An Information Report of the Joint Committee on the NTCIP

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The NTCIP Guide

National Transportation Communications for ITS Protocol

September 1999

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The previous edition of the *NTCIP Guide* was prepared in February 1997. Realizing that it had become outdated, the NTCIP Joint Committee initiated a project to develop an updated guide document. The NTCIP Guide Update Team has prepared this document as part of that project, with direction from the NTCIP Joint Committee and input from a peer review team selected for this effort.

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NTCIP Guide

1 FOREWORD

The National Transportation Communications for ITS Protocol (NTCIP) is receiving considerable attention these days. The transportation community has long needed a mechanism whereby interchangeability and interoperability amongst the various components of transportation systems could be achieved. It is for this reason that NTCIP is being widely embraced and is being specified in many new system deployments.

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

1.1 Disclaimer

It is well understood that, because of the need for technical precision, accuracy, and completeness in standards documents, these documents are often very difficult to read. Thus this NTCIP Guide is an educational tool that has been created to assist decision makers, planners, specification writers, and implementers understand the various NTCIP standards documents and how to use them, as well as the overall motivations behind the use of NTCIP. This document is an NTCIP standards document, but it is not an NTCIP standard and must therefore not be considered a binding specification. The NTCIP suite of standards documents is comprised of numerous stand alone documents, some of which have been fully approved, some of which are in the approval process, and some of which are still being drafted. Further, as the NTCIP concept continues to grow in transportation community acceptance, the need will no doubt arise for additional NTCIP standards documents, the subject of which has not yet been established. As a result, there is a strong likelihood that at any given point in time this document may be out of sync in some respects with the actual standards documents. While every reasonable effort will be made to keep this document current, the reader should understand that, in writing specifications or implementing systems, only the actual NTCIP standards documents govern, not this NTCIP Guide.

1.2 Purpose of the NTCIP Guide

The subject of communications protocols and standards is a challenging one, even for engineers experienced in these issues. In the case of NTCIP, the level of difficulty is heightened by the fact that NTCIP is a whole suite of documents and protocols aimed at meeting the communications needs of the various fixed-point communications components of the National ITS Architecture, not just a single one. This NTCIP Guide is an educational tool that has been created to assist decision makers, planners, specification writers, and implementers understand the various NTCIP standards documents and how to use them, as well as the overall motivations behind the use of NTCIP.

1.3 Organization of the NTCIP Guide

The *Executive Summary* of this NTCIP Guide is intended principally for decision makers. This section provides a brief overview of the NTCIP as well as a discussion of the motivations behind the use of these approaches, cast largely in the context of the National ITS Architecture. It also discusses the issues associated with NTCIP use, as well as required resources, testing, and configuration management issues.

The *Understanding NTCIP* section of this guide is intended principally for systems planners, though it is also intended to be a general purpose technical overview of the issues associated with the use of NTCIP, and is a good starting point for anyone wishing to become better informed on the various technical aspects of the approach.

The *Procuring NTCIP* section is intended principally for specification writers. As the NTCIP standards suite consists of many documents, and many have numerous optional requirements, it is very important that specification writers have a good grasp of the decision process by which these various options will be deemed necessary or unnecessary for any given planned deployment. Satisfying the user agency in an NTCIP deployment requires a careful analysis of the agency's requirements up front, then a careful mapping of the various NTCIP options to those requirements by way of a well written procurement specification. Further, this section describes the need for and a means by which the technical requirements of the communications infrastructure can be determined.

The *Designing NTCIP* section is intended principally for those faced with the task of designing the communications element of transportation systems that utilize NTCIP protocols. This section includes a detailed discussion on bandwidth analysis and system timing.

The *Implementing NTCIP* section is intended principally for the various systems implementers, i.e., field equipment software and hardware developers, traffic management center software and hardware developers, and systems integrators. Inasmuch as the principal authors of this NTCIP Guide document consisted of field equipment and central traffic management center software and hardware developers and integrators involved in actual NTCIP deployments, it is hoped that this section will provide the necessary "read between the lines" type of insight often required to achieve successful deployments. In particular, some of the lessons learned and common pitfalls encountered during actual deployments will be discussed, with suggested solutions given.

The remaining sections provide a listing of terms, abbreviations, acronyms, and definitions. A document listing of NTCIP standards and the status each document is also provided. Lastly, example NTCIP stack selections are shown for center-to-field communications using routing and non-routing protocols.

1.4 Additional Information

For more information about NTCIP standards, visit the NTCIP Web Site at http://www.ntcip.org. For a hardcopy summary of NTCIP information, contact the NTCIP Coordinator at the following address.

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In preparation of this NTCIP document, input of users and other interested parties was sought and evaluated. Written inquires, comments, and proposed or recommended revisions should be submitted to the NTCIP Coordinator, at the above address, in the following form:

Document Name:
Version Number:
Section Number:
Paragraph:
Comment:

Please include your name, address, and organization in your correspondence.

2 EXECUTIVE SUMMARY

2.1 Introduction

A communications protocol is a set of rules for how messages are coded and transmitted between electronic devices. The equipment at each end of a data transmission must use the same protocol to successfully communicate. It is a bit like human languages that have an alphabet, vocabulary, and grammar rules used by everyone speaking that language.

Historically, each vendor of microcomputer control devices and software used in management systems adopted a different, proprietary protocol for data communications. This required extensive integration projects to mix equipment and software from different vendors in the same system and to communicate between systems operated by adjacent agencies. The National Transportation Communications for ITS Protocol (NTCIP) provides common protocol standards that can be used by all vendors and system developers to help overcome these differences.

NTCIP is a family of communications standards for transmitting primarily data and messages between microcomputer control devices used in Intelligent Transportation Systems (ITS). An example of such a system is a computer at city hall monitoring and controlling the operation of microprocessor-based roadside controllers at traffic signals within a city. The computer may send instructions to the traffic signal controllers to change signal timings as traffic conditions change and the controllers send status and traffic flow information to the computer.

In another example, two transit management systems (computers) may need to exchange real-time information about the location of transit vehicles bound for a shared timed-transfer center. This allows each system to know instantly when one vehicle is running significantly behind schedule and is unable to make the scheduled transfer time. Passengers can be notified automatically, and the local traffic management center can be automatically requested to provide priority at traffic signals for the delayed transit vehicle.

NTCIP is intended for use in all types of management systems dealing with the transportation environment, including those for freeways, traffic signals, transit, emergency management, traveler information, and data archiving. NTCIP is intended for use between computers in different systems or different management centers, and between a computer and devices at the roadside. The current NTCIP standards are not intended for use in devices owned by individual travelers; other standards either currently exist or are in development for that purpose.

2.2 Overview of NTCIP

NTCIP provides communications standards for two fundamentally different types of ITS communications. The first type is between a management system or center and multiple control or monitoring devices managed by that system or center. Examples of this type of communications include:

- A traffic signal management system communicating with traffic signal controllers at intersections.

- A transit management system communicating with monitoring devices and passenger information signs on transit vehicles and at transit stations and stops.

- A freeway management system communicating with detectors and ramp meters on freeways.

- A traffic management system controlling CCTV cameras, dynamic message signs, advisory radio transmitters, environmental sensors, and traffic count stations on roadways.

Since most applications of this type involve a computer at a management center communicating with various devices at the roadside or on agency vehicles, this type is referred to as "center-to-field". The NTCIP protocols intended for this communications application are often used in an environment in which a central management station routinely polls each field device, as in the most common case of multiple field devices sharing a communications channel. This is called an unbalanced, one-to-many network.

The second type of communication involves messages sent between two or more management systems. Examples of this type of communication include:

- Two or more traffic signal management systems exchanging information (including second-by-second status changes) to achieve coordinated operation of traffic signals managed by the different systems and to enable personnel at one center to monitor the status of signals operated from another center.

- A transit system reporting schedule adherence exceptions to kiosks, to a transit customer information system, and to a regional traveler information system, while also asking a traffic signal management system to instruct its signals to give priority to a behind-schedule transit vehicle.

- An emergency management system reporting an incident to a freeway management system, to a traffic signal management system, to two transit management systems, and to a traveler information system.

- A freeway management system informing an emergency management system of a warning message just posted on a dynamic message sign on the freeway in response to its notification of an incident.

This type of communication is referred to as "center-to-center". It involves peer-to-peer communications between any number of systems (computers) in what is called a balanced, many-to-many network. This type of communication is similar to the Internet, in that any center can request information from, or provide information to, any number of other centers. It is possible, though not yet common, to use such protocols for communication to and between field devices as well as between computers.

Although both center-to-field and center-to-center communications can involve a human operator making requests or issuing instructions, one of the features of the NTCIP protocols is their support for continuous, automated data transmissions with no human in the loop.

2.3 What is NTCIP?

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

NTCIP differs from past practice in defining communications protocols for management systems in that it is not a single communications protocol designed for one purpose. Rather it consists of a whole suite of protocols covering the spectrum from simple point-to-point command/response protocols to quite sophisticated object oriented techniques. This is because of the diversity of the applications into which NTCIP will be deployed, and the resulting diversity of application specific characteristics such as type and quantity of data to be transferred, criticality of data transfer times, acceptable cost of communications infrastructure, criticality of data security and integrity issues, to name a few. Insofar as data definitions are concerned, NTCIP does not completely define the functionality of the central or field devices to which it applies. It only specifies the data objects to be transferred and limited functionality directly related to these objects. For example, NTCIP does not define the details of how a traffic controller operates, e.g., it does not define that a green must be terminated by a yellow and that a red must be displayed after a yellow. However, it precisely defines the data that may be communicated between traffic controllers and traffic management centers, and thereby defines the aspects of functionality (e.g., it requires that the length of the yellow clearance interval must be as indicated by the phaseYellowChange object).

2.4 Why Do We Need NTCIP?

There have been numerous problems historically associated with the deployments of management systems. Before describing some of these issues we will first define two terms. The term interchangeability reflects the ability to use multiple brands of a device on the same communications channel, along with the ability to swap them out. For example, the ability to put any brand of NTCIP compliant traffic signal controller in the same system at the same time reflects interchangeability. The term interoperability reflects the ability to use many different types of devices on the same communications channel. For example, using the same communications channel to interconnect a management system with traffic signal controllers, dynamic message signs, video surveillance controls, and other devices, reflects interoperability.

One common problem historically encountered results from the use of proprietary communications protocols in management systems. These protocols are often proprietary to the specific project, as well as to the specific manufacturers involved in the project. As a result, expansion of the system after initial deployment can generally only be done using equipment of the same type and brand as in the initial deployment. There is no opportunity for realistic competitive bidding as additional field devices are added to the system (due to the lack of interchangeability), nor is there any opportunity to add additional types of field devices to the system (due to the lack of interoperability).

The proper use of NTCIP in a management system will allow the future expansion of the system to benefit from true competitive bidding, as well as allow other types of field devices to be added.

The Transportation Equity Act for the 21st Century (known as "TEA-21") requires that federally funded ITS projects "conform" with the National ITS Architecture. As defined in TEA-21, the term "intelligent transportation system" means “electronics, communications, or information processing used singly or in combination to improve the efficiency or safety of a surface transportation system”. The National ITS Architecture defines both the functions performed in implementing ITS, and the information flows between transportation subsystems. In its October 2, 1998 report entitled “Interim Guidance on Conformity with the National lTS Architecture and Standards”, the US DOT stated “Highway Trust Fund recipients shall take the appropriate actions to ensure that development of the project(s): (a) engages a wide range of stakeholders, (b) enables the appropriate electronic information sharing between shareholders, (c) facilitates future ITS expansion, and (d) considers the use of applicable ITS standards.”

The terms interchangeability and interoperability are used throughout the TEA-21 legislation, but interoperability is used extensively. While the simple view of NTCIP often focuses on interchangeability, interoperability is actually far more important, for two reasons. First, since the communications infrastructure is usually the most costly element in a new system, using this infrastructure for multiple purposes lowers the overall cost of the system. Second, and more important in terms of the TEA-21 legislation, interoperability suggests the sharing of data, thereby enhancing the operators ability to efficiently manage these transportation systems, even to the extent of sharing data across jurisdictional boundaries.

2.5 Lessons Learned

The principal issue associated with the use of NTCIP is that it is an emerging technology in transportation. As is the case with most new or emerging technologies, the early implementers were on the leading edge of specifying NTCIP. These early implementers often lacked appropriate educational material on the best way to specify, procure, deploy, integrate, and test these systems. This ***NTCIP Guide*** document has been created largely in recognition of these issues, and to assist future implementers in avoiding the problems associated with the deployment of any new technology.

The authors of this document include suppliers and integrators in early NTCIP deployments, and this document reflects the lessons learned in these deployments. Further, this document has been reviewed by a team of public sector reviewers to ensure it meets the needs of future implementers.

The NTCIP has been designed based upon existing and widely supported industry standard Internet communications protocol standards to the greatest extent possible, thus minimizing the risk associated with the use of these protocols.

Agencies considering deployment of NTCIP should carefully consider their functional requirements, and then determine which objects are mandatory and which objects are optional. For example, some agencies may only be concerned with strict interchangeability of field devices, and not with using the various proprietary features and functions specific to certain manufacturer’s devices, while others may desire a reduced level of interchangeability in order to benefit from these various proprietary features. A desire to mix various devices in the communication infrastructure must also be considered. All of these issues will have significant impact on the procurement specification and agencies should consider their overall objective early in the system design and procurement phases.

Furthermore, it may not be practical to retrofit NTCIP center-to-field protocol onto some older traffic control equipment due to a lack of processing power and memory capacity. Agencies should consider these issues when considering a system upgrade.

2.6 Resources

Agencies are often concerned with what resources they should bring to an NTCIP implementation. This section of the *NTCIP Guide* offers some discussion on some of the resources available for additional information on NTCIP.

2.6.1 Training

An understanding of the technical issues surrounding NTCIP will benefit agencies considering deployment. Various training opportunities are available. Training seminars on NTCIP are available from AASHTO, ITE, and NEMA. Further, numerous consulting firms offer in-depth training services on this topic. General information on the subject of NTCIP is also available at www.ntcip.org. Because the NTCIP suite of communications protocols draws heavily on the Internet based protocols, books and other descriptive information are readily available from public libraries, bookstores, and the World Wide Web to assist in the planning of training programs.

2.6.2 Technical Abilities

While users of management systems need not understand the intricacies of the NTCIP protocols. Others should have a basic understanding of the relevant NTCIP standards documents, this ***NTCIP Guide*** document, and the referenced Internet protocols that are applicable to their project. Those who need to have a basic understanding of NTCIP include specification writers, system designers, integrators, suppliers, and persons responsible for testing.

2.6.3 Projects

It is highly recommended that projects using NTCIP include in their deliverables certain items relating to NTCIP training and documentation. General NTCIP training for system operators and administrators throughout the project would assist with an understanding of the benefits associated with the use of NTCIP, as well as the opportunities and procedures for future expansion and/or improvement of the system. It is further recommended that a project-specific NTCIP manual should be included in the list of deliverables that thoroughly documents the details associated with the various NTCIP options and features in the system. This document will greatly facilitate any future work on the system, including improvements or expansions. The lack of such a document in older proprietary systems has been a great deterrent to future improvements.

2.6.4 Compliance Testing

Compliance testing of NTCIP devices can best be accomplished by independent laboratories or consulting firms specializing in these services.

3 UNDERSTANDING NTCIP

3.1 Introduction

This chapter is intended for those with interest in exploring NTCIP beyond the Executive Summary, and particularly for those involved in planning ITS systems. It is assumed that the reader has already read the Executive Summary which provides much of the basic information about NTCIP that is not repeated here.

This chapter contains the following sections:

- Benefits of NTCIP
  - Avoid Early Obsolescence
  - Provide Choice of Vendor
  - Enable Interagency Coordination
  - Use One Communications Network for All Purposes
- Types of Systems and Devices Supported by NTCIP
- Applications Not Addressed by NTCIP
- The Levels or Modules Involved in Communications
  - Information
  - Application
  - Transport
  - Subnetwork
  - Plant
- The NTCIP Framework
- NTCIP Standards and Protocol Stacks
- Options and Conformance Levels
- Center-to-Center Protocols
  - Data Exchange Between Systems (DATEX)
  - Common Object Request Broker Architecture (CORBA)
- Center-to-Field Protocols
  - Simple Network Management Protocol
  - Simple Transportation Management Protocol
- Communications Infrastructure for Center-to-Field
- Retrofitting Existing Center-to-Field Systems with NTCIP

3.2 Benefits of NTCIP

NTCIP offers increased flexibility and choices for agencies operating transportation management systems. It removes barriers to interagency coordination and allows equipment of different types and manufacturers to be mixed on the same communications line. For these reasons, operating agencies will benefit from specifying that NTCIP be included in all future purchases and upgrades, even if NTCIP is not planned to be used initially.

3.2.1 Avoid Early Obsolescence

Even though it may not be practical to retrofit NTCIP support in some old equipment, most vendors will offer NTCIP support in current and future products. It is possible to operate a mixture of NTCIP and non-NTCIP devices in the same system, although not on the same communications line. Alternatively, equipment may continue to use a current protocol even though it also supports NTCIP. In either case, an operating agency can ensure that its equipment remains useful and compatible long into the future by requiring NTCIP support in all future purchases and upgrades of transportation management systems, including purchases of computer software, field masters, and controllers for any type of traffic or transit control or monitoring device.

Buying a field device or central control system that has no software available to support NTCIP, is like buying an incompatible computer that has no software available to access the Internet. Even if purchasers do not use the Internet now, they surely will during the lifetime of the computer.

3.2.2 Provide Choice of Vendor

Once an agency has a computer system that includes support for NTCIP, it can purchase other systems, field devices, or software from any vendor offering NTCIP-compliant products, and they will communicate with that system. Only products from the same vendor will be able to fully use the features within the software or controller that are manufacturer specific, but basic functionality will be available regardless of the manufacturer, provided the procurement documents adequately specify the mandatory and optional conformance requirements that support the agency's functional requirements. However, NTCIP will make it easier for such an agency to gradually change its software, controllers and other field devices from one vendor to another in the future as part of a switch to a new vendor for the entire system.

3.2.3 Enable Interagency Coordination

NTCIP allows agencies to exchange information and (with authorization) basic commands that enable any agency to monitor conditions in other agencies' systems, and to implement coordinated responses to incidents and other changes in field conditions when needed. Such data exchange and coordinated response can be implemented either manually or automatically. One agency can monitor, and issue basic commands to (if authorized), field devices operated by another agency, even though those devices may be from a different vendor than those used by the monitoring agency. Potential applications of interagency coordination include coordinating timed transfers at a shared transit center, coordinating traffic signals across jurisdictional boundaries, providing traffic signal priority for selected (e.g., behind schedule) transit vehicles, providing real-time information to a shared traveler information center, monitoring traffic volumes on another agency's roadway, coordinating the operation of a freeway ramp meter with an adjacent traffic signal, or posting a warning message on another agency's dynamic message sign.

3.2.4 Use One Communications Network for All Purposes

NTCIP allows a management system to communicate with a mixture of device types on the same communications channel. For example, with the addition of appropriate application software in the system computer, a dynamic message sign could be installed near a signalized intersection, and the computer could communicate with the sign controller using the communications channel already in place for the traffic signal controller. Similarly, a wide area network interface installed for communications with a system operated by another agency can be used for communications with any number of other systems, of any type, if NTCIP is used. The communications network is usually one of the most expensive components of a transportation management system. NTCIP ensures maximum flexibility in future use of that major investment.

