properly, any rehabilitation effort during system implementation will be minimal -- at the very worst, the existing conduits may require cleaning.
9.3. **ITS Equipment Communication Requirements**

9.3.1. Field Elements

**Detection and Ramp Meter Controllers**

Typically, both the detector stations and ramp meters use the same processing/controller hardware and controlling software. These are the most numerous field devices in the current system being located at on-ramps and at nominal 1/2-mile intervals along the freeway — approximately 3 or 4 per mile in the “high-density” segments. In District 2, these types of equipment currently require 1200-baud data circuits in a multi-dropped configuration, with up to 12 controllers on one channel. Communication between hubs and field processors are regularly polled therefore require full time availability.

**Other Detectors**

In addition to the vehicle detectors for measuring volume, occupancy, and speed, additional detectors have been and will continue to be installed along the freeway for vehicle classification (i.e., number of axles) and pavement condition (e.g., dry, wet, ice, etc.). Each type of detector communicates over separate low-speed channels to the hub or control center on a regular polled basis. Accordingly, these channels will require full-time availability.

**Variable Message Signs**

Variable message signs (freeway, arterial, line) use field controllers furnished by sign vendors and implement the communications protocol that is compatible with the central system VMS protocol and format. VMS communications typically use the same type of data channels as detectors and ramp meters, but on channels separate from the vehicle detectors and ramp meters. There is a requirement for 100 percent availability for “instantaneous” message display when required and verification purposes, though there is actually less than 25 percent actual use.

**Video Equipment**

The primary purpose of video surveillance is incident verification, requiring only short duration visual information. However, during the verification process, the video must have resolution and sharpness near broadcast quality video. The video network for the District 2, MONITOR cameras are available 100 percent of the time for incident verification and other surveillance functions, though the time that most of the cameras will be used for that purpose will be relatively small. The exception to this general rule might be construction areas where the detectors are disabled, and it becomes necessary for the system operators to constantly monitor the freeway (via CCTV) for congestion management and incident detection.

A major issue for the District 2, MONITOR system has been whether the video signals will be full-motion analog or digital using CODEC hardware. This has involved a trade-off between video quality, communication costs (both capital and recurring), and the capabilities of future compression technologies. For the initial implementation stages, the video communications has been analog; communications media and methods have been followed which allows such a mode of transmission. Initially, video communications was provided through leased analog video services provided by Ameritech. However, as Ameritech’s digital services became available and capable of producing significant revenue for Ameritech, the pricing structure for the leased analog video created a situation that a State-owned fiber optic
communications system became cost effective. CODEC hardware and compression techniques continue to become more standardized, equipment costs are decreasing, and quality of the digitized video will equal and likely surpass current “broadcast” quality in the future. As such, ITS video transmissions will ultimately be digital. Since the State-owned fiber optic network is capable of both analog and digital configurations, the future transition from current analog video to digital will be straightforward — replacing analog communications hardware with the improved digital equipment (e.g., CODECs, multiplexers) with minimal configuration of the fiber optic cabling and conduit network itself.

9.3.2. Communication Channels

In telecommunications in general, a channel is a separate path through which signals can flow. The existing District 2 communication system assigns a channel and drop to each individual field device. Each channel is capable of carrying 16 drops (device). As a general rule, 12 drops are initially assigned per channel, allowing for increased system reliability and future expansion. While multiple data devices can be placed on a single channel, variable message signs (freeway or arterial) must be placed on a channel separate from other data devices such as ramp meters, detector stations, etc. For additional information on data channel and drop assignments, consult the District Freeway Operations Systems Engineer.

For fiber optic communications, fiber allocation is critical when designing a system. For each individual fiber, the fiber optic system operates as follows for both of these types of devices:

- **Data Devices** - 2-way data communication, with 2 fibers per data channel allocated across the system. Each channel carries up to 12 drops, with each drop consisting of 1 data device (ramp meter, detector station, etc.)
- **Video Devices** - 1-way video communication with 2-way data control communication. Each camera (or video sharing) site requires only 1 fiber for video and data communication.

