50.1.1 Introduction

The guidance in Chapter 50 is intended for the placement of new communication systems as part of new construction projects only. The STOC must be contacted if retrofitting a communication system to existing systems or in any other circumstances where the addition of a communication system is being considered.

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. This section discusses the options and recommendations for the design of a communications network.

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.

The Department’s freeway 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.

50.1.2 Needs Assessment

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:
• Rules for communicating (called protocols), and
• 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).

50.1.3 Communication Types

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 such as closed-circuit television cameras or local agency video which require transmission of full-motion video (large bandwidth/transmission requirements) for incident verification and traffic surveillance.

In terms of carrier technologies for communications, there are numerous options available to use. This ranges from regular telephone service, one of the most basic forms of communication, to optical carrier (OCx) levels up to OC-48 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 50.1-1. 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 Mbps), 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. A sampling of various communication types, data rates, and media are shown in Table 50.1-1.

<table>
<thead>
<tr>
<th>Carrier Technology</th>
<th>Data Rate</th>
<th>Primary Medium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voice-grade telephone</td>
<td>56 kbps</td>
<td>twisted pair</td>
</tr>
<tr>
<td>T-1</td>
<td>1.544 Mbps</td>
<td>twisted pair or fiber optic</td>
</tr>
<tr>
<td>T-3</td>
<td>44.736 Mbps</td>
<td>twisted pair or fiber optic</td>
</tr>
<tr>
<td>OC-1</td>
<td>51.84 Mbps</td>
<td>fiber optic</td>
</tr>
<tr>
<td>OC-3</td>
<td>155.52 Mbps</td>
<td>fiber optic</td>
</tr>
<tr>
<td>OC-12</td>
<td>622.08 Mbps</td>
<td>fiber optic</td>
</tr>
<tr>
<td>OC-48</td>
<td>2.488 Gbps</td>
<td>fiber optic</td>
</tr>
</tbody>
</table>

*Table 50.1-1 - Communication Data Rates*

Various communication system mediums (types) are associated with ITS deployment, and include the following:

- **Fiber optic communication** - Fulfills communication requirements for either data or video devices
- **Twisted-pair communication cable** - Typically reserved for communication with data devices 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, either data or video device communications may apply. Typically, leased video communication alternatives are substantially higher in cost than those available for data devices.

The overall communications network architecture has a major impact on the design of communications network. Network architecture 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 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 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 multidrop 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 design manual primarily addresses the configuration of the network’s main trunk line.

### 50.1.4 Inter-Agency Considerations

The STOC should be involved in the decision-making process for acquiring inter-agency communication networks.