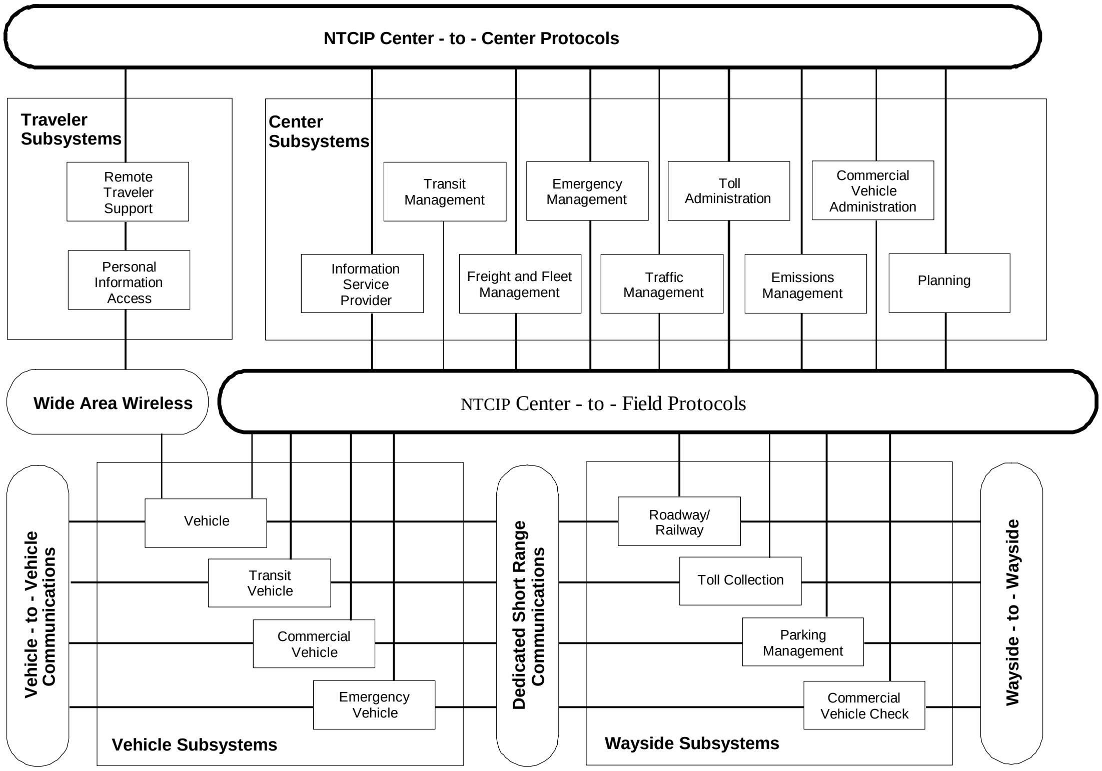
3.3 Types of Systems and Devices Supported by NTCIP

NTCIP defines a family of general-purpose protocols that support all types of computer systems and field devices used in transportation management. Applications for NTCIP are generally divided into two categories – center-to-field and center-to-center. The former, normally involve devices at the roadside or on agency-owned vehicles, communicating with management software on a central computer. Center-to-center applications usually involve computer-to-computer communications where the computers can be in the same room, in management centers operated by adjacent agencies, or across the country. The role of NTCIP in the National ITS Architecture is illustrated in Figure 3.1.

For both center-to-field and center-to-center applications, NTCIP supports systems and devices used in both traffic, transit, emergency management, traveler information, and planning (data archiving) systems. Figure 3.2 illustrates how various transportation management systems and devices can be integrated using NTCIP.

Note that some computers involved in center-to-center communications may be located in the field (e.g., kiosks, field masters, advanced controllers). NTCIP's center-to-field and center-to-center protocols have options to support dial-up communications links.

Figure 3.1 - NTCIP and the ITS National Architecture



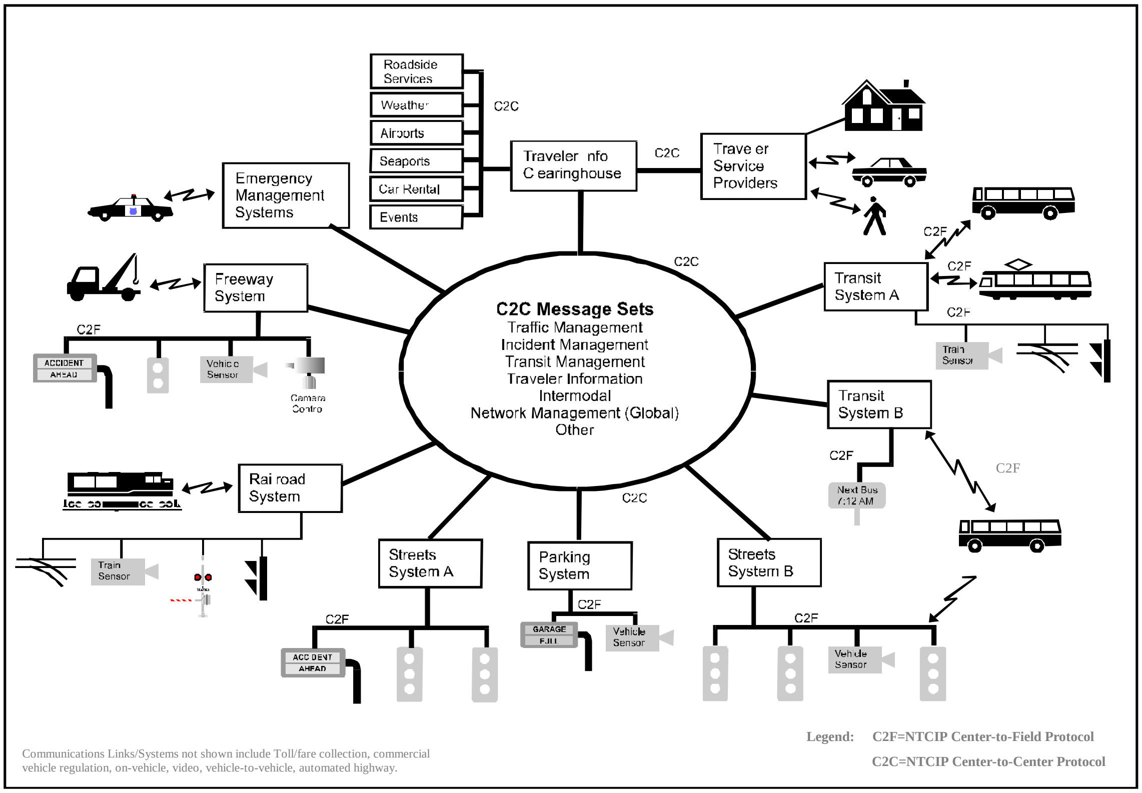
The following are examples of systems and devices that can take advantage of NTCIP:

- Center-to-Field
  - Dynamic message signs
  - Traffic signals
  - On-board sensors and controllers
  - Environmental sensors
  - Ramp meters
  - Vehicle detectors
  - Closed circuit television cameras
  - Audio message transmitters
  - Any mix of the above

- Center-to-Center
  - Traffic management (freeway/surface street, urban/rural)
  - Transit management (bus/rail/other)
  - Emergency management
  - Parking management
  - Traveler information (all modes)

- Commercial vehicle operations regulation
- Any mix of the above

Figure 3.2 - Example of ITS Integration Using NTCIP



Communications Links/Systems not shown include Toll/fare collection, commercial vehicle regulation, on-vehicle, video, vehicle-to-vehicle, automated highway.

Legend: C2F=NTCIP Center-to-Field Protocol
C2C=NTCIP Center-to-Center Protocol

Many applications of NTCIP are related to near real-time communications and involve continuous, automated transmissions of data or commands. NTCIP also supports human-to-remote-machine/system transmissions. Historical data can also be sent using NTCIP, but other communication standards, especially electronic mail and file transfer protocols developed for the Internet, are also suitable for this purpose. Human-to-human communications are generally better served by fax/telephone and Internet protocols (e.g., e-mail, chat) but basic support is also provided in the NTCIP center-to-center protocols.

3.4 Applications Not Addressed by NTCIP

Some of the data transfers involved in ITS have special needs that are the subject of other standards development efforts. The NTCIP effort is coordinating with the activities of these other groups to the extent practical. These other standards efforts include:

- A roadside device reading and/or writing to an electronic tag on a vehicle. This involves very fast and compact wireless data transfers over short distances (a few meters) during the few milliseconds that a passing vehicle's tag is within reception range. However, NTCIP is suited to communications between the roadside tag reader and a central computer.

- Full motion video transmitted from a camera or recorded media. This involves specialized protocols able to accommodate the large volume of continuous streaming information making up a video signal, and several such standards already exist. However, NTCIP is suited to transmission of video camera and switch control data using a separate communications channel.

- Transmission of traveler information data to privately-owned vehicles. This involves special protocols such as those that work in conjunction with the FM radio standards or cellular radio. However, NTCIP is suited to sending the information from various data sources to the traveler information service provider.

- Communications for financial transactions. This involves special security measures not currently supported in NTCIP.

- In-vehicle communications for operation monitoring, and advanced vehicle control and safety. This involves specialized protocols for very high speed and fail-safe transmissions between devices housed on the same vehicle.

- In-cabinet communications between a controller and other electronic devices in a roadside cabinet. This involves specialized protocols for very fast high-volume data transmissions over short distances.

Other communications standards are available or under development to serve each of these specialized needs.

3.5 The Levels or Modules Involved in NTCIP Communications

NTCIP uses a layered or modular approach to communications standards, similar to the layering approach adopted by the Internet and the International Standards Organization (ISO). In general, data communications between two computers or other electronic devices can be considered to involve the following primary layers, called "levels" in NTCIP to distinguish them from those defined by ISO and the Internet:

- Information Level – This level provides standards for the data elements, objects, and messages to be transmitted (e.g., TCIP, TS3.5, MS/ETMCC, etc.).

- Application Level – This level provides standards for the data packet structure and session management. (e.g., SNMP, STMP, DATEX, CORBA, FTP, etc.).

- Transport Level – This level provides standards for data packet subdivision, packet reassembly, and routing when needed (e.g., TCP, UDP, IP).

- Subnetwork Level – This level provides standards for the physical interface (e.g., modem, network interface card, CSU/DSU, etc.), and the data packet transmission method (e.g., HDLC, PPP, Ethernet, ATM, etc.).

- Plant Level – This level consists of the physical transmission media used for communications (e.g., copper wire, coaxial cable, fiber optic cable, wireless)

The information level standards used in Intelligent Transportation Systems (ITS) are unique to the transportation industry. The National ITS Architecture and much of the on-going standards development effort for ITS involve identification of required data elements and their compilation into standard objects or message sets for all the different domains and functions within ITS (e.g., traffic, transit, traveler information, emergency management, etc.). For the subnetwork and transport levels, ITS can generally use existing standards used by the broader computer and telecommunications industries. NTCIP has not had to develop significantly new standards in these areas, but has merely chosen which existing standards are to be used in ITS (the Internet standards have been adopted where possible), and has specified which options to use where alternatives are available in some standards.

The application level, is the primary focus of NTCIP. Although some existing standards are useful here, ITS has special requirements that have necessitated the extension of existing standards, or development of entirely new protocols for specific applications within ITS. Some of the special communications requirements of ITS are:

- Continuous, automated, secure, real-time exchange of large volumes of small data packets in a many-to-many multi-agency network.

- Continuous high volumes of real-time data sent to and from embedded processors in roadside or on-vehicle equipment sharing the same, often low-speed, data channel and requiring low latency.

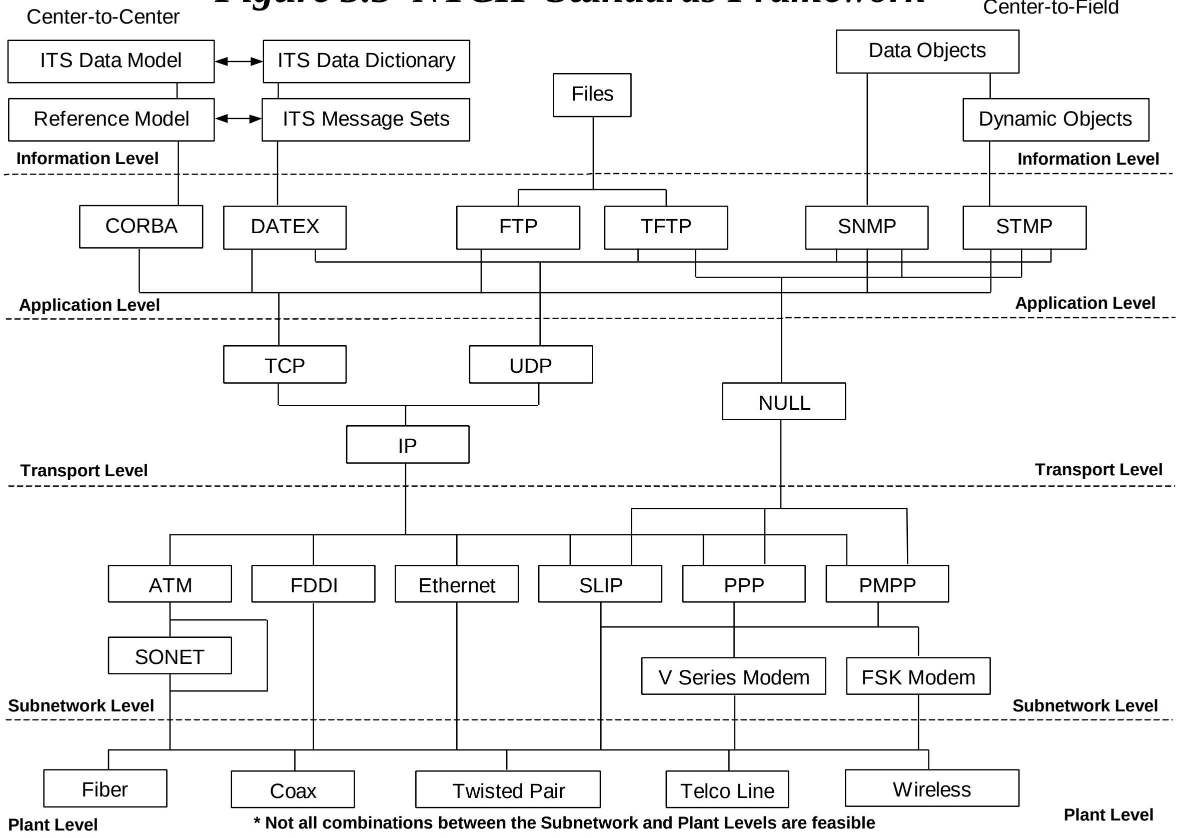
Through a layered combination of existing communications standards and a few new standards developed specifically for ITS, NTCIP provides a family of communications protocols that serve most of the common needs in ITS.

3.6 The NTCIP Framework

Figure 3.3 illustrates the framework for NTCIP. The diagram shows the different standards that can be chosen at each level (boxes) and which ones are compatible (lines connecting boxes). See Section 7.2 for an explanation of the acronyms used in this diagram.

As discussed above, a particular message transmission can use, at most, one standard at each level or sublevel of the NTCIP framework. The series of standards used in the message transmission is called a “stack” of standards, or a “protocol stack”. It is possible for a pair of electronic devices to exchange some messages using one stack and other messages using a different stack, though usually, such stacks will differ only at one or two levels or sublevels. In Figure 3.3, optional standards at each level are shown by the lines connecting standards at different levels. If there is a continuous line (without reversal of direction) from one standard to another, then they are compatible and can be used together as part of a protocol stack.

Figure 3.3 NTCIP Standards Framework

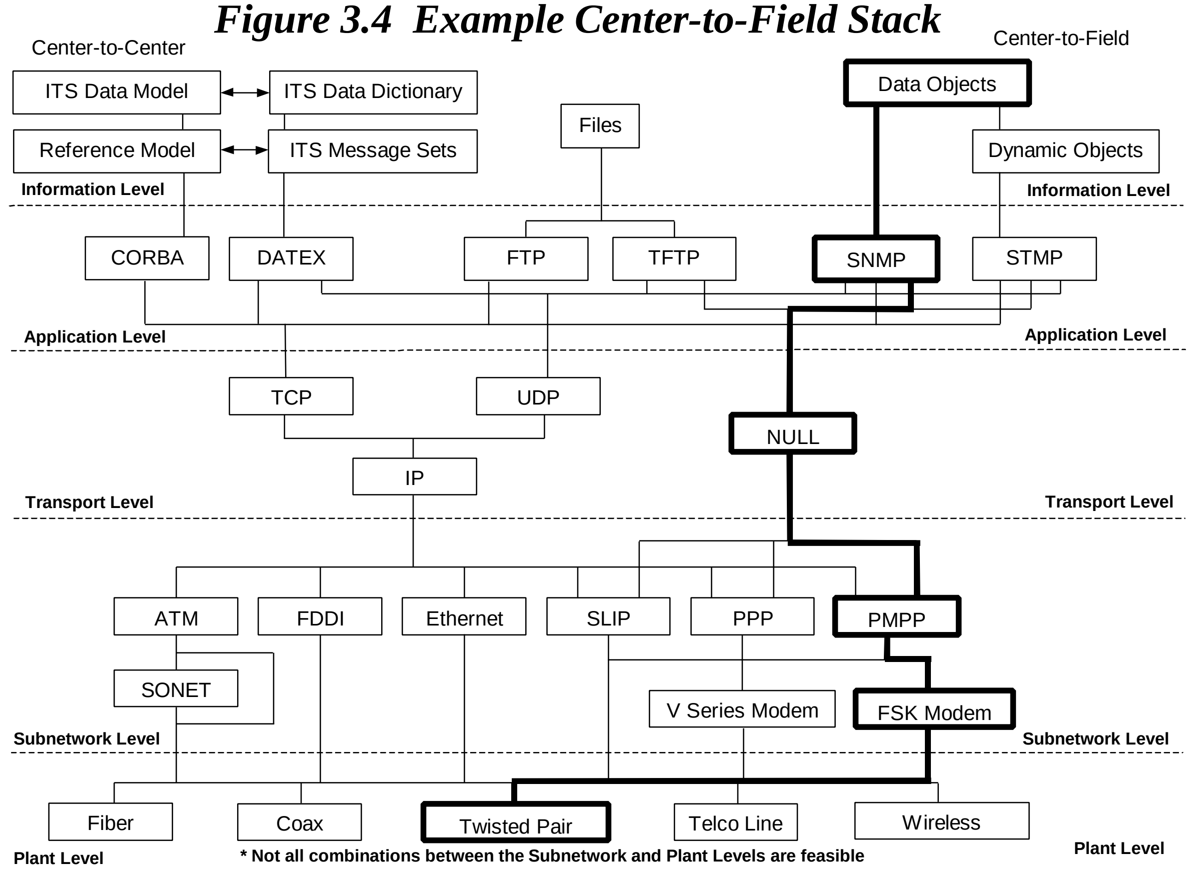


* Not all combinations between the Subnetwork and Plant Levels are feasible

The levels shown in the framework are somewhat different from communication stack layers defined by the International Standards Organization (Open Systems Interconnect seven-layer reference model) and other standards making organizations. This document describes the NTCIP stack as extending beyond the communications stack to include informational data and interfaces to the physical communications infrastructure. The levels and terminology used in NTCIP were chosen for simplicity and ease of understanding by lay readers, and relevance to typical applications in the transportation industry. The OSI layers and terminology are often referenced in later technical sections of this guide and in many of the standards defined by NTCIP.

Figure 3.4 illustrates an example Center-to-Field protocol stack that can be defined using NTCIP standards. A stack is a subset of the overall NTCIP framework – a particular route through the levels. Some stacks include two standards at some levels, which usually means the protocol can use either of the optional standards. NTCIP stacks generally offer further options within some of the component standards (not shown in these figures). Examples of sub-options within a standard are: which subset of messages are supported; or which bit rate is used at the physical interface.

Figure 3.4 Example Center-to-Field Stack



As explained above, most of the standards in the lower levels are existing standards used in the telecommunications industry and were not developed by NTCIP (although NTCIP often specifies which sub-options within those standards are to be used). The standards unique to Intelligent Transportation Systems are found in the first two levels (Information and Application levels) in Figures 3.3 and 3.4. Each NTCIP protocol stack involves a mixture of NTCIP-specific standards at the upper levels and several existing standards at the lower levels.

3.7 NTCIP Standards and Protocol Stacks

The first NTCIP standards developed were those intended for center-to-field applications. This involved a *new* application level standard called Simple Transportation Management Protocol (STMP), and several sets of *new* standard data elements called "objects" at the information level. The initial NTCIP center-to-field protocol development also involved specifications for using two *existing* standards – the Simple Network Management Protocol (SNMP) standard at the application level, and the High-level Data Link Control (HDLC) standard at the subnetwork level.

In 1999, the approach for documenting NTCIP standards and protocol stacks has changed. NTCIP currently defines the options at each level of a protocol stack using "profile" documents. Each profile document specifies one or more standards to be used at a level, and the sub-options allowed or required within each of those standards. A profile document typically references one or more "base standard" documents – documents that contain the specifications for the standard(s) being called out in the profile. A base standard may be an NTCIP document (if the standard was developed by NTCIP) or a document developed by any other standards development organization. The numbering scheme for NTCIP documents also changed, as shown in the appended list of NTCIP documents.