9.4. State-Owned Communication Conduit Design Standards

State-owned communication conduit design standards can be broken down into the following categories:

- General installation considerations
- Trenched communication conduit guidelines
- Directional bore guidelines, and
- Structure mount conduit guidelines

Guidelines for each category are presented in the following sections.

9.4.1. General Design Considerations

When designing communication conduit systems, the following general issues should be considered:

- As a general rule, multicell conduits should be installed on a single side of the...
The conduit path is to provide a continuous system. The various components of ITS deployments will likely be located on both sides of the freeway, and therefore lateral conduits (described below) will be necessary to access equipment locations. The designer should avoid conduit design which switches back and forth on either side of the freeway whenever possible. This is not always possible due to obstacles or constructability concerns, however minimizing the amount of cross-over will make it easier for future maintenance, locating, and system record-keeping.

- **More than one conduit per run is desirable**, particularly if the Department wishes to lease conduit space to other public agencies or private concerns. Under such an arrangement, one conduit would be used by the system, the other conduit would be leased. The majority of installation expense (especially with trenched conduit) is in digging and back-filling the trench, not in the material cost itself.

- For multi-cell conduit design, all inner ducts should **include a pre-lubricated woven pull tape**.

### 9.4.2. Trenched Conduit Design Guidelines

When designing trenched communication conduit, the following general issues should be considered. Illustrations of both trenched multicell conduit and plowed and trenched HDPE conduit are provided in Figure 9-2 and Figure 9-3.

- Communication conduit consists of two different types: multi-cell conduit, or high-density polyethylene (HDPE) conduit. **Multi-cell conduit** consists of 3 or 4 innerducts (1¼-inch diameter each) within a 4½-inch conduit, whereas HDPE conduit comes in varying sizes. Multi-cell conduit is installed via “in-trench” installation, where a trench is opened, the conduit is assembled, placed in the trench, and back-filled. With **HDPE conduit**, reels are placed on a plowing machine, where the trench, placement, and back-fill is performed in one operation rather than three. For this reason, in addition to material costs, the cost to install four 1¼-inch HDPE conduits is approximately half the cost to install 1 multi-cell conduit.

- **HDPE conduit must be UL listed.**
- **HDPE conduit must be installed in one continuous run** between access points.
- Freeway conduits should be generally a **minimum of 36-inches below finished grade.**
- Installation of **conduits in grass freeway medians should be avoided.** This limits the potential for communication system disruption under future additions of acceleration, deceleration, or auxiliary lanes.
- The **most desirable location of communication conduit is near the right-of-way edge** (typically a right-of-way fence), as far from the traveled way as possible.
- Conduit designed in sloped terrain with a 4:1 or steeper slope should be designed to run longitudinally to (i.e., up/down) the slope, not along the slope.
- **Underground warning tape** should be laid above all underground conduits, 12-inches below grade.
- A **copper wire** (10 or 12-awg typ.) should be installed in one of the conduits between access points. This locate wire is to be electrically connected between conduit runs to allow for continuous locate signal transmission throughout the
Conduit network.

- Communication conduit may be installed in the same trench as other conduit systems, such as freeway lighting. However, the freeway conduit should never enter the street light foundations, handholes, or pullboxes. Similarly, the street light conduit should never interfere with the communication conduit. In essence, the conduit network for street lighting and the conduit network for the freeway system should be totally separate and independent of one another, even though they are co-located in the same trench.