There are different types of profile documents for the different levels of the stack, as follows:

- Information profiles
- Application profiles
- Transport profiles
- Subnetwork profiles

For a particular application of NTCIP, the user must select (in the procurement specifications) which element(s) are desired at each level – i.e., select from the options called out in one or more profile documents for each level. The set of selections for all levels is referred to here as a "protocol stack". Each NTCIP protocol stack will have different characteristics, and a stack that works well for one application or communications environment may not suit another.

Standards that NTCIP has defined, or is in the process of defining, enable protocol stacks that can be categorized as follows:

Simple Network Management Protocol (SNMP) – Stacks based on SNMP provide a simple, but bandwidth inefficient, protocol for center-to-field applications, based on the Internet protocol of the same name (SNMP). It is suitable only for networks with high bandwidth or low volumes of messages. Options are available at the Transport level for routing messages using the Internet Protocol if desired.

Simple Transportation Management Protocol (STMP) – STMP is an extension of SNMP that allows center-to-field messages to be sent more efficiently using dynamic composite objects. Stacks based on this protocol are suitable for networks with low bandwidth and high volumes of messages, including traffic signal systems. Options are available at the Transport level for routing messages using the Internet Protocol if desired.

***Data Exchange Between Systems (DATEX)* –** DATEX provides a general purpose center-to-center data exchange protocol stack. It uses pre-defined messages transmitted by the base Internet protocols (TCP/IP and UDP/IP) in a peer-to-peer network. The base standard at the application level is an ISO standard (developed by an NTCIP working group) called DATEX-ASN.

***Common Object Request Broker Architecture (CORBA)* –** A general purpose center-to-center communications protocol based on the computing industry standard of the same name. For object-oriented systems, it enables a higher degree of integration and some services not provided by DATEX, but may not be suitable for near real-time applications and loosely coupled systems.

The standards that can be used in each of these categories of protocol stacks are highlighted in Figure 3.3.

Two electronic devices will be able to communicate with each other if they use the same protocol stack and implement the needed options within that stack.

Section 10.1 contains a complete listing of NTCIP related documents.

3.8 Options and Conformance Levels

In addition to specifying a protocol stack, the system designer must also choose between various options and alternatives available in the selected stack. These options exist in both center-to-center and center-to-field protocol stacks. Major options, such as which protocol(s) to support at each level in the stack, are sometimes grouped according to conformance levels. Others are individually selectable. [Most manufacturers and system suppliers typically offer features that go beyond the standard. To make use of such features, it is necessary to specify the inclusion of manufacturer specific objects or messages when procuring a system.]

Details on options and conformance levels, and how to specify your selection, are presented in later sections of this Guide.

3.9 Center-to-Center Protocols

NTCIP provides two alternative protocol choices for center-to-center communications, as discussed above. One is called DATEX and the other is called CORBA. Two different protocols were found necessary to meet the variety of requirements for inter-system data exchanges. It is feasible to use both protocols in the same network, with some centers acting as a bridge, or translator, between the two. The key is in determining where to deploy each protocol.

DATEX was designed to provide simple, cost-effective solutions for basic needs. It is especially well suited for:

- Systems requiring real-time, fast data transfer (e.g. traffic signal status data)
- Systems with limited communications bandwidth but high data transfer load
- Systems with infrequent event driven exchanges over dial-up links
- Non-object oriented systems

Conversely, CORBA provides several features to support networks connecting object oriented systems, and assuming sufficient processing power and communications bandwidth are provided, it could be used for all applications between such systems. Object oriented software can take full advantage of CORBA and implement it easily, traditional procedural software cannot.

It is expected that most systems will support DATEX, and may initially use it solely. Even if some systems in the network are object oriented and use CORBA, they will likely also support DATEX to allow interfaces with DATEX-only systems and to assist in real-time data exchange needs. Over time, as a standardized reference model emerges, new object-oriented systems come on line, and processing and communications resources are upgraded, more and more systems may migrate to CORBA. Non-object-oriented systems that reside in large regions of interconnected ITS systems may choose to wrap their interface and provide a CORBA interface to leverage CORBA capabilities. These and other implementation issues are discussed in later sections of this Guide.

Center-to-center networks allow each system to request any available information from any or all other systems. Each system can be configured to either accept or reject any request. The “data” sent can be informational or can constitute a “command” to take some action. Consider a message sent from one traffic signal system to another and containing a signal timing pattern number. In DATEX for example, depending on the message type, it could represent a command to implement that timing pattern at a particular traffic signal or group of signals, or it could represent a status report indicating that this timing pattern was just implemented at a particular traffic signal or group of signals.

In either case, the user can establish standing subscriptions for data if it wants the same data sent repeatedly. In DATEX, subscriptions can specify that data be sent one-time-only, periodically, or repeatedly on occurrence of some event defined in the subscription. Each subscription message has a corresponding publication message. Unless the subscription is a one-time request, the data will continue to be automatically “published” repeatedly until the subscription is cancelled, or until a predefined end date specified in the subscription. Using CORBA, a system can automatically and dynamically “discover” data available from other systems.

Center-to-center communications require a peer-to-peer network connection between the involved computers. This is typically a local area network, a wide area network, or a dial-up connection. Local area networks typically use agency-owned twisted pair cable or fiber optic cable. Wide area networks typically use commercial telecommunications links such as frame-relay, partial T1 leased lines, packet radio, or leased “virtual private networks”. Dial-up connections typically use ISDN, V.90 or similar modems over plain-old telephone lines. Any type of communication link can be used, as long as it enables use of the Internet transport and routing protocols (TCP/IP and UDP/IP) and has sufficient bandwidth for the planned communications load (frequency and size of messages to be transmitted).

3.10 Center-to-Field Protocols

NTCIP provides two closely related protocols choices for center-to-field communications. These are based on the Simple Network Management Protocol (SNMP) and the Simple Transportation Management Protocol (STMP). Both of these base protocols use the get/set messaging paradigm used in the Internet's Simple Network Management Protocol. Both choices use the same base data objects, as defined in the NEMA TS 3.x series of documents. They differ in the level of complexity to implement and the types of services offered. Table 3.1 summarizes the services offered and implementation requirements.

Table 3.1 SNMP and STMP Comparisons

	SNMP	STMP
Can send any base object?	Yes	Yes
Bandwidth Efficiency – inverse of packet overhead	Worst	Best (uses dynamic composite objects)
Supports routing & dial-up	Options	Options
Message Set	Supported	Limited to 13
Ease of implementation	Easiest	Hardest

The Simple Transportation Management Protocol (STMP) is the most bandwidth efficient option and includes full support of SNMP for infrequent messaging demands. It includes SNMP as a subset, so that any management system that implements STMP can also communicate with a device that supports only SNMP. Occasional messages requiring additional security can be sent using SNMP. The greatest advantage of STMP is its support for dynamic composite objects which, combined with a more efficient encoding scheme, dramatically reduce the packet overhead (relative to SNMP). Dynamic composite objects also enable users to define custom messages that are composed of any number of individual data objects. It is the most flexible and bandwidth efficient option.

Devices that use either the PMPP or Ethernet Subnetwork Level can share the same communications line with other devices using the same subnetwork. It doesn't matter if such devices are from different manufacturers or are totally different devices (e.g., a traffic signal and a dynamic message sign). Each device is assigned an address that is unique on that line or channel. The management system can communicate with any of the devices at any time by sending a message addressed to that device. However, it can communicate with only one of the devices on the line or channel at a time. Devices can send a message to the management system only when requested to do so by the management system. The NTCIP protocols enable broadcast messages intended for all devices (e.g., a time clock update). No devices can reply to a broadcast message.

The NTCIP center-to-field protocol stacks can be used in management systems of any configuration or complexity. There are options within each stack to add support for message routing via intermediate communications hubs or field masters if needed. However, a particular implementation of a center-to-field protocol stack may not provide support for such options unless specifically requested at the time of procurement.

The communications link can use any medium, such as twisted wire pairs, coaxial cable, optical fibers, or radio (e.g., narrow band, spread spectrum, microwave). It does not matter whether the communications media is agency owned, leased, or dial-up. Multiplexers can be used to combine multiple channels on one trunk link. Theoretically, any data transmission rate can be used with NTCIP. However, field devices typically support transmission rates in the range of 1200 to 19,200 bits per second. The only requirement is that the time for transmission (including any delay in intermediate relay devices) and the response time in the end device, be reasonable and within the tolerances needed to allow all devices to communicate within the required time frame. These requirements, together with the bit rate and quantity of information to be transmitted, determine the maximum feasible number of devices on each communications channel, as discussed below.

3.11 Communications Infrastructure for Center-to-Field

In planning a center-to-field communications network using NTCIP that involves continuous polling of field devices (e.g., a traffic signal system or transit fleet AVL system), it is important to consider the relationship between the following key variables:

- Transmission rate (bit rate)
- Transmission method (e.g., full or half duplex, sequential or overlapping)
- Transmission delay (including any modem/radio set-up/turn-around time)
- Response delay in the field device (time from receipt of request to sending response)
- Time between devices or between polling cycles (if needed)
- Length of message(s) to be sent (dynamic composite object definitions)
- Frequency of each type of message (per second, per minute, per day)
- Number of devices sharing the same line or channel
- Frequency of communication (e.g., polling period)

The first seven of these variables will determine the total time needed to communicate once with each device. If this time is then treated as fixed (say T), the number of devices sharing the same line or channel (say N) and the frequency of communication with each device (say P for polling period, the inverse of frequency) are related by the equation; $P = N \times T$. This is a very simplified explanation of what can be a quite complex design issue that should be addressed early in project planning.

Although the NTCIP Simple Transportation Management Protocol is designed for use with communications channels that use a slow transmission rate (as low as 1200 bits per second), it is not as bandwidth efficient as most proprietary protocols used in the past. With existing communications infrastructure, it may not be possible to maintain the same polling period with the same number of devices per channel. This is due to the fact that proprietary protocols are optimized for each manufacturer's equipment and one or two fixed short messages, while standard protocols are designed to accommodate all needs and a wide variety of information and messages in a multi-vendor environment. However, careful design can usually find a reasonable compromise between the principal variables. The higher the bandwidth available (bit rate), the fewer the compromises or tradeoffs required. If new communications infrastructure can be provided, it should allow for additional channels and/or higher transmission rates.

Such implementation issues are discussed in more detail in later sections of this guide.

3.12 Retrofitting Existing Center-to-Field Systems with NTCIP

It may not be feasible to modify old versions of controllers or controller software to make them NTCIP compatible. Constraints such as computing power, memory available, cost of modification may well preclude such modifications. If such controllers or software cannot be upgraded or replaced, traffic control systems that continue to make use of older equipment or older software versions will likely have to continue using the protocols unique to communications with those devices. However, current version controllers and software within the system may be capable of modification to use NTCIP, and all future versions should be NTCIP compatible. If in doubt, the equipment manufacturer should be contacted and asked if upgrades for NTCIP compliance are available.

In general, NTCIP and non-NTCIP devices cannot be mixed on the same communications channel. Therefore all devices sharing a channel must be upgraded simultaneously. A computer or master that communicates with both NTCIP and non-NTCIP devices will need to use a different communications port for NTCIP devices and for non-NTCIP devices, and will need to support both protocols. In traditional closed-loop traffic signal systems, the most likely and simplest solution is to limit each field master to one protocol. Only field masters with NTCIP-compatible controllers would be upgraded to support NTCIP. This avoids the need for field masters to simultaneously support two protocols on two separate ports.

In closed-loop traffic signal systems, the central computer could communicate with field masters using a different protocol than that used by the field master to communicate with controllers. As with the controller and the field master, the central computer software will need to be modified to add support for an NTCIP protocol if NTCIP is to be used for communications with field masters.

Any upgrade of an existing system to add support for NTCIP is probably best designed in consultation with the system vendor. Each vendor will likely adopt an upgrade strategy that is most efficient for the majority of its customers. If a particular customer wants a unique arrangement, that customer will probably have to pay the full cost of the software modifications, whereas the cost of the general solution can be spread among many customers.

One approach to the introduction of NTCIP in a center-to-field system is to operate two totally separate systems - one NTCIP and one non-NTCIP - during a transition period. Field devices can gradually be switched over from one to the other as they are replaced or their software is upgraded. This may be the only choice if the current system is quite old and upgrading it for NTCIP is not practical. Such a transition would logically be done as part of a general system upgrade.

Even if a system continues to use a proprietary protocol, new controllers and masters, or new software packages should include the appropriate NTCIP protocol stack as an option. Some vendors will support both their existing protocols and NTCIP in the same software package. Others will require a change of software to switch from one protocol to the other. Regardless of how it is done, the owning agency should ensure that an appropriate NTCIP protocol stack is available for future use even if it is not needed immediately. This will maximize the useful life of the new equipment and enable introduction of NTCIP at any time in the future without further upgrades. It also maximizes options and competition when choosing new equipment, since different vendors' equipment can be mixed if needed (assuming support is available for manufacturer-specific information).

4 PROCURING NTCIP

4.1 Introduction

The purpose of this section is to provide guidance to those who are responsible for developing specifications for and procuring NTCIP compliant devices and systems. This section is written specifically to target the systems planner/specification writer, or that person responsible for preparing procurement and system design and specifications for NTCIP systems.

This chapter contains the following sections:

- Procurement Roadmap
  - Procurement Request
  - Proposal Initiation
  - Investigate Issues
    - Requirements
      - How NTCIP Standards Fit Together
      - Selecting Standards and Conformance Statements
      - Manufacturer Extensions
    - Implementation Alternatives
    - Other Factors
      - Stability of the Standard
      - Support of Amendments
      - Agency / Developer Understanding
      - Certification Process
      - Performance Issues
    - Proposal Submission
    - Delivery / Acceptance Testing
      - Unit Testing
      - Integration Testing
      - System Testing
    - Maintenance
    - Design Requirements
    - Testing Requirements
- Center-to-Field
  - NTCIP Stack Options
  - Available Resources for Additional Information
  - NTCIP Specification Development Examples
    - NTCIP Stack for Center-to-Field Traffic Signal Controller
    - Conformance Group and Data Object Selection for Traffic Signal Controllers
    - Object Range Values for an Actuated Traffic Signal Controller
- Center-to-Center

The NTCIP effort represents a family of open communication standards for ITS deployments. Standardized communication protocols enable Interoperability and Interchangeability and with this comes an eagerness to implement these standards. Too often, we have seen the desire to implement these standards overshadow our knowledge of which standards are really needed and how those standards should be specified.

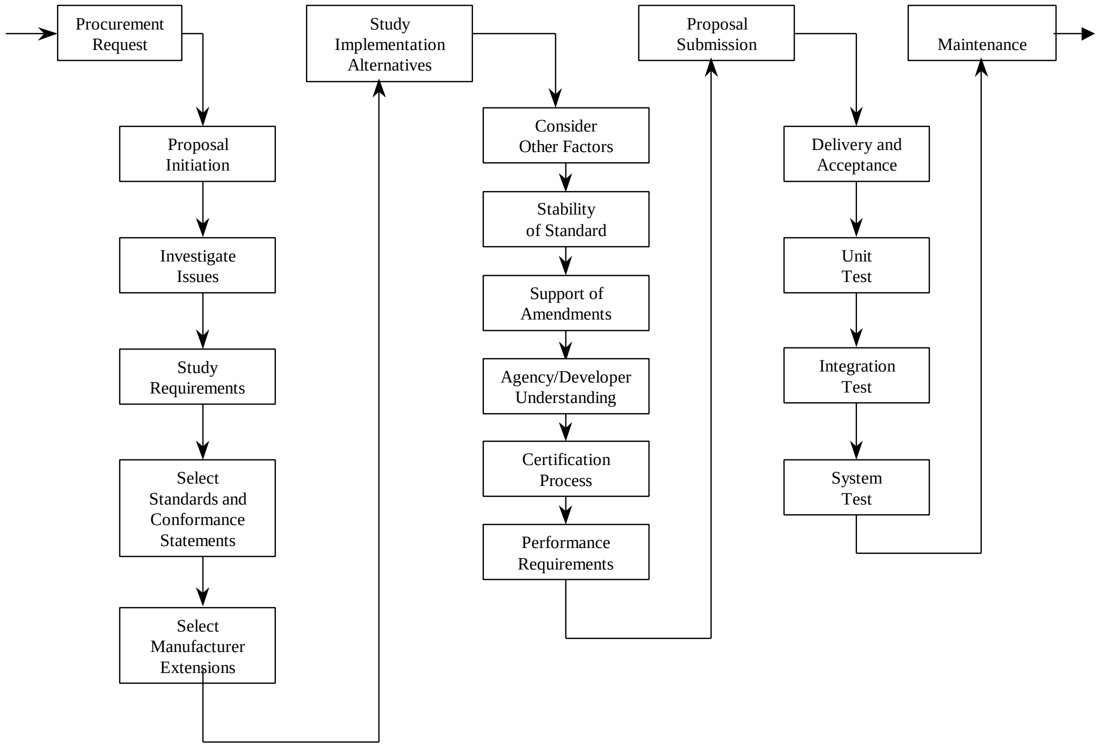
Systems and equipment procurement specifications sometimes include simply a sentence such as *"All components shall be NTCIP compliant,"* or *"The system shall use NTCIP as the communications protocol."* These single statements provide no information to manufacturers or systems integrators on the type, scope, and functionality of the system or hardware to be implemented. Specifying detailed requirements for NTCIP is not a trivial task and requires a great deal of study to develop a set of detailed specifications that will ultimately meet the intended needs. This section is intended to guide the systems planner/specification writer through the specification development process, pointing out key considerations along the way, and provide additional understanding of NTCIP when coupled with the information provided in previous sections.

It has been said on many occasions that there is no exact specification wording that can simply be copied into procurement documents. The reason for this is that there is no single system design that is standard across the country. Available resources and functionality needs vary from agency to agency and as a result, system designs vary from agency to agency. Obviously, defining a system that encompasses all the functionality and options that are available would be a costly burden for smaller agencies to bear. And, defining a system with minimal functionality would not meet the needs of many larger agencies. Therefore, this section will focus on the presentation of a process to follow when developing procurement specifications for systems and equipment using NTCIP.

4.2 Procurement Roadmap

There are certain steps that should be taken in any systems procurement project to successfully meet the intended goals. It is especially critical to follow an orderly procedure when procuring systems that are intended to meet standards. Figure 4.1 summarizes some of the more important steps that should be followed by any organization considering the procurement of NTCIP devices/software.

Figure 4.1 Roadmap for Procuring NTCIP



4.2.1 Procurement Request

The procurement request can take many forms. Devices are often purchased through a low-bid process administered by the agency. Software is routinely procured through service oriented contracts. As such, the specifications and requirements that are made part of the procurement package can range from detailed specifications to more general requirements documents. The procurement of NTCIP compliant devices and software does not change the normal procurement methods that most agencies use. Additional steps, however, may need to be added to traditional procurement processes for NTCIP related procurements to ensure an adequate understanding of the intended requirements and assurance of adherence to the standards and specifications.

4.2.2 Proposal Initiation

There are two alternative approaches that can be used when considering the preparation of procurement documents for NTCIP systems and devices. One approach might be for the agency to solicit a proposal during the procurement process that allows the manufacturer, vendor, developer, or systems integrator to present detailed information on how the intended system or device compliance with NTCIP standards are to be achieved. This method of procurement relies on the preparation of general requirements documents during the initial stages of the procurement process. At some point thereafter, either during selection or after award, the agency solicits for approval a detailed proposal from the systems developer or integrator that presents detailed information as to which specific standards, conformance groups, data objects, and range values can be provided to meet the procurement requirements. Additionally, any other pertinent information should be included. The proposal submission and approval process described here might be an iterative process, depending on the specific requirements of the agency.

Another method of preparing procurement specifications is the development of detailed NTCIP system or device specifications, in addition of any detailed functional specifications. This route requires extensive knowledge both NTCIP standards and the device or system functionality needed to meet the intended needs. Pursuit of this alternative would require the agency to make the necessary selections at all levels within the NTCIP Framework to determine an NTCIP stack that will meet their needs. Specific NTCIP standards, conformance groups, data objects, and range values will need to be identified as well. It should be stressed that this method of preparing procurement documents will require expertise in both communications and systems design, in addition to extensive knowledge of the intended device or system functionality.

4.2.3 Investigate Issues

Both the agency and the systems developer or integrator must ensure that there is an adequate understanding of the requirements set forth in the procurement request. Some requests to-date have been very ambiguous, like "The device shall be NTCIP compliant.", others have been very detailed and precise, and some have even had precise statements that conflicted with each other. Thus, the agency should expect that a systems developer or integrator would first perform an investigation to ensure a proper understanding of project needs. This should then be followed by an investigation of how the system may be implemented while recognizing the development risks that may be encountered.

It should be realized that this process often works best in an iterative fashion. This allows the agency and the system developer or integrator to work together in developing a list of requirements and a proposal that best matches everyone's needs. However, this is not always possible due to the procurement regulations of some organizations.

4.2.3.1 Requirements

The first aspect of the investigation should be to determine the exact requirements for the system. This will often require expanding the original request. For example, if the procurement request is simply for an "NTCIP compliant device", the developer must determine what functionality the device is supposed to support and then determine what NTCIP options might be appropriate.

An agency should understand that the developer might also need to modify or limit the original procurement request in order to meet safety, schedule, or other concerns. For example, the request may be for a signal controller and require "support for the full range of all objects." However, for safety and liability reasons, the developer may want to develop his software to limit the valid values for the yellow clearance interval to 3.0 to 5.0 seconds. It is important to identify any such variances from the request as early as possible so that the expectations for the resulting product are properly managed.

The result of this effort should be a detailed requirements document with which both the client and developer can be satisfied. Additional details of this investigation are given below. As a minimum, the document should address those issues identified throughout this section.

4.2.3.1.1 How NTCIP Standards Fit Together

Ideally, there would only be one NTCIP standard that met everyone's needs. However, reality requires a large number of options to meet the unique needs of specific sites. For example, some agencies have a large amount of twisted pair copper that they want to continue to use. Other agencies are installing new systems and want to take advantage of fiber optic cable and other technologies. Likewise, some agencies have fairly simple data exchange needs with field devices, whereas other centers need to exchange large amounts of information with other centers. The NTCIP accommodates these various needs by providing a suite of standards, each providing unique features.

Figure 4.2 depicts the NTCIP Standards Framework. The framework is based upon five levels including Information, Application, Transport, Subnetwork, and Plant Levels. The middle three of these five levels loosely relate to the various layers of the seven-layer OSI model. The Plant Level is included as a reference to show the relationship to field infrastructure. The figure shows all the various standards that reside on each level and represents the various choices that must be made during the specification development process. The connecting lines represent the compatibility linkages between the various standards.

- Information Level – Information Profiles define the meaning of data and messages and generally deal with ITS information (rather than information about the communications network). This is similar to defining a dictionary and phrase list within a language. These standards are above the traditional ISO seven layer stack.

- Application Level – Application Profiles define the rules and procedures for exchanging information data. The rules may include definitions of proper grammar and syntax of a single statement as well as the sequence of allowed statements. This is similar to combining words and phrases to form a sentence or a complete thought and defining the rules for greeting each other and exchanging information. These standards are equivalent to the Session, Presentation and Application Layers of the ISO seven layer stack.

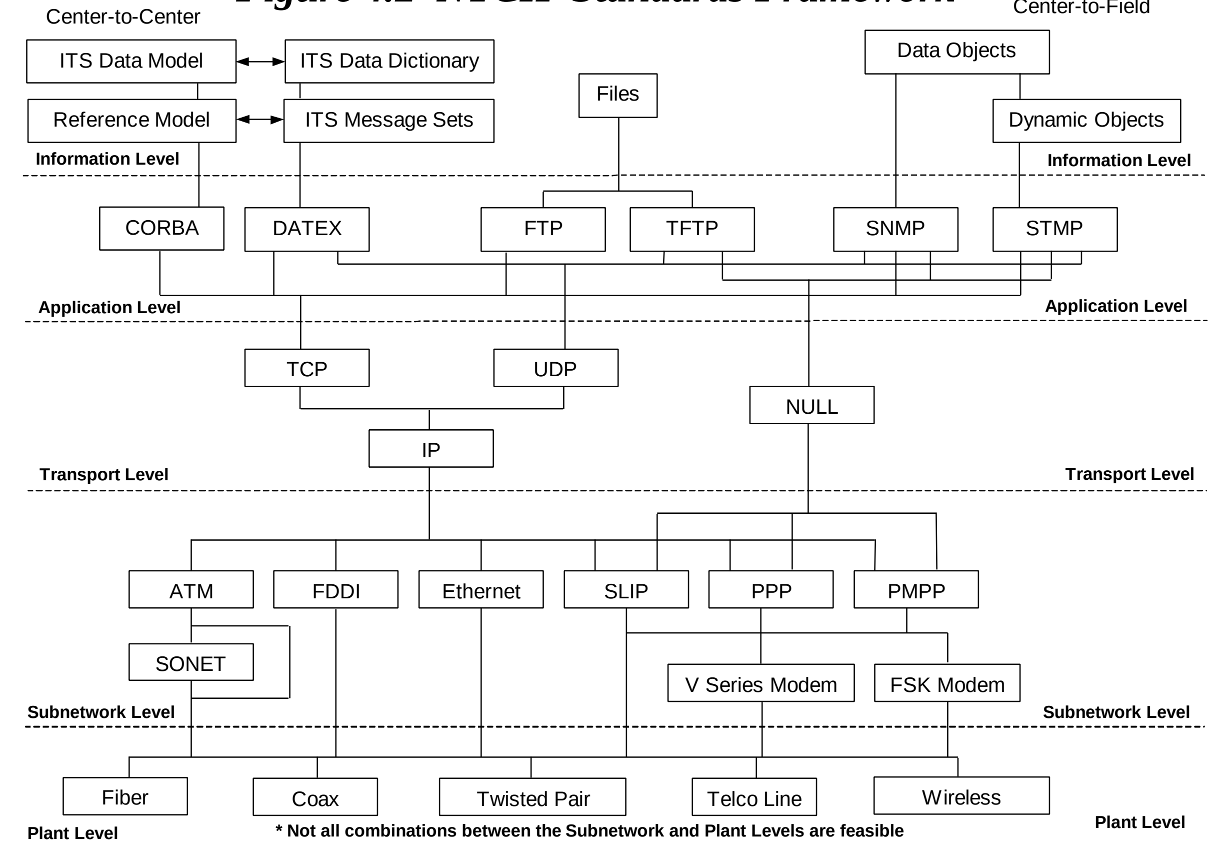
- Transport Level – Transport Profiles define the rules and procedures for exchanging the Application data between point 'A' and point 'X' on a network. This includes any necessary routing, message disassembly/re-assembly and network management functions.

This is similar to the rules and procedures used by the telephone company to connect two remotely located phones.

- Subnetwork Level – Subnetwork Profiles define the rules and procedures for exchanging data between two 'adjacent' devices over some communications media. This is equivalent to the rules used by the telephone company to exchange data over a cellular link versus the rules used to exchange data over a twisted pair copper wire.

- Plant Level – The Plant Level is shown in the NTCIP Framework as a means of providing a point of reference to those learning about NTCIP. The Plant Level includes the communications infrastructure over which NTCIP communications are intended. The NTCIP standards do not prescribe any one media type over another.

Figure 4.2 NTCIP Standards Framework



* Not all combinations between the Subnetwork and Plant Levels are feasible

Any data exchange requires the use of one standard taken from each of the five levels. In theory, a profile from one level should be designed such that it can be combined with any profile from another level; however, in practice, profiles will often require certain services from other levels. Thus, only certain combinations are desirable and recognized by the NTCIP effort.

4.2.3.1.2 Selecting Standards and Conformance Statements

The selection of standards for implementation is largely dependent on the specific requirements and design of each system. Subsequent sections in this chapter will provide some additional insight as to how to select the applicable standards for implementation. As a matter or course, agencies should work closely with systems developers and integrators to determine details specific to particular implementations. One method for doing this is through the use of a proposal response that is part of the procurement process. Essentially, an early deliverable in the procurement process should be a proposal from the systems developer or integrator showing applicable details specific to the procurement. The proposal topics should cover the specific standards to be implemented, applicable conformance groups, applicable data objects and their associated range values, and any other information pertinent to the procurement or implementation. The agency should provide an approval of the proposal prior to proceeding with device or software development and delivery.

4.2.3.1.3 Manufacturer Extensions

Users, manufacturers, and systems integrators have traditionally implemented functionality based upon the needs of the system being implemented. Often, these features and enhanced functionality have been implemented in a different manner, depending on the manufacturer, user, or system. As such, there are a variety of alternative methods of performing some functions and providing some enhanced features.

In many cases the standard may not support all of the features supported by a manufacturer's device or software. The NTCIP has been explicitly designed to allow for innovations and it is recognized that the NTCIP standards do not currently define standardized objects for every feature of every device. Thus, there could be special features or requirements in the procurement that are not standardized by the NTCIP. If such features are present, then the systems developer or integrator will need to determine precisely how these features will be supported without conflicting with the standardized implementations. Usually, this is accomplished by simply defining additional objects under a developer specific node for the manufacturer specific MIB extensions. It is important that the agency be aware of the use of manufacturer extensions and request that the systems developers or integrators clearly identify these in their proposal.

4.2.3.2 Implementation Alternatives

The agency should be aware that systems developers and integrators have a variety of resources available to implement desired features and the proposal should address these alternatives. For example, the developer may be able to acquire off-the-shelf software to minimize the effort required to implement the features. A layered design will minimize the effort required to maintain the code and to implement different profiles in the future. However, these benefits may impose other constraints on the system.

The NTCIP has used widely recognized standards whenever possible. For example, the NTCIP standards reference the Transmission Control Protocol (TCP), Internet Protocol (IP), Simple Network Management Protocol (SNMP), Common Object Request Broker Architecture (CORBA), and High Level Data Link Control Protocol (HDLC) standards to name just a few.

In many cases, the private industry has developed off-the-shelf tools to aid system developers in implementing these protocols. Being aware of what products are available and for what costs will allow the developer to provide a more realistic estimate of development costs. For example, most developers use an off-the-shelf implementation of TCP/IP rather than creating their own. Standards for which there are known products include:

- File Transfer Protocol (FTP)
- Trivial File Transfer Protocol (TFTP)
- SNMP
- CORBA
- Data Exchange in ASN.1 (DATEX-ASN)
- TCP/IP and UDP/IP
- Point-to-Point Protocol (PPP)
- Ethernet

While off-the-shelf software can save a considerable amount of development time and greatly simplify maintenance of the software, it may not always provide the most efficient implementation. Off-the-shelf software has generally been designed in a very layered fashion for easy maintenance and fully generic use; however, real-time system performance can frequently be improved by violating the rules of a true layered design and by embedding customized code for a specific purpose. The agency should be aware of the benefits and detriments of each approach before determining the development approach and cost estimate.

It should also be recognized that the availability of off-the-shelf tools might affect the selection of features to be included in the requirements document.

4.2.3.3 Other Factors

There may be a variety of other factors that may need to be considered in order to finalize a proposal. Each of these issues may impact the proposed budget, schedule, and/or scope. Therefore, they should be explicitly addressed in the proposal in order to manage expectations. Without the management of expectations early in the process, a product, which the developer believes is compliant, may be perceived to be lacking by the client. A sample of these issues is provided in the following subsections.

4.2.3.3.1 Stability of the Standard

The NTCIP standards are still relatively new and all standards are subject to amendments. Amendments typically result from developers attempting to implement the subject standard and recognizing either a technical problem with the specification or ambiguous wording. Thus, new standards are frequently amended to solve these problems and the standards become more and more stable over time. Requiring the use of unproved standards can be risky and agencies should work closely with systems integrators and developers if they intend to pursue early implementation of standards.

4.2.3.3.2 Support of Amendments

Because the standards are relatively new, the agency must consider what will happen if an amendment to the standard is approved during the life of the project. As a general rule, it may be difficult to require developers to support amendments that are made late in the procurement life cycle. However, many times, a draft amendment may be present during the initial procurement stages and the agency should expect developer proposals to address the existence of any amendments or proposed amendments.

4.2.3.3.3 Agency / Developer Understanding

Another factor to consider is whether or not the procurement documents provide realistic expectations. While the NTCIP provides a standardized interface that is flexible enough to meet various needs, it may be more bandwidth intensive than previous systems and/or it may use a slightly different database design. It is important to make sure that there are realistic expectations at the start of the project in order to ensure that the project will be perceived as a success.

4.2.3.3.4 Certification Process

The agency must also consider how the procured devices and software are to be tested and certified as being NTCIP compliant. While a rigid certification process will undoubtedly provide a greater assurance to the client, it will also increase costs. Many agencies perform in-house testing, or the certification of NTCIP compliance may be outsourced as part of the procurement (e.g., through hiring an independent testing lab).

4.2.3.3.5 Performance Issues

The agency should also realize that the flexibility of NTCIP also comes at the price of a more complex system than the industry has traditionally used. Therefore, the system may require more sophisticated processors or better communication facilities than traditional systems in order to achieve the same performance level (e.g., response times, etc.). If the agency overlooks these issues during the early stages of the procurement process, there could be significant implementation problems or setbacks late in the project in order to provide the necessary performance.

4.2.4 Proposal Submission

In order to ensure a thorough understanding of the procurement requirements, the agency should request that the systems developer or integrator submit a proposal for approval that acknowledges the various issues addressed in this procurement roadmap. This proposal should also specifically address issues such as conformance statements and range values as appropriate. Additionally, any requirements that are unique to the specific procurement or implementation should also be addressed in the proposal. The proposal provides an opportunity for both the agency and the systems developer or integrator to form a better understanding of the NTCIP implementation and reach consensus on issues that might be unique to the specific procurement.

4.2.5 Delivery / Acceptance Testing

Another important aspect of the procurement process is deliver and acceptance testing. The agency should be aware of any time constraints that might be required for the development of new software as a result of implementing a new standard.

Upon delivery, the agency should conduct acceptance testing to ensure that the device or software conforms to the procurement requirements and is compliant with the applicable standards. The agency should require that acceptance testing be covered in the system developer’s or integrator’s proposal. It should be realized that the NTCIP is a very complex set of standards and it is impractical to perform comprehensive testing. However, well designed test plans can be produced to provide a high level of confidence for a reasonable cost. In some cases, the agency may want to include any applicable test plans as part of the procurement documents.

In general, there are three levels of testing: unit testing, integration testing, and system testing.

4.2.5.1 Unit Testing

Unit testing focuses on comparing an implementation against the standard. This may be performed by inspecting the code or with the use of "proven" software to send test messages to the device. This process should be formalized by documenting a specific test procedure that will be followed and during the test, the result of each step of the procedure should be recorded.

Unit testing provides a basic level of assurance that a product is compliant to a standard. Many times, the test plan will be designed such that the failure of one procedure will provide a clear indication of what problem resides within the implementation; thereby minimizing the cost of finding the 'bug'. A device that fails such a test plan would almost certainly not be able to interoperate with other systems. A device that passes such a test has a reasonable probability of interoperating.

4.2.5.2 Integration Testing

Integration testing consists of connecting two or more devices together and having them exchange data. Assuming the individual devices have previously passed a sufficiently designed unit test plan and the two devices support the same features, the devices should integrate together fairly easily. However, there are a few problems that may arise during this phase. Examples include two different interpretations of a specific requirement (typically a problem of newer standards) and problems related to system timing between the two implementations.

In theory, the unit test should be thorough enough to prevent any problems in integration testing; however, the integration testing provides a higher level of confidence that nothing has been overlooked.

4.2.5.3 System Testing

A final level of testing is system testing. At this level, each device on the system is integrated together to form the final system. This level of testing could identify global problems such as modem carriers being left on (i.e., preventing other devices from talking) or system timing issues (e.g., too many signals on a channel to maintain a desired once-per-second poll rate).

Once again, in theory, devices that successfully pass unit testing and integration testing should pass this system level testing as well, given that the system was properly designed. However, the final check is only provided when this system test is performed and it is not infrequent that problems arise at this stage.

4.2.6 Maintenance

Agencies should be aware of the fact that procurement requirements may need to address maintenance and subsequent device and/or software upgrades. In general, it should be recognized that the NTCIP standards are still relatively new and thus changes may occur to the standards. Further, as there are relatively few implementations available, ambiguities may still be discovered in the standard and the standards may be modified in order to correct these problems. Any such change may require a modification to deployed equipment if the equipment is to maintain compatibility with the new version of the standard. A basic understanding of requirements for maintenance and subsequent upgrades should be addressed early during the procurement process with the systems developer or integrator.

4.2.7 Design Requirements

The systems planner/specification writer should consider the various levels of the NTCIP Framework when preparing procurement specifications. Appropriate choices from each of the five levels that make up the NTCIP Framework will need to be made sometime during either the specification development process or the procurement process. One alternative that has been presented in this section, places much of the burden on the systems developer or integrator to assist in making the appropriate standards selections and presents a mechanism for agency approval. Another alternative puts the burden for detailed specification development on the agency.

It is important to understand that if the agency is planning to prepare detailed procurement specifications for NTCIP compliant systems, there are several issues that must be addressed in order to satisfy basic specification requirements. These basic requirements consist of making the appropriate choice of standards for each level within the NTCIP Framework. To effectively make these selections, there needs to be a good understanding of what resources, like existing communications infrastructure and equipment, might be available from an existing system. Additionally, there needs to be a good understanding of what functionality is needed from the NTCIP compliant system. Table 4.1 presents overview of a basic check-list for use in preparing detailed specifications for NTCIP systems. Detailed procurement specifications will first require knowledge that is specific to the system implementation, such as infrastructure media; communication, processing, and data needs; and, intended system functionality.

Table 4.1 Procurement Check-List Overview

□ Consider specific communications needs
□ Analyze available resources
□ Define an entire NTCIP Stack for intended system(s)
□ Gather appropriate standards for each level within the NTCIP Stack
□ Determine required Conformance Groups
□ Determine required Data Elements (objects)
□ Define realistic Range Values for implementation
□ Tailor specifications to meet intended needs

The systems planner/specification writer should consider the communication needs and available resources specific to the system being deployed in order to effectively provide detailed specifications for an NTCIP compliant system. Important considerations for determining specific communications needs include communications data and timing, channel loading, and device latency issues. An entire NTCIP Stack should be defined, along with an identification of standards required at each level.

The next step in the process would then be to determine the required optional and mandatory Conformance Groups within each standard that are needed to ensure that the intended functionality needs are met. Additionally, realistic Range Values need to be defined for each of the data elements (or objects) within each of the Management Information Bases (MIBs), based upon the functional requirements of specific device specifications. Essentially, detailed NTCIP specifications should be tailored to meet the intended needs of the system implementation.

Procurement specifications should also include information related to hardware and/or devices, systems integration, testing, and device configuration.

4.2.8 Testing Requirements

Testing for NTCIP compliance is a subject that has been on the minds of many of those going through the process of implementing NTCIP. The biggest question that often arises is, How do I know that my device is NTCIP compliant? Other concerns include, how to do testing and what tools are available for testing. Testing is an important part of any procurement and should not be overlooked.

Essentially, testing for NTCIP compliance can take several forms, from the simple perspective of determining if a device will accept objects transmitted using NTCIP to the more complex notion of ensuring that the device provides the appropriate functional response for the message that was received. While it is not the purpose of this document to define functionality or specific testing procedures, the authors feel that it is important for procuring agencies to rigorously test devices and systems to ensure NTCIP compliance. Early testing will avoid future heartache when the need for interoperability or interchangeability arises. Testing for NTCIP compliance will likely need to address message structure and content, as well as the appropriate functionality responses to the messages transmitted.

One tool that is available for use in NTCIP testing is the NTCIP Exerciser. This software tool was developed for the purpose of testing the ability to transmit and receive NTCIP objects. The tool is designed to verify the communications process by allowing the user to determine if the messages are in an NTCIP format and are transportable. Functionality testing to determine if the appropriate operations occur as a result of the transmitted message is left to the user and is not a function of the Exerciser. It should be stressed that the NTCIP Exerciser is simply one tool at the disposal of testing agencies for use in a comprehensive testing program.

4.3 Center-to-Field

Table 4.2 builds on the previous discussion by expanding on the considerations that should be addressed during the initial planning and development stages for procurement documents. These are items that the systems developer or integrator should provide as part of their proposal submission, or in the case of an agency pursuing the detailed specification route these should be addressed in the procurement documents. The table also points to additional resources that are available in further refining detailed specifications.