Figure 9-2: Typical Multicell Conduit Installation

Figure 9-3: Typical HDPE Conduit Installation
9.4.3. Directional Bore Conduit Design Guidelines

When designing communication conduit under paved surfaces, the following general issues should be considered:

- **Lateral conduits** should be installed at all interchanges, as well as all existing and potential future equipment locations. For estimating future locations, a nominal 0.5-mile interval, depending on the spacing of interchanges, is typically adequate.
- Directional bore locations require adequate room for conduit assembly and layout for “pull-back” operation. This distance must allow for assembly of the entire length of conduit for the directional bore installation. During directional boring operations, multi-cell conduit is assembled, and a cable/wire rope is installed in one of the cells and is attached to a pullback assembly plate at the far end of the conduit run. This is done to prevent conduit separation during the pullback operation.
- Directional bore installations under railroad tracks require a minimum depth of 5-feet or as required by the railroad company. In addition, railroads typically require use of metallic conduit underneath railroad tracks.

9.4.4. Structure-Mount Conduit Design Guidelines

Guidelines for designing and installing the conduit network are summarized below:

- If a bridge (or other elevated section) is to be included as part of the reconstruction project, four to eight 1-¼ inch conduits matching the innerduct should be incorporated within the barrier wall and parapets. (See Figure 9-4) If this is not feasible, or if a multiple conduit network is being installed, 4½-inch fiberglass multi-cell conduits should be attached to the structure of the overpass (i.e., surface-mounted) in accordance with WisDOT Standards.
- **Expansion fittings** should be installed wherever surface mounted 4-1/2 inch conduit crosses an expansion joint in the freeway structure to provide a sliding joint, in addition to matching the expansion requirements of the conduit.
- All structure-mounted multi cell conduit should be constructed of fiberglass. All other conduit should be PVC constructed.
- **For each bridge or structure requiring exterior-mounted conduit, a separate construction detail must be provided.** (An example is provided in Figure 9-5) The designer should avoid providing “typical” construction details for a wide variety of bridge types, since mounting methods and installation requirements will vary greatly.
- Junction boxes should be installed opposite manholes on concrete parapet walls in which fiber optic conduit is being installed. A 4-inch sleeve should be provided connecting the fiber optic cabinet to the pull box.
- Two junction boxes should be installed, one on either end of the bridge, allowing access to the conduits on either side of the bridge.
- Each junction box should be equipped with a cable rung assembly allowing 20-30 ft. of fiber optic cable to be looped around inside the box.
- Junction boxes should conform to NEMA 4 or 4X, with a nominal dimension of 36 inches wide by 30 inches high by 12 inches deep.
Figure 9-4: Conduit Transition From Trenched to Interior Parapet Conduit Systems

Figure 9-5: Bridge-specific Structure Mount Conduit Detail Example
9.4.5. Communication Manhole Design Standards

Guidelines for designing and installing the communication manholes are summarized below. A typical manhole installation detail is provided in Figure 9-6.

- Fiber optic manholes should be **spaced at recommended intervals of 2500 feet**, with the maximum allowable interval being 3500 feet allowing access to the multi-cell conduit at regular intervals.

- Fiber optic manholes should be **installed at all locations wherever the conduit bends** (as measured cumulatively from the last manhole) **exceeds 360 degrees** (180 degrees preferred).

- **Manhole installation is not required** whenever there is a change in the conduit installation method (e.g., from "in-trench" to "on-structure").

- Fiber optic manholes should not be installed along on-ramps, rather there should be a **minimum of one manhole at each interchange** where the distribution communication cabling transitions from multi-cell conduit to normal PVC conduit.

- The **minimum dimensions** of the manholes should be **36-inches (diameter) x 60-inches (depth)**. Manholes deeper than 60-inches may be considered "confined spaces" thereby adding complexity to persons entering the manholes.

- Manholes should be equipped with heavy-duty covers as they will be subject to occasional passage of heavy vehicles and cable rungs to allow excess cable to be coiled and raised off the ground.

- **Final installed elevation for manhole**, including cover, **should be noted on plan** when placed in the areas where roadwork (ramp widening, etc.) will be performed simultaneous with manhole installations.

- **Two "knock-outs" should be provided** on each sidewall of the manhole where the conduit does not enter.