Table 4.2 Procurement Check-List Overview

- ❑ Consider specific communications needs
  - ❑ Communications data and timing
  - ❑ Channel loading
  - ❑ Device latency
- ❑ Analyze available resources
  - ❑ New system with no existing resources
  - ❑ Existing system with available resources
- ❑ Define an entire NTCIP Stack for intended system(s)
  - ❑ See Table 4.3
- ❑ Gather appropriate standards for each level within the NTCIP Stack
  - ❑ See Table 4.4
- ❑ Determine required Conformance Groups
  - ❑ Mandatory
  - ❑ Optional
  - ❑ See specific standards that relate to needed functionality
- ❑ Determine required Data Elements (objects)
  - ❑ Mandatory
  - ❑ Optional
  - ❑ See specific standards that relate to needed functionality
- ❑ Define realistic Range Values for system implementation
  - ❑ See functionality requirements
  - ❑ See specific standards that relate to needed functionality
- ❑ Tailor specifications to meet intended needs

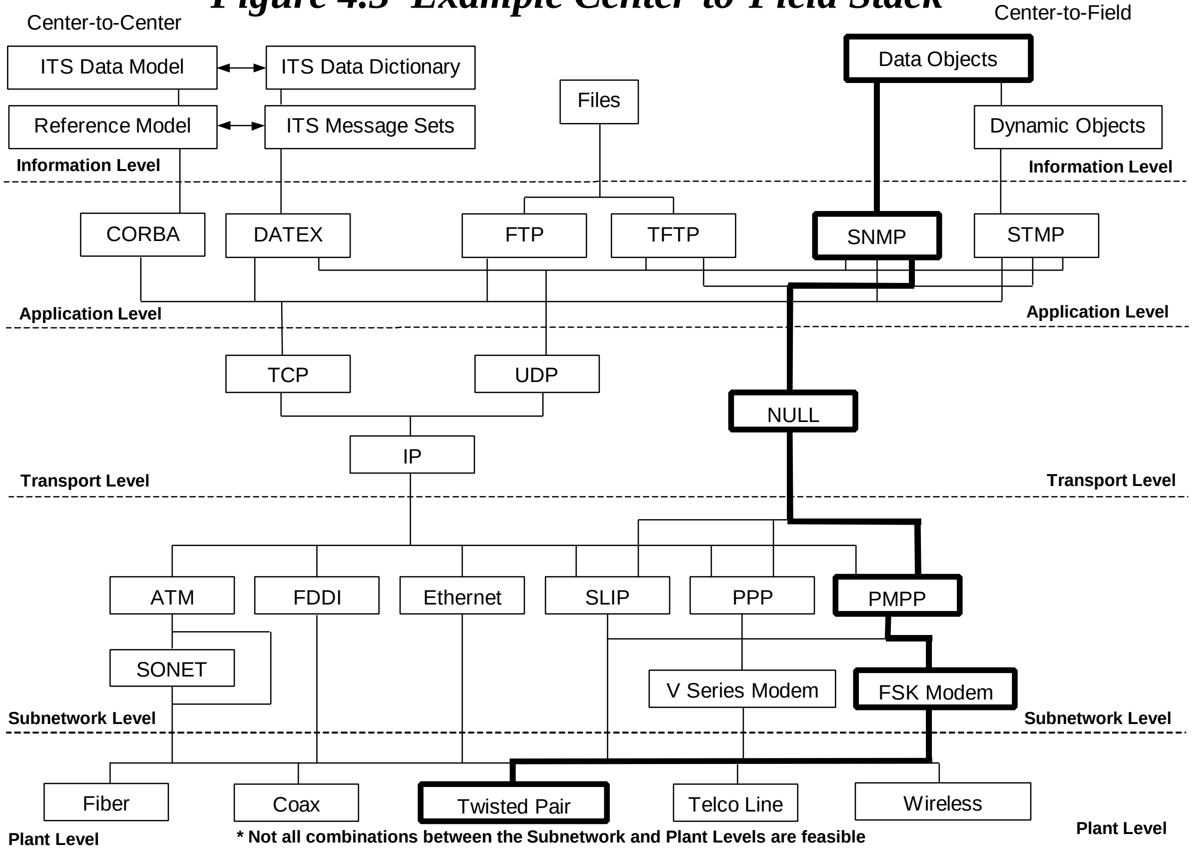
Example 4.1 Example of a Center-to-Field Stack using SNMP

This example shows one possible path through the NTCIP Framework for the commonly referred to and published Class B Profile. It should be noted that the preferred terminology for this path is STACK, rather than profile.

Figure 4.3 depicts an example center-to-field NTCIP Stack and is one variation of what was published as the Class B Profile. The Stack is shown as it relates to the NTCIP Standards Framework. The Stack is created by combining appropriate selections from each of the Information, Application, Transport, Subnetwork, and Plant Levels. The figure shows the choices at each NTCIP Framework level that are required to create one variation of Class B, as it is now published. For example, the SNMP protocol selection is made at the Application Level within the NTCIP Stack. It should be noted that the trend is moving away from denoting the various stacks with alphanumeric characters and is moving towards the designation of specific standards at each level within the NTCIP Framework. As a result, Class B should be regarded as a legacy term that will ultimately be abandoned in-lieu of an array of specific NTCIP Framework level standards.

The Class B stack that was originally published includes only the Application, Transport, and Subnetwork Levels of the NTCIP Framework. The choices that are offered at the Application Level include SNMP and STMP. The only choice that is defined for the Transport Level is NULL. The Subnetwork Level option includes Point to Multi-Point, using either EIA 232 or FSK-1200bps modems. The Plant Level is assumed to be agency owned twisted pair wire.

Figure 4.3 Example Center-to-Field Stack



* Not all combinations between the Subnetwork and Plant Levels are feasible

In working through this example it is easy to see that these options are quite limited. Extrapolating for all the various system configurations, one can easily see that publishing distinct documents for all possible system configurations could be quite exhausting. As a result, the presentation of NTCIP standards have moved away from the Class Profile presentation and toward a presentation of standards specific to each Stack layer. This enables the user to better specify choices specific to the system being deployed.

4.3.1 NTCIP Stack Options

The Information, Application, Transport, Subnetwork, and Plant Levels of the NTCIP Framework present a variety of options that can be selected to form an NTCIP stack. Table 4.3 presents an expanded view of the available center-to-field options that are available at the time this Guide was prepared.

The Information Level of the NTCIP Framework specifically focuses on the informational requirements of the NTCIP device or system to achieve its desired functionality. A thorough discussion of the available Information Level options will be presented later in this section.

In the case of center-to-field, the selection of an appropriate Application Level protocol is an important consideration. There are two choices for center-to-field protocols, Simple Network Management Protocol (SNMP) that is commonly used in Internet and computer industry applications. The other choice is the Simple Transportation Management Protocol (STMP) which is a more efficient protocol (in that it reduces the amount of overhead required for communications) that allows a user to access multiple objects using a single request.

At the Transport Level the options are essentially comprised of a choice between the use of routing protocols or not. A Null Transport Level is used with non-routing protocols. In the case of routing protocols and additional choice is required between connection-oriented and connectionless. The Transmission Control Protocol (TCP) is connection-oriented protocol that is used in conjunction with the internetworking protocol simply know as Internet Protocol (IP). The User Datagram Protocol (UDP) is a connectionless protocol that is also used in conjunction with the Internet Protocol (IP).

The Subnetwork Level presents a series of networking, point-to-point, and point-to-multi-point protocols. ATM, SONET, FDDI, and Ethernet are all examples of broadband networking protocol options. SLIP, PPP, and PMPP are also available options at the Subnetwork Level.

The Plant Level of the NTCIP Framework are not specific NTCIP communications standards, but offers a complete relationship to the physical infrastructure that would typically be deployed in modern systems. The Plant Level includes fiber, coax, twisted pair wire, telco lines, and wireless options.

In the cases of protocol selection, it would be advisable to consult equipment and system manufacturers for assistance in the selection of the most appropriate supported Protocol(s) that meet the overall requirements of the applicable system. STMP should be considered essential for traffic signal systems operating over traditional media, but other devices may not need it.

Table 4.3 Center-to-Field Options

- ❑ *Information Level*
    - ❑ Select applicable standards
        - ❑ TS 3.4 – Global Object Definitions
        - ❑ Device specific
    - ❑ Specify Conformance Groups
        - ❑ Mandatory
        - ❑ Optional
        - ❑ Based upon device functionality
    - ❑ Specify Data Objects
        - ❑ Mandatory
        - ❑ Optional
        - ❑ Determine appropriate Range Values
- ❑ *Application Level*
    - ❑ Simple Network Management Protocol
        - ❑ Internet Standard
        - ❑ Support is Mandatory in Conformance Level 1 and 2
    - ❑ Simple Transportation Management Protocol
        - ❑ More efficient protocol
        - ❑ Defines dynamic objects (multiple object request in single message)
        - ❑ Support is Mandatory in Conformance Level 2
- ❑ *Transport Level*
    - ❑ TCP
        - ❑ IP
    - ❑ UDP
        - ❑ IP
    - ❑ Null
- ❑ *Subnetwork Level*
    - ❑ ATM
        - ❑ SONET
    - ❑ FDDI
    - ❑ Ethernet
    - ❑ SLIP
        - ❑ V Series Modem
        - ❑ FSK Modem
    - ❑ PPP
        - ❑ V Series Modem
        - ❑ FSK Modem
    - ❑ PMPP
        - ❑ V Series Modem
        - ❑ FSK Modem
- ❑ *Plant Level*
    - ❑ Fiber
    - ❑ Coax
    - ❑ Twisted Pair
    - ❑ Telco Line
    - ❑ Wireless

The functionality needs of particular devices, equipment, and systems are important when considering the selection of appropriate conformance statements. While the NTCIP communication standards do not specifically prescribe functionality requirements, such can be inferred by data object construction. The NTCIP communications requirements should be consistent with the functional specifications for the device. As in the case of a center-to-field traffic signal system, a selection of appropriate standard data object sets that yield the functionality required for a specific implementation might include data objects from two NTCIP standards, Global Object Definitions and Actuated Signal Control Objects. Table 4.4 lists the NTCIP standards that are published at the time this Guide document was produced. Lastly, specific range values associated with these data objects would also need to be consistent with the functional requirements of the device.

Table 4.4 Currently Published NTCIP Standards

❑ TS 3.2 – Simple Transportation Management Framework
❑ TS 3.3 – Class B Profile
❑ TS 3.4 – Global Object Definitions
❑ TS 3.5 – Object Definitions for Actuated Traffic Signal Controller Units
❑ TS 3.6 – Object Definitions for Dynamic Message Signs*
❑ TS 3.7 – Environmental Sensor Stations*

* publication in progress

Please note that the above Standard number designations refer to those documents that have been published to-date. The numbering scheme for NTCIP documents has been revised and the new designations are shown in Section 9 of this *NTCIP Guide*.

Upon reviewing standards that might be applicable to a specific implementation, attention should be drawn to the Conformance Statement section of the document. Data objects are arranged in groupings based upon the data associated with various levels of functionality. Some groups are mandatory and some are optional. Specific data objects within each group may also be mandatory or optional. The specific implementation and functionality requirements will dictate the selection of appropriate conformance groups and data objects. Once the Data Objects are identified, a determination of appropriate range values can be assigned to each to represent the desired level of functionality.

It would be advisable to consult equipment and system manufacturers for assistance in the selection of the most appropriate supported Conformance Groups and Data Objects that meet the overall requirements of the specific procurement or implementation.

4.3.2 Available Resources for Additional Information

Ultimately, specifying NTCIP does not make life easier for the systems planner and specification writer. Detailed specifications must be carefully thought out and a more thorough knowledge of operation and functionality is needed early on (in the specification preparation stage) in order to adequately specify equipment and systems that meet the required needs. For these reasons, a preferred method of procurement might be the issuance of a more generalized requirements document that outlines the desired functionality as part of the procurement package and solicit a proposal from the manufacturer, vendor, developer, or integrator addressing the specific implementation details.

There are a variety of resources available for the user when preparing NTCIP specification. The NTCIP web site is a valuable tool for reviewing what standards are now available and any amendments that might be associated with those standards. The various sections of this Guide can provide additional detailed information. In addition, the Standards themselves represent a valuable resource for learning about NTCIP.

Ongoing NTCIP deployments are a valuable resource for learning what works and what doesn't. There is an ongoing effort to capture some of this information specific to deployments using NTCIP, in the form of Case Studies. These Case Studies will focus on lessons learned from recent deployments.

There are also a variety of companies, groups, and individuals involved in the development of NTCIP standards that can provide additional information.

4.3.2.1 NTCIP Specification Development Examples

This section is devoted to examples of how the system planner/specification writer would step through a process to develop detailed procurement specifications for NTCIP systems. Examples are provided for determining an appropriate NTCIP Stack based upon the NTCIP Framework, determining appropriate optional and mandatory conformance groups and objects needed to achieve a desired functionality, and determining the range values that might be needed for a specific implementation.

4.3.2.1.1 NTCIP Stack for Center-to-Field Traffic Signal Controller

> *Example 4.1 An appropriate NTCIP Stack is needed for a typical traffic signal controller application. In this example, the controller is to be located in a field cabinet and is one device on a multi-drop communication channel. The central transportation management system constantly communicates directly to the traffic signal controller(s) over agency owned twisted wire pair cable.*

The system planner/specification writer can start by determining the appropriate selections for each level using the NTCIP Framework, as shown in Table 4.5. It is a given that an agency owned twisted wire pair communications plant will provide the physical infrastructure for Center-to-Field communications. The selection at the *Plant Level* should reflect the selection of twisted wire pair cable.

The selections made at the *Transport and Subnetwork Levels* can now be made based upon the type of communications desired between the central transportation management system and the field traffic signal controller(s). In this example, a dedicated point-to-multipoint communications link without routing through higher level devices is the desired alternative. As such, the selections of PMPP and FSK Modem can be made at the Subnetwork Level. And, the selection of Null can be made at the Transport Level.

For the appropriate selections at the *Application Level* the system planner/specification writer is referred to the NTCIP documents describing the Simple Transportation Management Framework (STMF). The Simple Transportation Management Framework document describes two conformance levels. The original document has been amended to reflect the use of the following protocols:

- Conformance Level 1
  - Simple Network Management Protocol (SNMP)
- Conformance Level 2
  - Simple Network Management Protocol (SNMP)
  - Simple Transportation Management Protocol (STMP)

SNMP is a commonly used Internet Standard that is very well supported. STMP is a more efficient protocol for use by the transportation industry that allows the use of dynamic objects. The preferred selection at the Application Level for traffic signal systems is STMP because of the low data rates that are common to most traffic systems.

The selection of *Information Level* standards, conformance groups, and data objects is based upon the desired functionality of the system being implemented. In the case of this example where a traffic signal system is being implemented, the system planner/specification writer will need to look specifically at the requirements of TS 3.5 – Object Definitions for Actuated Traffic Signal Controller Units standard for specific conformance criteria and data objects. Additionally, the TS 3.4 – Global Object Definitions standard defines a series of cross-cutting data objects for configuration, database management, time management, timebase event schedules, reports, STMP, and PMPP. As a result, standards for both Global Object Definitions and Actuated Signal Control will be needed to achieve the desired level of functionality. These standards define a series of optional and mandatory conformance groups and data objects. The appropriate selection criteria for these optional and mandatory conformance groups and data objects will be the subject of subsequent examples.

Table 4.5 NTCIP Framework Example for a Center-to-Field Traffic Signal Controller

- ➡ ❑ *Information Level*
  - ➡ ❑ Select applicable standards
    - ➡ ❑ TS 3.4 – Global Object Definitions
    - ➡ ❑ Device specific
      - ➡ ❑ TS 3.5 – Object Definitions for Actuated Traffic Signal Controller Units (ASC)
  - ➡ ❑ Specify Conformance Groups
    - ➡ ❑ Mandatory
    - ➡ ❑ Optional
    - ➡ ❑ Based upon device functionality
  - ➡ ❑ Specify Data Objects
    - ➡ ❑ Mandatory
    - ➡ ❑ Optional
  - ➡ ❑ Determine appropriate Range Values
- ➡ ❑ *Application Level*
  - ❑ Simple Network Management Protocol
  - ➡ ❑ Simple Transportation Management Protocol
- ➡ ❑ *Transport Level*
  - ❑ TCP
    - ❑ IP
  - ❑ UDP
    - ❑ IP
  - ➡ ❑ Null
- ➡ ❑ *Subnetwork Level*
  - ❑ ATM
    - ❑ SONET
  - ❑ FDDI
  - ❑ Ethernet
  - ❑ SLIP
    - ❑ V Series Modem
    - ❑ FSK Modem
  - ❑ PPP
    - ❑ V Series Modem
    - ❑ FSK Modem
  - ➡ ❑ PMPP
    - ❑ V Series Modem
    - ➡ ❑ FSK Modem
- ➡ ❑ *Plant Level*
  - ❑ Fiber
  - ❑ Coax
  - ➡ ❑ Twisted Pair
  - ❑ Telco Line
  - ❑ Wireless

4.3.2.1.2 Conformance Group and Data Object Selection for Traffic Signal Controllers

> *Example 4.2 An appropriate selection of conformance groups and data objects are needed for a typical traffic signal controller application. In this example, the controller will be based upon the NEMA TS-2-Type2 Actuated Traffic Controller standards. The Type2 NEMA controller is one that is backwards compatible to the NEMA TS-1 Traffic Controller Cabinets with the MS A, B, and C connectors.*

The NEMA TS 2 – 1998 Standard for Traffic Controller Assemblies describes a functional specification for traffic controller assemblies, including the controller unit, malfunction management unit, terminals and facilities, auxiliary devices, cabinet, and bus interface unit. The

NEMA TS 2-1998 also incorporates the NTCIP standards that relate to traffic signal controllers. The notable NTCIP standards that are referenced are the TS 3.4 – Global Object Definitions and TS 3.5 – Object Definitions for Actuated Traffic Signal Controller Units.

NEMA TS 2 – 1998 describes traffic signal controllers in terms of being either Actuated or Pretimed. Also, there are two interface options cited as Type 1 and Type 2. The Type 1 interface is a new performance based standard using serial communications and the Type 2 interface utilizes the MS A, B, and C connectors to provide backwards compatibility to TS – 1 style cabinets.

Table 4.6 Global Object Definitions Conformance Table

Conformance Group/Object	**Reference**	**Conformance Requirement**	**NEMA TS 2 (A2N)**	
			M – Mandatory O – Optional	
			Level 1	**Level 2**
Configuration	TS 3.4	**Mandatory Group**	M	M
globalSetIDParameter	TS 3.4	Optional	O	M
globalMaxModules	TS 3.4	Mandatory	M	M
globalModuleTable	TS 3.4	Mandatory	M	M
moduleNumber	TS 3.4	Mandatory	M	M
moduleDeviceNode	TS 3.4	Mandatory	M	M
moduleMake	TS 3.4	Mandatory	M	M
moduleModel	TS 3.4	Mandatory	M	M
moduleVersion	TS 3.4	Mandatory	M	M
moduleType	TS 3.4	Mandatory	M	M
Database Management	TS 3.4	**Optional Group**	O	M
dBCreationTransaction	TS 3.4	Mandatory	O	M
dBErrorType	TS 3.4	Mandatory	O	M
dBErrorID	TS 3.4	Mandatory	O	M
dBTransactionID	TS 3.4	Mandatory	O	M
dBMakeID	TS 3.4	Optional	O	M
Time Management	TS 3.4	**Optional Group**	O	M
globalTime	TS 3.4	Mandatory	O	M
globalDaylightSaving	TS 3.4	Mandatory	O	M
Timebase Event Schedule	TS 3.4	**Optional Group**	O	M
maxTimeBaseScheduleEntries	TS 3.4	Mandatory	O	M
timeBaseScheduleTable	TS 3.4	Mandatory	O	M
timeBaseScheduleNumber	TS 3.4	Mandatory	O	M
timeBaseScheduleMonth	TS 3.4	Mandatory	O	M
timeBaseScheduleDay	TS 3.4	Mandatory	O	M
timeBaseScheduleDate	TS 3.4	Mandatory	O	M
timeBaseScheduleDayPlan	TS 3.4	Mandatory	O	M
maxDayPlans	TS 3.4	Mandatory	O	M
maxDayPlanEvents	TS 3.4	Mandatory	O	M
timeBaseDay PlanTable	TS 3.4	Mandatory	O	M
dayPlanNumber	TS 3.4	Mandatory	O	M
dayPlanEventNumber	TS 3.4	Mandatory	O	M
dayPlanHour	TS 3.4	Mandatory	O	M
dayPlanMinute	TS 3.4	Mandatory	O	M
dayPlanActionNumberOID	TS 3.4	Mandatory	O	M
dayPlanStatus	TS 3.4	Mandatory	O	M

Table 4.6 Global Object Definitions Conformance Table

Conformance Group/Object	Reference	Conformance Requirement	NEMA TS 2 (A2N)	
			M – Mandatory O – Optional	
			Level 1	Level 2
Report	TS 3.4	**Optional Group**	O	M
maxEventLogConfigs	TS 3.4	Mandatory	O	M
eventLogConfigTable	TS 3.4	Mandatory	O	M
eventConfigID	TS 3.4	Mandatory	O	M
eventConfigClass	TS 3.4	Mandatory	O	M
eventConfigMode	TS 3.4	Mandatory	O	M
eventConfigCompareValue	TS 3.4	Mandatory	O	M
eventConfigCompareValue2	TS 3.4	Mandatory	O	M
eventConfigCompareOID	TS 3.4	Mandatory	O	M
eventConfigLogOID	TS 3.4	Optional	O	M
eventConfigAction	TS 3.4	Optional	O	M
maxEventLogSize	TS 3.4	Mandatory	O	M
eventLogTable	TS 3.4	Mandatory	O	M
eventLogClass	TS 3.4	Mandatory	O	M
eventLogNumber	TS 3.4	Mandatory	O	M
eventLogID	TS 3.4	Mandatory	O	M
eventLogTime	TS 3.4	Mandatory	O	M
eventLogValue	TS 3.4	Mandatory	O	M
maxEventClasses	TS 3.4	Mandatory	O	M
eventClassTable	TS 3.4	Mandatory	O	M
eventClassNumber	TS 3.4	Mandatory	O	M
eventClassLimit	TS 3.4	Mandatory	O	M
eventClassClearTime	TS 3.4	Mandatory	O	M
EventClassDescription	TS 3.4	Optional	O	M
eventClassNumRowsInLog	TS 3.4	Mandatory	O	M
STMP	TS 3.4	**Optional Group**	O	M
dynamicObjectPersistence	TS 3.4	Mandatory	O	M
PMPP	TS 3.4	**Optional Group**	O	M
maxGroupAddresses	TS 3.4	Mandatory	O	M
hdlcGroupAddressTable	TS 3.4	Mandatory	O	M
hdlcGroupAddressIndex	TS 3.4	Mandatory	O	M
hdlcGroupAddress	TS 3.4	Mandatory	O	M

Tables 4.6 and 4.7 show how the NTCIP group and data object conformance statements relate to the NEMA TS 2 – 1998 Standard for Traffic Controller Assemblies. The Level 1 actuated TS 2 traffic controller is intended to support only the mandatory NTCIP objects from TS 3.4 – Global Object Definitions and TS 3.5 – Actuated Signal Control. The mandatory objects of these two NTCIP standards to not address the advanced functions relative to coordination, time base, preemption, system control, overlaps, or the TS 2 port 1. A user requesting Level 1 conformance should not expect these features unless the user specification includes a definition of additional conformance groups from the standard, or defines and lists specific alternates. A user specifying Level 2 conformance is requesting that all of the mandatory and most of the optional data objects within the NTCIP standards TS 3.4 – Global Object Definitions and TS 3.5 – Actuated Signal Control be supported.

Table 4.7 Actuated Traffic Signal Controller Unit Object Definitions Conformance Table

Conformance Group/Object	Reference	Conformance Requirement	NEMA TS 2 (A2N) M – Mandatory O – Optional	
			Level 1	Level 2
Configuration	TS 3.4	**Mandatory Group**	M	M
Database Management	TS 3.4	**Optional Group**	O	M
Time Management	TS 3.4	**Optional Group**	O	M
Timebase Event Schedule	TS 3.4	**Optional Group**	O	M
Report	TS 3.4	**Optional Group**	O	M
STMP	TS 3.4	**Optional Group**	O	M
PMPP	TS 3.4	**Optional Group**	O	M
Phase	TS 3.5	**Mandatory Group**	M	M
maxPhases	TS 3.5	Mandatory	M	M
phaseTable	TS 3.5	Mandatory	M	M
phaseNumber	TS 3.5	Mandatory	M	M
phaseWalk	TS 3.5	Mandatory	M	M
phasePedestrianClear	TS 3.5	Mandatory	M	M
phaseMinimumGreen	TS 3.5	Mandatory	M	M
phasePassage	TS 3.5	Mandatory	M	M
phaseMaximum1	TS 3.5	Mandatory	M	M
phaseMaximum2	TS 3.5	Mandatory	M	M
phaseYellowChage	TS 3.5	Mandatory	M	M
phaseRedClear	TS 3.5	Mandatory	M	M
phaseRedRevert	TS 3.5	Optional	O	O
phaseAddedInitial	TS 3.5	Mandatory	M	M
phaseMaximumInitial	TS 3.5	Mandatory	M	M
phaseTimeBeforeReduction	TS 3.5	Mandatory	M	M
phaseCarsBeforeReduction	TS 3.5	Optional	O	O
phaseTimeToReduce	TS 3.5	Mandatory	M	M
phaseReduceBy	TS 3.5	Mandatory	M	O
phaseMinimumGap	TS 3.5	Mandatory	M	M
phaseDynamicMaxLimit	TS 3.5	Optional	O	O
phaseDynamicMaxStep	TS 3.5	Optional	O	O
phaseStartup	TS 3.5	Mandatory	M	M
phaseOptions	TS 3.5	Mandatory	M	M
phaseRing	TS 3.5	Mandatory	M	M
phaseConcurrency	TS 3.5	Mandatory	M	M
maxPhaseGroups	TS 3.5	Mandatory	M	M
phaseStatusGroupTable	TS 3.5	Mandatory	M	M
phaseStatusGroupNumber	TS 3.5	Mandatory	M	M
phaseStatusGroupReds	TS 3.5	Mandatory	M	M
phaseStatusGroupYellows	TS 3.5	Mandatory	M	M
phaseStatusGroupGreens	TS 3.5	Mandatory	M	M
phaseStatusGroupDontWalks	TS 3.5	Mandatory	M	M
phaseStatusGroupPedClears	TS 3.5	Mandatory	M	M
phaseStatusGroupWalks	TS 3.5	Mandatory	M	M
phaseStatusGroupVehCalls	TS 3.5	Mandatory	M	M
phaseStatusGroupPedCalls	TS 3.5	Mandatory	M	M
phaseStatusGroupPhaseOns	TS 3.5	Mandatory	M	M
phaseStatusGroupPhaseNexts	TS 3.5	Mandatory	M	M
phaseControlGroupTable	TS 3.5	Optional	O	M
phaseControlGroupNumber	TS 3.5	Mandatory	O	M
phaseControlGroupPhaseOmit	TS 3.5	Mandatory	O	M
phaseControlGroupPedOmit	TS 3.5	Mandatory	O	M
phaseControlGroupHold	TS 3.5	Mandatory	O	M
phaseControlGroupForceOff	TS 3.5	Optional	O	O
phaseControlGroupVehCall	TS 3.5	Mandatory	O	M
phaseControlGroupPedCall	TS 3.5	Mandatory	O	M

Table 4.7 Actuated Traffic Signal Controller Unit Object Definitions Conformance Table

Conformance Group/Object	Reference	Conformance Requirement	NEMA TS 2 (A2N) M – Mandatory O – Optional	
			Level 1	Level 2
Detector	TS 3.5	**Mandatory Group**	M	M
maxVehicleDetectors	TS 3.5	Mandatory	M	M
vehicleDetectorTable	TS 3.5	Mandatory	M	M
vehicleDetectorNumber	TS 3.5	Mandatory	M	M
vehicleDetectorOptions	TS 3.5	Mandatory	M	M
vehicleDetectorCallPhase	TS 3.5	Mandatory	M	M
vehicleDetectorSwitchPhase	TS 3.5	Mandatory	M	M
vehicleDetectorDelay	TS 3.5	Mandatory	M	M
vehicleDetectorExtend	TS 3.5	Mandatory	M	M
vehicleDetectorQueueLimit	TS 3.5	Optional	O	M
vehicleDetectorNoActivity	TS 3.5	Mandatory	M	M
vehicleDetectorMaxPresence	TS 3.5	Mandatory	M	M
vehicleDetectorErraticCounts	TS 3.5	Mandatory	M	M
vehicleDetectorFailTime	TS 3.5	Optional	O	M
vehicleDetectorAlarms	TS 3.5	Mandatory	M	M
vehicleDetectorReportedAlarms	TS 3.5	Optional	O	M
vehicleDetectorReset	TS 3.5	Mandatory	M	M
maxVehicleDetectorStatusGroups	TS 3.5	Mandatory	M	M
vehicleDetectorStatusGroupTable	TS 3.5	Mandatory	M	M
vehicleDetectorStatusGroupNumber	TS 3.5	Mandatory	M	M
vehicleDetectorStatusGroupActive	TS 3.5	Mandatory	M	M
vehicleDetectorStatusGroupAlarms	TS 3.5	Mandatory	M	M
maxPedestrianDetectors	TS 3.5	Mandatory	M	M
pedestrianDetectorTable	TS 3.5	Mandatory	M	M
pedestrianDetectorNumber	TS 3.5	Mandatory	M	M
pedestrianDetectorCallPhase	TS 3.5	Mandatory	M	M
pedestrianDetectorNoActivity	TS 3.5	Mandatory	M	M
pedestrianDetectorMaxPresence	TS 3.5	Mandatory	M	M
pedestrianDetectorErraticCounts	TS 3.5	Mandatory	M	M
pedestrianDetectorAlarms	TS 3.5	Mandatory	M	M
Volume Occupancy Report	TS 3.5	**Optional Group**	O	M
volumeOccupancySequence	TS 3.5	Mandatory	O	M
volumeOccupancyPeriod	TS 3.5	Mandatory	O	M
activeVolumeOccupancyDetectors	TS 3.5	Mandatory	O	M
volumeOccupancyTable	TS 3.5	Mandatory	O	M
detectorVolume	TS 3.5	Mandatory	O	M
detectorOccupancy	TS 3.5	Mandatory	O	M
Unit	TS 3.5	**Optional Group**	O	M
unitStartUpFlash	TS 3.5	Mandatory	O	M
unitAutoPedestrianClear	TS 3.5	Mandatory	O	M
unitBackupTime	TS 3.5	Mandatory	O	M
unitRedRevert	TS 3.5	Mandatory	O	M
unitControlStatus	TS 3.5	Mandatory	O	M
unitFlashStatus	TS 3.5	Mandatory	O	M
unitAlarmStatus2	TS 3.5	Mandatory	O	M
unitAlarmStatus1	TS 3.5	Mandatory	O	M
shortAlarmStatus	TS 3.5	Mandatory	O	M
unitControl	TS 3.5	Mandatory	O	M
maxAlarmGroups	TS 3.5	Optional	O	M
alarmGroupTable	TS 3.5	Mandatory	O	M
alarmGroupNumber	TS 3.5	Mandatory	O	M
alarmGroupState	TS 3.5	Mandatory	O	M
Special Function	TS 3.5	**Optional Group**	O	M
maxSpecialFunctionOutputs	TS 3.5	Mandatory	O	M
specialFunctionOutputTable	TS 3.5	Optional	O	M
specialFunctionOutputNumber	TS 3.5	Mandatory	O	M
specialFunctionOutputState	TS 3.5	Mandatory	O	M

Table 4.7 Actuated Traffic Signal Controller Unit Object Definitions Conformance Table

Conformance Group/Object	Reference	Conformance Requirement	NEMA TS 2 (A2N) M – Mandatory O – Optional	
			Level 1	Level 2
Coordination	TS 3.5	**Optional Group**	O	M
coordOperationalMode	TS 3.5	Mandatory	O	M
coordCorrectionMode	TS 3.5	Mandatory	O	M
coordMaximumMode	TS 3.5	Mandatory	O	M
coordForceMode	TS 3.5	Mandatory	O	M
maxPatterns	TS 3.5	Mandatory	O	M
patternTableType	TS 3.5	Mandatory	O	M
patternTable	TS 3.5	Mandatory	O	M
patternNumber	TS 3.5	Mandatory	O	M
patternCycleTime	TS 3.5	Mandatory	O	M
patternOffsetTime	TS 3.5	Mandatory	O	M
patternSplitNumber	TS 3.5	Mandatory	O	M
patternSequenceNumber	TS 3.5	Mandatory	O	M
maxSplits	TS 3.5	Mandatory	O	M
splitTable	TS 3.5	Mandatory	O	M
splitNumber	TS 3.5	Mandatory	O	M
splitPhase	TS 3.5	Mandatory	O	M
splitTime	TS 3.5	Mandatory	O	M
splitMode	TS 3.5	Mandatory	O	M
splitCoordPhase	TS 3.5	Mandatory	O	M
coordPatternStatus	TS 3.5	Mandatory	O	M
localFreeStatus	TS 3.5	Mandatory	O	M
coordCycleStatus	TS 3.5	Mandatory	O	M
coordSyncStatus	TS 3.5	Mandatory	O	M
systemPatternControl	TS 3.5	Mandatory	O	M
systemSyncControl	TS 3.5	Mandatory	O	M
Time Base	TS 3.5	**Optional Group**	O	M
Time Management Conformance Group	TS 3.4	Mandatory	O	M
timebasePatternSync	TS 3.5	Mandatory	O	M
maxTimebaseAscActions	TS 3.5	Mandatory	O	M
timebaseAscActionTable	TS 3.5	Mandatory	O	M
timebaseAscActionNumber	TS 3.5	Mandatory	O	M
timebaseAscActionPattern	TS 3.5	Mandatory	O	M
timebaseAscActionAuxillaryFunction	TS 3.5	Mandatory	O	M
timebaseAscActionSpecialFunction	TS 3.5	Mandatory	O	M
timebaseAscActionStatus	TS 3.5	Mandatory	O	M
Preempt	TS 3.5	**Optional Group**	O	M
maxpreempts	TS 3.5	Mandatory	O	M
preemptTable	TS 3.5	Mandatory	O	M
preemptNumber	TS 3.5	Mandatory	O	M
preemptControl	TS 3.5	Mandatory	O	M
preemptLink	TS 3.5	Mandatory	O	M
preemptDelay	TS 3.5	Mandatory	O	M
preemptMinimumDuration	TS 3.5	Mandatory	O	M
preemptMinimumGreen	TS 3.5	Optional	O	M
preemptMinimumWalk	TS 3.5	Optional	O	M
preemptEnterPedClear	TS 3.5	Optional	O	M
preemptTrackGreen	TS 3.5	Mandatory	O	M
preemptDwellGreen	TS 3.5	Mandatory	O	M
preemptMaximumPresence	TS 3.5	Mandatory	O	M
preemptTrackPhase	TS 3.5	Mandatory	O	M
preemptDwellPhase	TS 3.5	Mandatory	O	M
preemptDwellPed	TS 3.5	Optional	O	O
preemptExitPhase	TS 3.5	Mandatory	O	M
preemptState	TS 3.5	Optional	O	M
preemptControlTable	TS 3.5	Optional	O	M
preemptControlNumber	TS 3.5	Mandatory	O	M
preemptControlState	TS 3.5	Mandatory	O	M

Table 4.7 Actuated Traffic Signal Controller Unit Object Definitions Conformance Table

Conformance Group/Object	Reference	Conformance Requirement	NEMA TS 2 (A2N) M – Mandatory O – Optional	
			Level 1	Level 2
Ring	TS 3.5	**Optional Group**	O	M
maxRings	TS 3.5	Mandatory	O	M
maxSequences	TS 3.5	Mandatory	O	M
sequenceTable	TS 3.5	Mandatory	O	M
sequenceNumber	TS 3.5	Mandatory	O	M
sequenceRingNumber	TS 3.5	Mandatory	O	M
sequenceData	TS 3.5	Mandatory	O	M
maxRingControlGroups	TS 3.5	Mandatory	O	M
ringControlGroupTable	TS 3.5	Mandatory	O	M
ringControlGroupNumber	TS 3.5	Mandatory	O	M
ringControlGroupStopTime	TS 3.5	Mandatory	O	M
ringControlGroupForceOff	TS 3.5	Mandatory	O	M
ringControlGroupMax2	TS 3.5	Optional	O	M
ringControlGroupMaxInhibit	TS 3.5	Optional	O	M
ringControlGroupPedRecycle	TS 3.5	Mandatory	O	M
ringControlGroupRedRest	TS 3.5	Optional	O	M
ringControlGroupOmitRedClear	TS 3.5	Optional	O	M
Channel	TS 3.5	**Optional Group**	O	M
maxChannels	TS 3.5	Mandatory	O	M
channelTable	TS 3.5	Mandatory	O	M
channelNumber	TS 3.5	Mandatory	O	M
channelControlSource	TS 3.5	Mandatory	O	M
channelControlType	TS 3.5	Mandatory	O	M
channelFlash	TS 3.5	Mandatory	O	M
channelDim	TS 3.5	Mandatory	O	M
maxChannelStatusGroups	TS 3.5	Mandatory	O	M
channelStatusGroupTable	TS 3.5	Mandatory	O	M
channelStatusGroupNumber	TS 3.5	Mandatory	O	M
channelStatusGroupReds	TS 3.5	Mandatory	O	M
channelStatusGroupYellows	TS 3.5	Mandatory	O	M
channelStatusGroupGreens	TS 3.5	Mandatory	O	M
Overlap	TS 3.5	**Optional Group**	O	M
maxOverlaps	TS 3.5	Mandatory	O	M
overlapTable	TS 3.5	Mandatory	O	M
OverlapNumber	TS 3.5	Mandatory	O	M
OverlapType	TS 3.5	Mandatory	O	M
overlapIncludedPhases	TS 3.5	Mandatory	O	M
overlapModifierPhases	TS 3.5	Mandatory	O	M
overlapTrailGreen	TS 3.5	Mandatory	O	M
overlapTrailYellow	TS 3.5	Mandatory	O	M
overlapTrailRed	TS 3.5	Mandatory	O	M
maxOverlapStatusGroups	TS 3.5	Mandatory	O	M
overlapStatusGroupTable	TS 3.5	Mandatory	O	M
overlapStatusGroupNumber	TS 3.5	Mandatory	O	M
overlapStatusGroupReds	TS 3.5	Mandatory	O	M
overlapStatusGroupYellows	TS 3.5	Mandatory	O	M
overlapStatusGroupGreens	TS 3.5	Mandatory	O	M
TS 2 Port 1	TS 3.5	**Optional Group**	O	M
maxPort1Addresses	TS 3.5	Mandatory	O	M
port1Table	TS 3.5	Mandatory	O	M
port1Number	TS 3.5	Mandatory	O	M
port1DevicePresent	TS 3.5	Mandatory	O	M
port1Frame40Enable	TS 3.5	Mandatory	O	M
port1Status	TS 3.5	Mandatory	O	M
port1FaultFrame	TS 3.5	Mandatory	O	M

4.3.2.1.3 Object Range Values for an Actuated Traffic Signal Controller

> *Example 4.3 An appropriate selection of range values are needed for a typical traffic signal controller application. In this example, the controller will be an 8 – Phase controller based upon the NEMA TS-2-Type2 Actuated Traffic Controller standards.*

As in Example 4.2, reference is made to the NEMA TS 2 – 1998 Standard for Traffic Controller Assemblies. The NEMA TS 2 – 1998 standard provides a listing of minimum NTCIP data object range values to be supported by the compliant traffic signal controller.

Table 4.8 shows a typical data object from the NTCIP TS 3.5 – Actuated Signal Control standard. The data object shown is the Maximum Number of Phases from the mandatory Phase Parameters conformance group. The Maximum Phases data object has a status of mandatory. The range value of this data object is denoted as integer values from 0 to 255. This means that the device may support any value within that range. Additionally, the data object indicates that this is a read-only object, where writing a new value is prohibited. Also, included in the data object is a description of what this object means.

Table 4.8 Sample Actuated Traffic Signal Controller Data Object

Phase Parameters Conformance Group – Maximum Phases

```
maxPhases    OBJECT-TYPE
     SYNTAX  INTEGER (0..255)
     ACCESS  read-only
     STATUS  mandatory
     DESCRIPTION
          “The Maximum Number of Phases this Actuated Controller
          Unit supports.  This object indicates the maximum rows which
          shall appear in the phaseTable object.”
::={phase1}
```

Table 4.9 shows all of the minimum ranges values that are defined as part of the NEMA TS 2 – 1998 Traffic Controller Assembly Standard. The range values shown are based upon the minimum functionality requirements of the NEMA standard. In the case of the Maximum Phases value, we can see that the minimum range value to be supported is 8. The NEMA standard requires a minimum of 8 phases to meet the functionality requirements of the NEMA TS 2 – 1998 standard. As such, the value to be communicated using NTCIP for the Maximum Number of Phases would be 8. Similarly, other range values can be related to the level of functionality that is either required by specification or provided by the manufacturer.