- Manholes should be **located to avoid drainage swells**. Manholes located on slopes should be designed to not expose the side of the manhole that might be a hazard to traffic.

- Wherever applicable, the multicell conduit will be beneath the lighting conduit. Therefore, the manholes will have to be offset from the long axis of the conduit run. It is recommended that this offset be 24 inches.
9.5. State-Owned Wireline Communication Design Standards

Fiber Optics

Fiber optic cable has numerous advantages when considered for a dedicated communications network. These advantages include large capacity, immunity to electromagnetic and RF interference, a small flexible lightweight cable, and the capability to transmit data, voice, and video. The electronic equipment required (e.g., fiber muxes, video transceivers, etc.) is commonly available in a robust market with a good future.

The use of fiber optics typically requires a dedicated, agency-owned communications network. This requires right-of-way and conduit throughout the network. Right-of-way is usually the limiting factor for private companies, but not for the State. The cost of installing conduit, however, can be significant.

Design criteria for fiber optic cable installation are as follows:

- **Use** cable with the correctly rated outer jacket material. Outdoor rated for underground installation in conduit, riser rated for vertical installations, and...
plenum rated for indoor installation.

- Design cable segments such that maximum pulling tension for individual cables is not exceeded. Different types and sizes of cabling have different maximum pulling tension.
- Design cable segments and access points (e.g., pull boxes, vaults, cabinets, etc.) such that minimum bending radius is not exceeded. Designers need to be aware that there are different bending radii depending upon loaded (during pulling, under tension) and unloaded (long term, at rest) conditions.
- Design cable segments and access points with nominal and maximum cable reel sizes in mind. Typical nominal reel sizes are 3,000 to 10,000 feet, with maximums upwards of 25,000 feet. Both the nominal and maximum reel sizes are dependant upon the type and diameter of the specific cable.
- Cables should not be pulled through any intermediate access point without the correct equipment and procedure. All tension must be eliminated at each access point. Alternately, the cable must be completely pulled from one access point to the next and safely stored in a figure-8 pattern.
- Excess fiber optic cable (100-ft typical) should be provided in each manhole in the system. This cable is coiled and fastened to cable support brackets. (See Figure 9-7)

Figure 9-7: Communication Cable Installation in Manholes
Twisted-Pair Cable

Agency-owned twisted pair cable has been widely used for the low-speed transmission of data in traffic signal systems, and between hubs and field elements within freeway management systems, with the network configured with between 8 and 12 field drops on each two-pair (4-wire) channel. The exact number of drops depends on the amount of data to be transferred between the hub and the field locations, and the rate of transfer. Twisted pair cable can support transmission distances of 8-10 miles before repeaters become necessary.

Twisted pair cable is a reliable and proven technology with established standards for cable and modems. A properly designed and installed twisted-pair communications system features reasonable low maintenance requirements in terms of average time between failures, the average time to repair, and the necessary levels of skill and equipment. Like fiber optics, it does require right-of-way and conduit, the latter often resulting in significant costs.

Design criteria for twisted-pair cable installation are as follows:

- **Use cable with the correctly rated outer jacket material.** Outdoor rated for underground installation in conduit, riser rated for vertical installations, and plenum rated for indoor installation.
- **Design cable size and number of pairs taking into account the smallest diameter conduit or inner-duct** the cable must pass through. A 25-pair cable has a nominal outer diameter of 1-inch.
- For interchanges consisting of multiple data devices, **consider the use of smaller numbers of twisted pairs** (e.g., 6-pair cable) to consolidate these devices to one of the local cabinets. For example, if three cabinets exist within a localized area, interconnect these cabinets with a 6-pair cable while bringing the mainline twisted pair cable into only one cabinet.
- In each manhole, provide for a service loop (one loop around the perimeter) of excess twisted pair cable.