Table 4.9 Object Range Values for Actuated Traffic Signal Controller Units

Object	Minimum Project Requirements
TS 3.4 – 1996 Global Object Definitions	
moduleType	Value 3
dBCreateTransaction	All Values
dBErrorType	All Values
globalDaylightSaving	Values 2 and 3
maxTimeBaseScheduleEntries	16
maxDayPlans	15
maxDayEvents	10
maxEventLogCongifs	50
mventConfigMode	Values 2 thru 5
mventConfigAction	Values 2 and 3
maxEventLogSize	255
MaxEventClasses	7
maxGroupAddress	2
TS 3.5 – 1996 Actuated Traffic Signal Controller Units	
maxPhases	8
pPhaseStartup	Values 2 thru 6
phaseOptions	All Values
maxPhaseGroups	1
maxVehicleDetectors	64
vehicleDetectorOptions	All Values
maxPedestrianDetectors	8
unitAutoPedestrianClear	All Values
unitControlStatus	All Values
unitFlashStatus	All Values
unitControl	All Values
maxAlarmGroups	1
maxSpecialFunctionOutputs	8
coordCorrectionMode	Values 2 thru 4
coordMaximumMode	Values 2 thru 4
coordForceMode	Values 2 and 3
maxPatterns	48
patternTableType	Either 2, 3, or 4
maxSplits	16
splitMode	Values2 thru7
localFreeStatus	Values 2 thru 11
maxTimebaseAscActions	48
maxPreempts	6
preemptControl	All Values
preemptState	Values 2 thru 9
maxRings	2
maxSequences	16
maxChannels	16
channelControlType	Values 2 thru 4
channelFlash	Values, 0, 2, 4, 6, 8, 10, 12, and 14
channelDim	Values 0 thru 15
maxChannelStatusGroups	2
maxOverlaps	4
overlapType	Values 2 and 3
maxOverlapStatusGroups	1
maxPort1Addresses	18
port1Status	Values 2 and 3

4.4 Center-to-Center

NTCIP defines two application level protocols for communications between computers – Data Exchange in ASN.1 (DATEX-ASN, commonly referred to as simply DATEX), and Common Object Request Broker Architecture (CORBA). Both protocols provide the same basic functionality, but they differ in the method of implementation and each has some unique features (see Chapter 3). A particular system may support either or both of these protocols. Gateways or translators can pass messages between the two when necessary. The Internet Protocol (IP) and both UDP and TCP are used at the transport level.

Regardless of the application level protocol, center-to-center communications requires participating systems to exchange standard messages or objects at the information level. Various center-to-center message sets and object models have been developed or are in development by ITS standards development organizations. Most of these are outside of the direct purview of NTCIP, but their development has been coordinated with the NTCIP center-to-center application protocol working group. The following standard inter-systems message sets have been defined, or are being defined, and can be used with DATEX:

- Traffic Management Center External Messages
- Transit Communications Interface Profiles
- Incident Management Messages
- Traveler Information Messages
- DATEX-ASN Administrative Messages

Various object models are in development for use with CORBA, but no standard models have yet been published.

The choice of protocol and message sets/object model depends on the application and environment. The following factors are relevant:

> *Note: The reader is reminded that center-to-center communications take place between computer systems, and those computers or systems may be within the same "center" or in separate centers. The following questions really apply to each system, including multiple systems within one center where relevant.*

- Is the procurement for just one center, or multiple centers?
- Is there an immediate need for center-to-center communications, or is the procurement for future use?
- Do other centers with which this one is likely to interact already have a DATEX or CORBA interface?
- What types of information will this center likely need to send or receive (traffic signal, freeway, other traffic management, transit, emergency, traveler information)?
- Is the procurement part of a new or upgraded system implementation, or an add-on to an existing system?
- Does the center use object oriented software?

- Can one or more connected centers now or in the near future provide gateway/translation services between DATEX and CORBA?

If multiple centers are to have center-to-center support added as part of the procurement, or in the near future, these questions need to be considered for each such center. It is desirable for agencies within a region to jointly consider these issues and make coordinated procurements where feasible to minimize costs and facilitate rapid achievement of all needed center-to-center links in the region.

Ultimately, it is hoped that all centers and systems for transportation management will have a DATEX and/or CORBA interface, just as virtually all computers now have standard protocol support for commonly used Internet communications, such as e-mail, web access, and file transfer. Systems with center-to-center protocol support will be able to automatically exchange transportation data with any other system with the same protocol, using the Internet or a private Internet Protocol based communications network.

The NTCIP center-to-center protocols and related message sets and object models are necessary, but not sufficient for two centers to usefully exchange data. Application software is needed to gather, process, display, interpret, act on, and generate the incoming or outgoing data. The same is true of any protocol. For example, the Internet's Simple Mail Transfer Protocol is a standard for e-mail transfer between computers, but a computer needs more than the protocol, it also needs an e-mail program that enables a user to compose and send mail, retrieve and read mail, to archive both sent and received messages, etc.

Center-to-center communications between computer systems will work only if the computers have suitable application software. This software does not have to be standardized, just as Microsoft's Outlook e-mail program works quite differently from Netscape's Communicator program, but e-mail can be sent between the two because they both use the Simple Mail Transfer Protocol.

Some of the functions that a center may need in a center-to-center communications management software package include the following:

- User interface (e.g., subscription form, data display, status reports, etc.)
- Interpretation and appropriate disposition of incoming messages
- Databases for storing subscriptions and other administrative data
- Interfaces with existing transportation databases and programs
- Network performance monitoring and management
- Event logging and reporting, etc.

None of these functions are specified or provided by the center-to-center protocols or message sets, since they do not have to be standardized. But at least some will need to be provided for a system to manage and make use of center-to-center communications. A system may choose to obtain a very elaborate and sophisticated center-to-center communications management package, or a basic one. The former will provide more functions and be easier to use, but will cost more.

Center-to-center protocol software and center-to-center communications management software are most easily provided as part of the initial development or implementation of a system, or during a system upgrade. However, it is possible to add on center-to-center software at any time.

Adding center-to-center software to an existing system can be achieved in either of two basic ways:

- Keep the center-to-center protocol and management software separate from the existing transportation management software – usually on a separate computer and with a separate user interface. This involves a loosely coupled connection between the two software packages, which may make use of an existing data interface available in the transportation management system, thus avoiding or minimizing the need for changes to the existing software.

- Tightly couple the center-to-center protocol and management software with the existing transportation management software – usually on the same computer, and usually with an integrated user interface. This involves alteration of the existing software to provide the integration. This option provides a more integrated application for ease of use and added functionality, but costs more.

The loosely coupled option allows use of a generic center-to-center "server" software package that can be replicated at multiple centers, with different interfaces to each local system. This may minimize costs, but it will likely mean users have to deal with two separate user interfaces, incoming data may not be viewable on the same dynamic displays as local data, data from other centers may not be able to be easily combined with local data in analysis and reports, and some remote control functions may not be supported. The tightly coupled approach and its functional benefits can often be obtained much more economically if it is provided as part of a new system development or upgrade and is part of the overall system requirements and specifications.

Eventually, each center will ideally support both the CORBA and DATEX protocols and all standard message sets and object models. If it is not practical to add support for both protocols, a center should provide, if feasible, the one that other centers in the area are already using or have planned, if any, and otherwise choose the one most suited to its abilities and needs. For example, object oriented systems will probably implement CORBA because it will be easier and more capable. Non-object oriented systems will probably implement DATEX because CORBA will be awkward for them. It is anticipated that state, regional, and large transportation management centers will support both protocols and also provide a regional translation or bridging service to enable data exchange between local systems with single but different protocols.

Finally, for center-to-center communications to operate, a computer network connection is needed between the centers. Any local or wide area network that supports the Internet Protocol is adequate. The Internet can be used, but many centers are reluctant to do this until better security measures are available. Latency is also an issue when considering use of the Internet. Private wide area network services are readily available from telecommunications companies, including virtual private networks that use the Internet infrastructure. As explained in Chapter 5, there are bandwidth considerations if low speed WAN links (e.g. 56 kbps) are being considered.

Dial-up access may be appropriate for remote or occasional data exchanges. Other than these introductory comments, the design and specification of the network connection is beyond the scope of this document.

5 DESIGNING NTCIP

5.1 Introduction

This chapter is intended to provide an overview of communication bandwidth calculations and some of the issues that should be considered when designing an NTCIP communications system. While the tile of this section is Designing NTCIP, the focus of the material presented herein deals with how to design a communications system for use with NTCIP. This section is intended for those system designers, system integrators, and manufacturers who are tasked with determining communication system design and performance criteria.

This chapter contains the following sections:

- Calculate Bandwidth Requirements
  - Center-to-Center Bandwidth Requirements
  - Center-to-Field Bandwidth Requirements
  - Center-to-Field Bandwidth Analysis
    - Estimate Message Exchanges and Frequency
    - Estimate Application Message Size
      - SNMP Application Message Bits and Bytes
      - STMP Application Message Bits and Bytes
    - Estimate Application Message Exchanges
      - SNMP Application Message Exchange Sizes
      - STMP Application Message Exchange Sizes
    - Estimate Transport and Subnetwork Protocol Size
    - Estimate Timing Factors
    - Modems
      - Electrical Limitations
      - Communications Limitations
    - SNMP Timing
    - STMP Timing
  - Center-to-Field Bandwidth Alternate Analysis
    - Estimate Message Exchanges and Frequency
      - SNMP Application Message Exchange Sizes
      - STMP Application Message Exchange Sizes
    - Other Estimates
    - Number and Size of Slots per Channel
    - Communications Drops (Drops per Channel)
    - SNMP Timing
    - STMP Timing

5.2 Calculate Bandwidth Requirements

The NTCIP Standards do not address issues related to specifying bandwidth requirements or how bandwidth is allocated. Bandwidth is basically how much information can be sent through a connection. It is usually expressed as bits-per-second. Most communications networks permit multiple applications, users and / or devices to access a common communications link. Sharing the link must be equitable. Some NTCIP Standards address the requirements of several communications links or subnetworks, but do not state which ones will be used for specific applications. These are application and implementation specific issues. Planners and implementers must decide these issues. This leads to the question of whether a communications link or subnetwork has enough bandwidth to support the desired information exchanges.

An implementation of a system must include specific choice of a subnetwork or subnetworks. That choice must be able to accommodate the information exchanges that are needed for proper setup, operation, and monitoring of a system. Planners and implementers must understand that a specific media may limit what can be sent. This section provides several examples of how to estimate what can be sent, the overhead associated with sending it, and the organization of the physical media to support the information exchanges.

5.2.1 Center-to-Center Bandwidth Requirements

Center-to-center communications typically involve communications networks connecting many computers in a peer-to-peer arrangement. These networks typically involve both local area networks (e.g., within a building or adjacent buildings) and wide area networks (e.g., across town or across the nation). The bandwidth requirements will vary for each link in each network, depending on the amount of center-to-center messaging traffic using that link, and whether or not the network is shared with other applications. Multiplexers, routers, switches, hubs, and other devices are commonly used to manage, segment, and optimize computer networks.

The typical subnetwork consists of a local area network adapter that operates at 10 Mbits-per-second (Mbps). In an office environment, even 100 Mbps is readily available. Point-to-point dialup and dedicated external links run at a minimum of 56 Kbits-per-second (Kbps). Most importantly to a planner or implementer is that there are plenty of information resources available. Network and communications consultants abound. In today's business environment, there is usually a computer guru or network administrator that can help understand and quantify bandwidth and allocations issues.

In a center-to-center environment, the computers that run the transportation applications are typically just users of the "network" or communication links. Other applications such as e-mail, database management, graphics design, and word processing may also users of the network. This has a big advantage when it comes to design and implementation. A network specialist usually handles its design and implementation. However, they expect the transportation system designer or implementer to be able to quantify what demands will be placed on the network.

The NTCIP center-to-center protocols (DATEX and CORBA) are used for two basic types of message exchange. The first type involves a human operator at a center requesting information on a one-time basis from another center. Since a human is in the loop, the volume of such messages is small, and they are unlikely to be critical in any network design. The other type of messaging occurs when an operator at a center sets up a permanent subscription for data to be sent from another center automatically – no human in the loop – and repeatedly. Such subscriptions may request the data to be sent every x seconds, or only when it changes. In most cases, network traffic is minimized if subscriptions specify change-based triggers rather than time based. Since each center can establish any number of permanent subscriptions with each of any number of other centers on the network, this is the type of messaging that can potentially overload the network, or at least some links in the network.

It may be difficult for a system designer to anticipate all the different types of data that may be subscribed for between each pair of centers. It is recommended that designers gather actual operating experience from exiting center-to-center networks to help make such estimates. One important consideration is the frequency of change in status or other data at each center, since changes are what other centers will be interested in monitoring. For example, a center that manages only incidents and related information is not likely to generate as much message traffic on the network as one that manages 200 traffic signals each of which changes status every few seconds.

It is possible to perform a worst case analysis by considering the frequency, or quantity per second, of useful information generation at each center, estimate which other centers will have an interest in receiving that information, and assign the message loads to network links accordingly. Some messages will not require a confirmation or other response message, but many will. These need to be allowed for as well. CORBA also uses various administrative and exchange initiation messages that can add more traffic on the channel. Further allowance needs to be made for retries when a message is not delivered successfully on the first attempt.

For DATEX, each IP packet containing data (a publication message – the most common type) will contain at least 70 bytes of overhead information (including the IP header), plus the actual encoded data. Most messages will contain only a relatively small quantity of actual data – say 20 to 100 bytes. An average DATEX-generated IP packet might contain 150 bytes. At this rate, a full duplex 56 Kbps wide area network link could support in the order of 30 messages per second in each direction. This will be sufficient for some centers, such as the incident management center, but may not be sufficient for others such as the large traffic signal system, or a center that wants to obtain a lot of data from other centers.

Figure 5.1 illustrates all the typical fields and values used in sending a set globalTime message over a typical office environment, network communications stack. The message is sent via the SNMP Application Profile over a UDP/IP Transport Profile over an Ethernet Subnetwork Profile. Figure 5.2 illustrates the same globalTime message sent via the STMP Application Profile over the same transport and subnetwork.

5.2.2 Center-to-Field Bandwidth Requirements

In center-to-field communications, bandwidth considerations are of great concern to planners and implementers. Unlike an office environment, center-to-field communications links are generally less than 56 Kbps. Hundreds of existing systems use multi-drop, 1200 bps modems. Compounding the issue, these links tend to be dedicated to the transportation application and are the full responsibility of the transportation personnel to design, implement, and maintain. The following bandwidth analyses should help to understand the factors and thinking that go into understanding bandwidth requirements and calculating an appropriate communications data rate. However, it should be noted that many other devices, such as dynamic message signs, advisory radio transmitters, ramp meters, traffic detector stations, and weather stations are usually much less sensitive to timing and latency issues, and can typically operate satisfactorily with SNMP, even at 1200 bps.

The two analyses will be used to discuss a few of the many alternative techniques that can be used in a center-to-field multi-drop communications system using NTCIP. Examples (by no means a complete list) of options available include:

- Use SNMP for all or some messages
- Use STMP for all or some messages
- Use only standard objects, or also use some manufacturer specific objects
- Use a bit rate of 1200, 2400, 4800, 9600, 19200, or other
- Use half duplex or full duplex communications
- For full duplex, overlap or don’t overlap outgoing with incoming messages
- Use twisted pair, fiber, radio, leased lines, or other media
- For twisted pair and leased lines, use one or two pairs per channel
- Use modems that are fast or slow to reach ready state when needed
- Limit the maximum number of devices on a channel to 2, 4, 6, 8, 10, or other number
- Gather detector data on a clock time basis (e.g. every minute) or signal cycle basis
- Request each type of data every second, every minute, or every hour, etc.
- Use a fixed or variable polling cycle duration
- Use a fixed or variable device sequence in the polling cycle
- Use a fixed or variable message sequence for each device
- Wait for response in same poll or get it in next poll
- Interleave upload /download messages or suspend status and “get it over with ASAP”
- Use the same status message all the time, or different status messages
- Insert occasional non-status requests in place of or in addition to status request
- Allow spare time in a polling cycle for additional non-status messages, or allow the cycle to expand when non-status messages added

With the exception of manufacturer-specific data objects, any controller that meets all mandatory, optional, and recommended requirements of the relevant NTCIP center-to-field standards for that field device type, will support all of the relevant functions and operations suggested above and many more, without any software change.

5.2.3 Center-to-Field Bandwidth Analysis

For purposes of discussion, lets say it is desired to use NTCIP center-to-field communications in an imaginary traffic control system. The system consists of a central management application that is used to setup, monitor, and control a network of intersection traffic signal controllers. The primary communications requirements of the imaginary system are:

1. Synchronize the time and date in all field devices.
2. Provide a map display of the status of all intersections.
3. Control the overall coordination timing pattern to be put into effect.
4. Control the operation of 2 lane-closed signs.
5. Monitor all intersections for any abnormal conditions.
6. Accumulate volume and occupancy data for 16 detectors to perform off-line optimization.
7. Provide full upload and download of the complete database or programming data in each field device.
8. Support 24 signalized intersections in the system.

This example will be used to:

- discuss what object definitions support this functionality,
- characterize the overhead of sending the information via various protocols,
- compare and contrast modems,
- define the number of drops on a communications channel, and
- calculate appropriate modem speed to accommodate the information and timing characteristics.

A slightly modified set of requirements will be used to describe a polling sequence approach to define when message exchanges take place.

5.2.3.1 Estimate Message Exchanges and Frequency

The first step in this analysis is to define what information exchanges will be used to meet the required functionality and how often they occur.

To synchronize the time and date in all field devices, the following object from TS 3.4 will be used:

globalTime - Section 2.4.1

This object can be used in a message to set or retrieve the current date and time in a remote device. Typical usage is to send the command to all intersections at least once a day. The time in each individual intersection is checked (read) at least once a day, as well.

To provide a map display of an intersection the following objects defined in TS 3.5 will be used:

phaseStatusGroupGreens - Section 2.2.4.4
phaseStatusGroupYellows - Section 2.2.4.3
phaseStatusGroupWalks - Section 2.2.4.7
phaseStatusGroupPedClrs - Section 2.2.4.6
phaseStatusGroupVehCalls - Section 2.2.4.8
phaseStatusGroupPedCalls - Section 2.2.4.9
overlapStatusGroupGreens - Section 2.10.4.4
overlapStatusGroupYellows - Section 2.10.4.3
cordPatternStatus - Section 2.5.10
shortAlarmStatus - Section 2.4.9

These objects provide green and yellow indications for up to 8 vehicle phases and 8 overlaps, walk and pedestrian clearance indications for up to 8 pedestrian movements, the current coordination pattern (cycle, split, and offset) in effect, and an indication of preemption, problems with the coordination pattern, any detector fault, or some other type of fault condition. This information is intended to provide a real-time display and is typically read from each intersection controller on a once-per-second basis.

To control the timing pattern to put into effect and turn on and off the lane closed signs, the following objects from TS 3.5 will be used:
    systemPatternControl - Section 2.5.14
    specialFunctionOutputState (1) - Section 2.4.14.2
    specialFunctionOutputState (2) - Section 2.4.14.2
This information is intended to be sent to all intersections about once per minute.

To retrieve volume and occupancy data from 2 volume / occupancy detectors at a time, the following objects from TS 3.5 will be used:
    volumeOccupencySequence - Section 2.3.5.1
    detectorVolume (1) - Section 2.3.5.4
    detectorOccupency (1) - Section 2.3.5.4
    detectorVolume (2) - Section 2.3.5.4
    detectorOccupency (2) - Section 2.3.5.4
The volume and occupancy data would be read approximately once-per-minute. It is typical to have "count stations" spread out over several intersections. This type of information would be asked for from the intersections that have one or more count stations.

To provide additional information about the status of an intersection, the following objects will be used:
    unitAlarmStatus1 - Section 2.4.8
    localFreeStatus - Section 2.5.11
These objects are to read only when the shortAlarmStatus indicates some type of fault condition. They provide more detail about any potential fault condition. Typically this would occur no more than once-per-hour.