One of the chief advantages of a radio-based communications subsystem is that no physical connection is required between the transmitter and receiver. This can translate into a significant cost savings over the capital-intensive cost of installing a cable conduit network, or the unpredictable ongoing costs for a leased facility. A proven radio alternative is the use of a spread-spectrum radio.

With spread-spectrum radio, the entire band (i.e., 902-928 MHz) is available for use by all users. Instead of subdividing the band, the FCC charged that each device operating in this range not exceed 1 Watt output power and be able to tolerate any interference generated in the band. This is accomplished by "spreading" the signal over the entire 26 MHz (in the 902-928 MHz band), and requiring that the receiver "know" where to look for the pieces of the signal. Due to the spreading of the signal over a wide frequency range, electromagnetic noise (interference typically generated at a very narrow band width) has less effect on signal integrity. Any noise interfering with a spread spectrum signal will tend to obscure only a very
small fraction of the entire band and, since the signal is divided and spread over the entire spectrum, the transmitted signal can still be reliably reconstructed at the receiver.

Several low-speed spread-spectrum products are currently on the market, providing the following capabilities:

- Channel data rates of 9600 bps - 56 kbps
- Multiple channel capability
- Nominal range of 5 miles in open or over unobstructed ground (i.e., line-of-sight), with antenna
- RS-232 serial interface
- No FCC license required (although the manufacturer must have operation authorization)

Spread-spectrum radios transmitting at fractional and full T-1 rates (i.e., 512 kbps to 1.44 Mbps) over the frequency range of 5725 to 5850 MHz are also available. Both of these devices have a nominal range (with directional antenna) of 10 miles.

Design criteria for spread spectrum radio and antenna installation are as follows:

- Antennas can be mounted on standard poles, such as WisDOT Type 5 poles (30-ft), light poles, or camera poles
- For large-diameter antenna (coaxial) cables, conduit installation between the local controller cabinet, pull boxes, and pole bases require the use of a 45-degree bend, a straight section, and another 45-degree bend to ease the installation sweep. (Typical installations into signal poles make use a single 90-degree bend.)
- Clear line-of-sight between antenna locations is not mandatory, but is preferred. Transmission quality is affected through significant changes in terrain elevations, trees, or tall buildings. If clear line-of-sight is indeterminable, engineering judgment should be used to determine the amount of terrain change or blockage between the two antenna locations.

9.7. Leased Communication System Considerations

Leased telephone circuits possess the flexibility and speed for application to ITS Deployment communications network as both low-speed and trunk connections. A wide variety of circuits are available from Ameritech or other local telephone company, including:

- Type 3002 voice-grade data channels providing full-duplex multi-point analog service at 1200 - 9600 bps. These circuits can be used to provide analog communications between the control center and the VMS, ramp meters, and detector stations, and for camera control.
- Ameritech Digital Services, which provide two-way digital data channels transmitting at rates between 2.4 (2400 bps) and 64 kbps. These circuits can be used for low-speed multi-point data channels operating at rates between 2400 and 9600 bps. These circuits thus can also be used for data trunking in which several low-speed channels are collected at a “hub”, multiplexed together in a higher speed...
Digital Services trunk, and transmitted to the control center. They may also be used for digital video transmission with a proprietary 56 kbps CODEC.

- ISDN channels each transmitting at 144 kbps (i.e., dual 64-kbps switched with 16 kbps data packet). These circuits can be used for data trunking, as well as for digitized video transmissions. For the video applications, 3 ISDN circuits would be used for each camera/CODEC to provide the appropriate video quality.
- DS1 (T-1) channels can also be used for digitized video. As compared to multiple ISDN circuits, the video quality would be significantly better, but at a greater monthly cost.
- DSL channels can also be used for both digital data and digitized video. Comparable to ISDN circuits, the video quality would be similar, but at a lower monthly cost.
- Fiber optic cables are also available from Ameritech. It is noted that telephone companies throughout the United States make extensive use of fiber optic cables; but these networks are typically utilized solely for digital communications. Ameritech is an exception in that they will offer fiber optic cables for analog video. This approach provides “broadcast quality” video images.

Leased telephone is a very reliable communications solution in that there is a grid redundancy element due to the general coverage of the carrier’s network. One potential advantage over a dedicated network is that maintenance responsibilities are shifted from WisDOT to Ameritech. Moreover, the service can generally be abandoned at any time, thereby providing flexibility to change the communications media should the need or opportunity arise. At the same time, the potential drawbacks associated with a leased approach must also be considered, including:

- Freeway Access - The leasing agency is typically required to provide the telephone company with a conduit between the field cabinet and the nearest telephone facility. Along some segments, this distance may be significant and could result in an extensive conduit network being installed. This is not a major concern for the Milwaukee MONITOR in that Ameritech only requires a conduit between the field cabinet and the freeway right-of-way.
- Cost - The costs for a leased network are not limited to the installation of the conduit. There are recurring expenses associated with the monthly cost of the circuits. Additionally, there is no guarantee that recurring charges will not significantly increase in the future unless the agency, and the telephone company enter into a contract. Several systems have converted from leased telephone to a jurisdiction-owned communications because of previous rate increases and the uncertainty of future hikes.
- Video Transmission - As a result of the improvements in CODEC technology during the last few years, the transmission of video over leased telephone is not as significant of an issue as it once was. Nevertheless, use of leased digital facilities for video requires a circuit capable of a data rate of 384 kbps (minimum for relatively good quality), a CODEC unit with CSU/DSU at both ends of the circuit, and an environmental enclosure (with heat and air conditioning) to house the field CODEC.

9.8. Communication Hub Requirements and Standards

Communication hub requirements for the state of Wisconsin have been established...
under previous ITS implementation projects. While these requirements are necessary to establish a basis for uniformity across the system, communication shelter manufacturers will have varying manufacturing processes materials which may or may not be acceptable.

Placement
- Communication hubs should be placed near logical crossing points of a communication network. Typically, system interchanges are ideal locations for communication hubs.
- The communication hub should be placed in a relatively flat area (4:1 slope or flatter)
- Hubs should be located in an area that is ultra-safe from vehicular travel.
- Communication shelters should be placed in a secure area, typically inside freeway right-of-way fences with access via a locked gate.

Size
- Minimum interior dimensions of 8-feet (W) x 12-feet (L) x 9-feet (H)
- Frame type construction with both interior and exterior walls perpendicular to the floor

Structural Parameters
- Minimum roof live load 40 pounds per square feet
- Minimum side-wall live load 100 mile per hour wind load
- Minimum uniform floor load 150 pounds per square ft (over entire area)
- Minimum concentrated floor load 300 pounds per square ft (over one sq. ft)

The floor deck should be supported on a structural steel base / frame designed to permit the entire structure, complete with floor load, to be relocated. The base / frame shall incorporate full perimeter structural members which protect and close off the complete building perimeter. The perimeter members shall accommodate lifting, anchoring, and support of the building. Skid-type base / frames shall not be acceptable. A concrete slab suspended between the perimeter members will provide necessary floor support. The entire underside of the base / frame shall be closed with a seam-welded steel plate to provide permanent barrier against moisture, insects, rodents, and vermin.

The base / frame shall be suitable for installation on a foundation system that provides multipoint support and anchoring along the long side of the base/frame structural members. Four concrete pier type foundations extending a minimum of 12-inches below normal frost line shall meet the requirements of the communication hub manufacturer. Piers shall be sized to accommodate an assumed soil bearing capacity of 3000 pounds per square feet.

A 8-feet (W) x 12-feet (L) x 12-inch (D) crushed aggregate base coarse pad shall be placed within the footprint of the fiber optic communications hub. Crushed aggregate base course shall adhere to the requirements of Section 304 in the Standard Specifications.

Anchoring shall permit repositioning, adjustment, and leveling of the building on the foundation during installation. Pre-cast anchor bolts shall not be allowed. Lifting and anchoring points shall be integral. No open holes shall be left in the perimeter of the base / frame after anchoring.

Insulation and Weather Proofing
• Insulation value - Floor R11
• Insulation value - Sidewall R11
• Insulation value - Ceiling / Roof R19
• Maximum air filtration 300 cubic feet per hour
• All areas insulated shall include a vapor barrier
• The communication hub shall be protected against the entrance of blowing rain or snow. All door and conduit/cable openings shall be suitably protected and sealed.

**Heating-Ventilation-Air Conditioning**

- Electric, forced air heating
- Operations controlled by environmental control panel
- Two speed ventilation system
- Exhaust fan w/ gravity damper
- Thermostatic control of the exhaust fan and exhaust damper shall be provided at the environmental control panel
- One (1) window type air conditioner (30,000 BTU per hour)
- AC unit shall permit the fan to cycle on and off with the compressor
- Air conditioner operation will be controlled by the environmental control panel

**Environmental Control Panel (ECP)**

- Provides remote thermostatic control of heating, ventilation, air conditioning, and emergency ventilation stages functions
- All environmental components shall be switched or otherwise controlled by devices properly rated and UL-listed
- Each environmental function shall be electrically interlocked to prevent simultaneous operation of multiple functions
- ECP shall have a five degree temperature differential between the ventilation and air conditioning stages to ensure the air conditioning does not conflict with outside ventilation, and vice-versa
- ECP shall contain visible indications of 1) Power ON, 2) Heat ON, 3) Vent ON, 4) Air Conditioner ON, 5) Emergency Vent ON; as controlled by the panel.
- Functional controls and internal terminal blocks shall be labeled with engraved plastic nameplates (dymo-type labels are not acceptable)

**Safety, Security, and Remote Alarms**

- Fire extinguisher
- Smoke detector
- Entrance intrusion
- High temperature
- Emergency Ventilation

(3) **Electrical.** Fiber optic communication hubs shall meet as a minimum the following electrical requirements:

**Electrical**

- Comply with National Electric Code
• All wiring will be surface mounted with straps in EMT conduit or other approved raceway
• All conduit will run horizontal or vertical
• 120/240 volt, single phase, 200 amps, with 30 branch circuits
• 100 amp auxiliary receptacle with manual transfer switch

Miscellaneous
• Four (4) 19-inch, non-enclosed racks, 7 feet in height, anchored to floor, wired complete with power with a minimum six (6) 120 VAC outlets along the rack
• One (1) 12-inch wide by 10-feet long cable tray
• One (1) 4-feet x 8-feet x ¾-inch plywood backboard

9.9. Communication Network Inventory and Documentation

9.9.1. Fiber Optic Cable Naming Convention
To assist in record keeping and other system configuration and maintenance activities, a standardized naming convention for fiber optic cables is necessary. Figure 9-8 provides guidance on proper designation of fiber optic cables. This method is based on industry standard nomenclature.

Figure 9-8: Fiber Optic Cable Designation and Naming Convention
9.9.2. Communication System Cable Assignment Record

Information on the fiber optic cable assignment record used in District 2 is currently under development, and will be incorporated in the next submission. For interim information, contact the State Electrical Engineer.

9.10. Communication System Construction Details

Construction details previously used during construction of communication system elements are found in Figure 9-9. These details, in Adobe Acrobat format, can be found in Appendix A. Electronic Microstation versions of these files can also be found on the ITS Design Manual CD.


Special provisions for items used in contracts containing communication system elements are listed in Figure 9-10. These special provisions, in Adobe Acrobat format, can be found in Appendix B. Electronic files of the special provisions (Microsoft Word version 7.0) can also be found on the ITS Design Manual CD.

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Figure 9-9: Communication System Construction Details
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Figure 9-10: Communication System Special Provisions