To provide complete upload and download of a controller's database, the following implementation specific, block objects are defined and used for upload and download purposes:
    Timing Plan 1 Programming Data (entries for phases 1-16)
    Timing Plan 2 Programming Data (entries for phases 1-16)
    Timing Plan 3 Programming Data (entries for phases 1-16)
    Timing Plan 4 Programming Data (entries for phases 1-16)
    Vehicle Detector Programming Data (entries for detectors 1-32)
    Pedestrian Detector Programming Data (entries for detectors 1-16)
    Vehicle Overlap Programming Data
    Pedestrian Overlap Programming Data
    Timebase Programming Data
    Coordination Pattern Programming Data
    Coordination Permissive Programming Data

Conditional Service and Dual Entry Data
Event Programming Data
Preempt Programming Data
Unit Configuration Programming Data
Communications Programming Data

These block objects are defined as implementation or vendor specific OCTET STRING [an ASN.1 data type that is used to specify octets (eight-bit bytes) of binary or textual information] objects consisting of anywhere between 10 and 128 discrete objects. The individual objects may be defined in the TS 3.5 Standard or may be implementation or vendor defined objects. The block objects could define the entire "database" of a device. They would only be sent and retrieved on an as-needed basis and would, at most, occur no more than once-per-day. They could represent the records in file upload or download. While these objects are not currently defined in an NTCIP standard, they represent real system requirements.

In the course of fine tuning an intersection, numerous programming entries for phase timing and coordination might be sent once or twice a day. The following objects would be typical:

phaseWalk - Section 2.2.2.2
phaseMinumumGreen - Section 2.2.2.4
phasePassage - Section 2.2.2.5
patternCycleTime - Section 2.5.7.2
patternOffsetTime - Section 2.5.7.3
splitTime - Section 2.5.9.2

The typical intersection is set up for 5-phase operation and has only 6 timing patterns defined. It is assumed that only one phase or pattern would be adjusted at any one time. Therefore, the number of objects associated with this type of operation is assumed to be 5.

The following table summarizes the messages and the how often they occur.

Table 5.1 Frequency of Messages

Message Exchange	Frequency
Date and Time	1 per day - all
Intersection Map Data	1 per second X 24 intersections
Pattern Command	1 per minute - all
Detector Data	1 per minute X 8 intersections
Detailed Status	1 per hour X 8 intersections
Upload Download	1 per day X 24 intersections
Tuning	2 per day X 24 intersections

5.2.3.2 Estimate Application Message Size

The following two rules of thumb can be used to estimate SNMP and STMP messages:

1. SNMP Message Size = 26 bytes of header + 23 bytes per object
2. STMP Message Size = 1 byte of header + 1 byte per object

These rules are approximations and do not include lower layer protocol overhead. The rules are based upon the assumption that most exchanges deal with status and control objects that can be expressed in one byte. The majority of set up objects can also be expressed in one byte. The rules of thumb would not apply to exchanges involving OCTET STRINGs or OBJECT IDENTIFIERs. If you are willing to accept the rules as such, you can skip the next two sections. If you're into technical details, then the following sections provide an in depth explanation on how exact sizes of messages can be derived. It is very detailed and not for the faint of heart.

5.2.3.2.1 SNMP Application Message Bits and Bytes

The actual bits and bytes of an SNMP message are defined using the *Tag-Length-Value* representation method defined in ISO 8825, Basic Encoding Rules (BER). All objects can be expressed as *Tag* (or Type) of either SEQUENCE, INTEGER, OCTET STRING, or OBJECT IDENTIFIER. The *Tag* indicates how to think of the *Value* component. It indicates that it may be number, string (or text), or the identifier of something. It can also indicate that what follows is a series of data that is expressed as a *Tag-Length-Value* of something. There are several derived types that represent subsets of SEQUENCE, INTEGER, OCTET STRING, or OBJECT IDENTIFIER but any derived type resolves to one of the aforementioned ones. The second component of an object is its *Length*. For example, the *Length* of the INTEGER "1" when represented in computer terminology technology is one. It represents how many bytes it takes to store "1" in memory. The OCTET STRING "public" has a *Length* of 6 because it is expressed in 6 bytes . The third component of an object is its *Value*. The *Value* of INTEGER "112" is expressed as 0x70 in computer terminology [decimal 112 = 70 hexadecimal = 0111 0000 binary]. The OCTET STRING "p" is also expressed as *Value* 0x70. The reason a computer can differentiate the 0x70 as either "112" or "p" is because of the *Tag*.

An SNMP message is defined as a SEQUENCE and Length of two predefined fields that describe the protocol plus a field that defines the data carried by the protocol. The predefined fields consist of version and community name. Both the version and community name expressed in the *Tag-Length-Value* form. A data field that follows it describes the operation that is to be performed. The **SetRequest PDU** field at the end of row is expanded in the row below. This is illustrated in the **SNMP Message Fields** row of Figure 5.1.

Note that the expanded **SetRequest PDU** field starts with the *Tag* of the operation, is followed by the *Length* of the data that follows, and consists of *Value*s of three *Tag-Length-Value* fields. The last field of **SetRequest PDU** consists of the **Variable Bindings** field. It is expanded on the next row.

As before, it begins as a *Tag-Length-Value* of a SEQUENCE and Length of one or more **Bindings**. The last row in the figure is getting closer to defining the actual data is, but we have to go through another *Tag-Length-Value* sequence to describe the *identity* and *value* of a single object or **Bindings**.

From the communications perspective, each of the objects defined in one of the Object Definitions Standards such as TS 3.4 or TS 3.5 has two components: an *identity* and a *value*. The *identity* part of the globalTime object is its OBJECT IDENTIFIER (OID). The full OID of globalTime is:

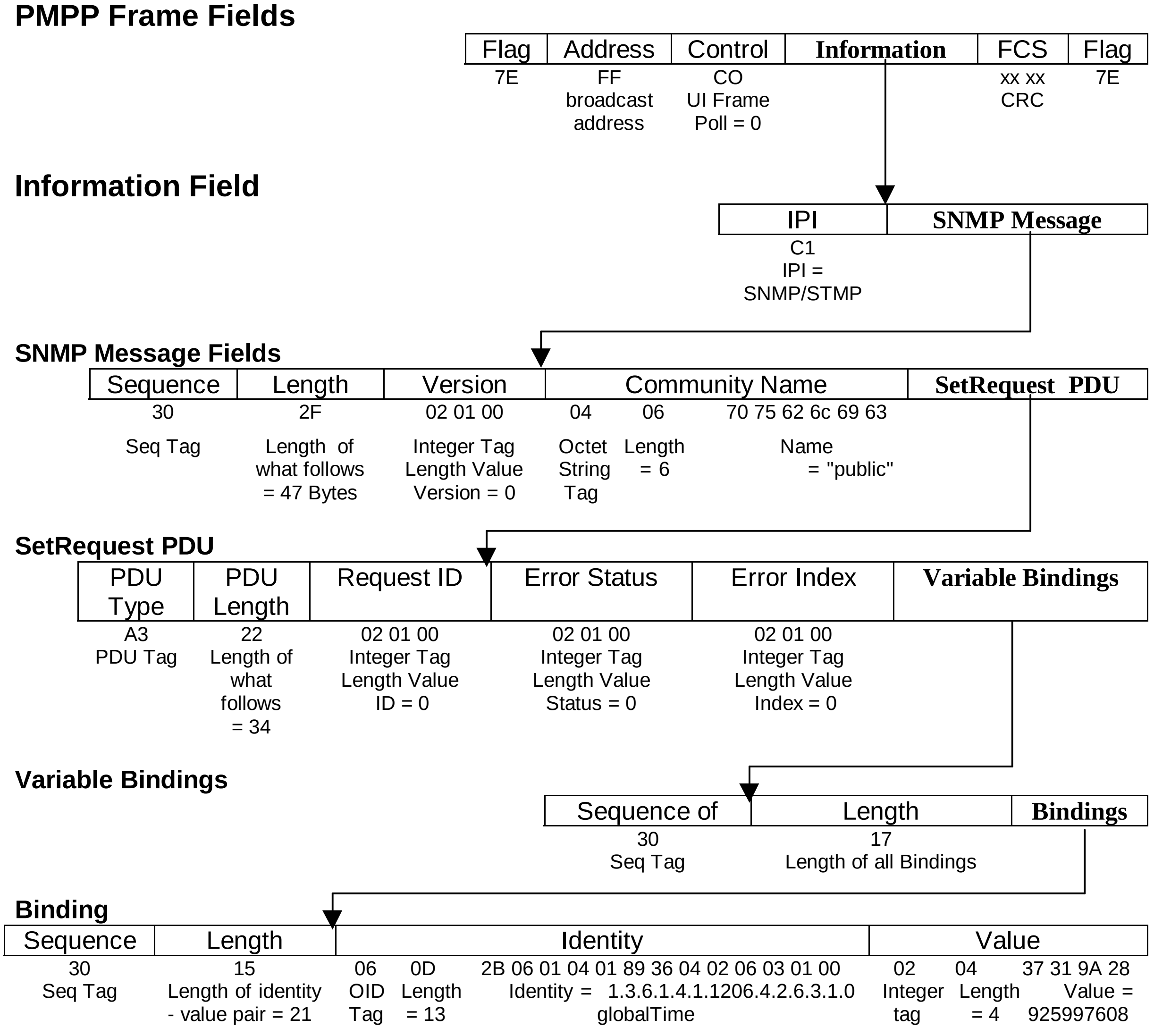
<iso.org.dod.internet.private.enterprises.nema.transportation.devices.global.globalTimeManagement.1>
or
<1.3.6.1.4.1.1206.4.2.6.3.1.0>

The *value* component of globalTime is an INTEGER with a value such as 925997608. This particular value represents May 6, 1999 at 2:33 PM UCT expressed as the seconds since Midnight January 1, 1970. For a more detailed discussion on OID, please refer to Section 6.

The actual number of bytes that are used to encode the *identity* and *value* of the globalTime object varies with protocols used. For SNMP, each component of the object is expressed in the form of (you guessed it) *Tag-Length-Value*. For globalTime, the *identity Tag* is OID (0x06). The *identify Length* value is 13 (0x0D). The *identity Value* is 1.3.6.1.4.1.1206.4.2.6.3.1.0 (0x2B06010401893604020603010 0). For the *value* component, the *value Tag* is INTEGER (0x02). The *value Length* is 4 (0x04). The *value Value* is 925997608 (0x37319A28).

If one goes through this exercise with various objects, one can derive some general characteristics about the objects used in this analysis. Most objects are organized into tables and the OIDs of these objects are 15 to 16 bytes long. Unlike globalTime, most objects are defined as INTEGERs that, **in the traffic signal controller application,** have a value between 0 and 255. Most values are therefore expressed in one or two bytes. Compared to the example of globalTime, a typical identity would 2-3 bytes longer and the value would be 2-3 bytes shorter. The average binding for an individual object is therefore 23 bytes, as shown in Figure 5.1. The fixed overhead of SNMP messages that are used to get or set one or more objects is 26 bytes, as shown in Figure 5.1.

Figure 5.1 Set Time operation using SNMP over PMPP



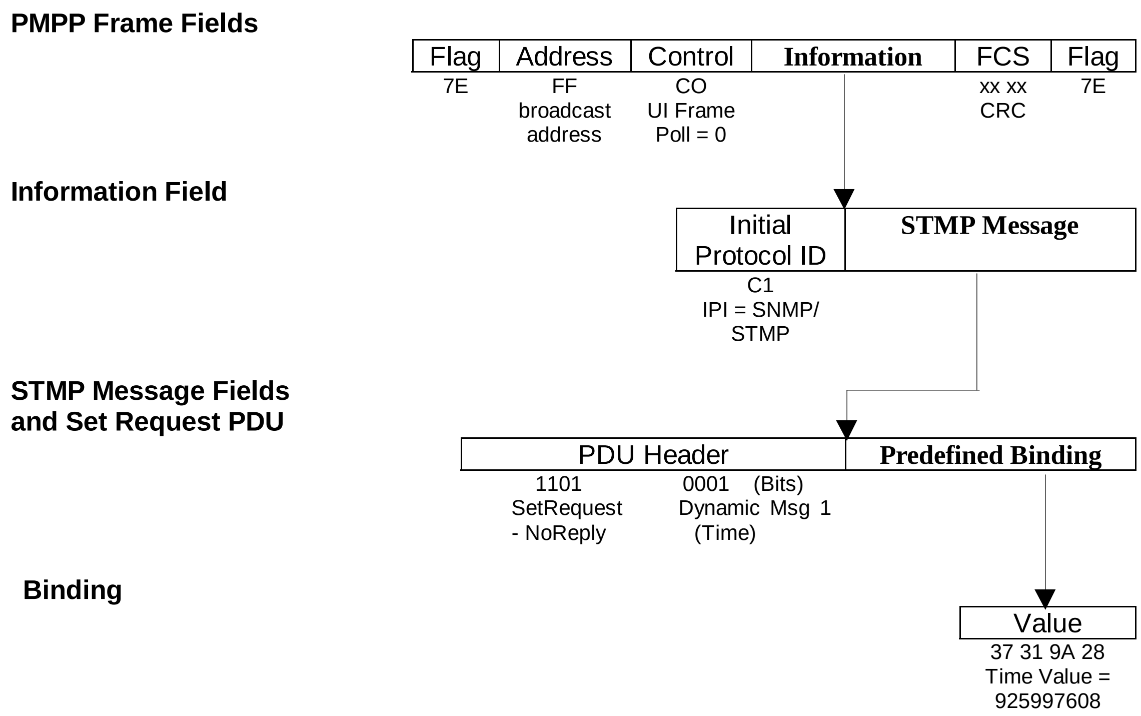
5.2.3.2.2 STMP Application Message Bits and Bytes

The actual bits and bytes of an STMP message are defined using Octet Encoding Rules (OER), as described in NTCIP 1102 – NTCIP Octet Encoding Rules (OER). Because the content of an STMP message is defined prior to being sent, it is possible to eliminate a number of fields and reduce overhead significantly. OER starts out with the *Tag-Length-Value* representation method used by SNMP. However, if the *Tag*, *Length*, or *Value* is known, the component is eliminated. If an object is always an INTERGER, the fact that it is an INTEGER is not sent. If an object is always 2 bytes long, the fact that it is 2 bytes long is not sent. Since all data are expressed as a

SEQUENCE, all SEQUENCE *Tags* and SEQUENCE *Lengths* are eliminated as well. What this all boils down to is that only the *Value* of an object is sent.

In Figure 5.1, the **Binding** for globalTime consisted of Sequence, Length, and Value of the Identity and Value pair where the Identity and Value pair were each encoded as *Tag-Length-Value*. The **Binding** in STMP would be the Value-*Value* or simply 0x37319A28 as shown in the last row of Figure 5.3. It is worth noting here that the same principle of eliminating any known *Tag*, *Length*, or *Value* was applied to the **SNMP Message Fields, Set Request PDU, and Variable Bindings** fields in Figure 5.1. This resulted in the one-byte **STMP Message Fields and Set Request PDU** field shown in Figure 5.2

Figure 5.2 Set Time operation using STMP over PMPP



5.2.3.3 Estimate Application Message Exchanges

In any exchange of messages, one has to consider the size of both the command and response. In SNMP, the size of the command and response are approximately the same size. In STMP, the size of the command and response are very different. The following two sections discuss the details.

5.2.3.3.1 SNMP Application Message Exchange Sizes

Using the SNMP rule of thumb, one can estimate the size of an SNMP message and exchanges by the number of objects that are contained in them. The following table summarizes the messages in the example, how many objects are in the message, the command size in bytes, and the size of an exchange.

Table 5.2 Message Size Example

SNMP Message Overhead	Objects	Command / Response Size	Exchange Size
Date and Time	1	49	98
Intersection Map Data	10	256	512
Pattern Command	3	95	190
Detector Data	5	141	282
Detailed Status	2	72	144
Upload Download	1 + bytes	59 - 177	118 - 254
Tuning	5	141	282

In SNMP, typical commands and the responses have about the same number of bytes. A getRequest command will contain placeholders for values that would be contained in a response to it. In a setRequest, the values of objects that are to be set are contained in the set command. In the corresponding setResponse, the same values would also be included to indicate what the objects were actually set to. Therefore, in an SNMP exchange, the number of bytes is equal to two times the message size.

5.2.3.3.2 STMP Application Message Exchange Sizes

The rule of thumb for estimating STMP message size is 1 byte + 1 byte per object. To estimate message exchanges, however, one has to understand that only a command or response contains the value(s) of any associated object(s). To eliminate as much overhead as possible, a management application can also send a command where no reply is necessary. An STMP getRequest, getNext, and setResponse do not contain any object values. An STMP setRquestNoReply does not return any response. The following table summarizes the typical command and responses:

Table 5.3 Typical Command and Responses

Command	Response
getRequest	GetResponse + value
getNext	GetResponse + value
setRequest + value	SetRespone
setRequestNoReply + value	[no response]

The next table shows what commands will be used to set or get the objects. It also lists the size for each command and response. By summing the size of the command and response, the size of the message exchange can be derived.

Table 5.4 Derivation of STMP Message Exchange Sizes

Dynamic Message	Command	# of Objects	Size		
			Command	Response	Exchange
Date and Time	setRequestNoReply	1	2	-	2*
Date and Time	getRequest	1	1	2	3*
Intersection Map Data	getRequest	10	1	11	12
Pattern Command	setRequestNoReply	3	4	-	4
Detector Data	getRequest	9	1	10	10
Detailed Status	getRequest	2	1	3	3
Upload Download	N/A	-	-	-	-
Tuning	N/A	-	-	-	-

* As with any rule of thumb, it does not always apply. The actual sizes are 5 and 6, respectively.

The setting of Date and Time and Pattern Command will be handled with the setRequestNoReply commands. Retrieving of Date and Time will be handled with a getRequest command and getResponse reply. The Intersection Map Data, Detector Data, and Detailed Status will be handled with the getRequest command and getResponse response. Several Upload Download messages could, in theory, be defined as Dynamic Objects. However, the limited number of definable Dynamic Objects (13) would tend to preclude this. Some implementations may specifically prohibit this, as well. The Tuning message while easily defined in SNMP cannot be predefined in STMP because various phases and patterns would have to be indexed.

5.2.3.4 Estimate Transport and Subnetwork Protocol Size

The Point-to-MultiPoint (PMPP) and Point-to-Point Protocols (PPP) share a common header structure that has 6 fields associated with it. These fields consist of starting flag, address, control, information, checksum, and a closing flag. The address field in PMPP is typically one byte but could be extended. The address field in PPP is always 0xFF and is one byte. The fields are illustrated in Figure 5.1, in the **PMPP Frame Fields** row.

The first field in the **Information Field** indicates the next higher level protocol to process the information. This field is referred to as the Initial Protocol Identifier (IPI). For non-networked communications, a "null" or no transport or network protocol is used. The IPI in this case is 0xC1 and indicates that the information should be passed directly to SNMP or STMP.

One particular facet of PMPP that may come into play but is not factored in to the rules of thumb is byte stuffing. Byte stuffing ensures that the opening and closing flags are unique in any exchange. Any value of 125 (0x7D) or 126 (0x7E) occurring between the two flags will be padded with an additional byte. In this way reception of a Flag (0x7E) uniquely identifies the beginning or ending of an HDLC frame. PPP also uses the byte stuffing technique but extends it to cover any value between 0x00 and 0x1F. On average, byte stuffing adds 1% overhead or 1 byte for every one hundred transmitted.

It is very likely that, in the future, field devices will support true networked communications. Messages and exchanges could be routed from workstations on a local area network through a communications server or field processor to a device. In this scenario the Internet UDP/IP Protocols would be used. Figure 5.3 illustrates all the typical fields and values used in sending a set globalTime message over a typical office environment, network communications stack. The message is sent via the SNMP Application Profile over a UDP/IP Transport Profile over an Ethernet Subnetwork Profile. The use of UDP/IP has an overhead of 28 bytes. A typical Ethernet Frame has an overhead of 24 bytes.

It is also possible to send STMP over UDP/IP over Ethernet. Figure 5.4 illustrates the same globalTime message sent via the STMP Application Profile over the same transport and subnetwork. Note that the only difference in transport and subnetwork layers is the value of the Destination Port in the UDP Header. SNMP uses the value 161 (0x00A1) and STMP uses the value 501 (0x1F5).

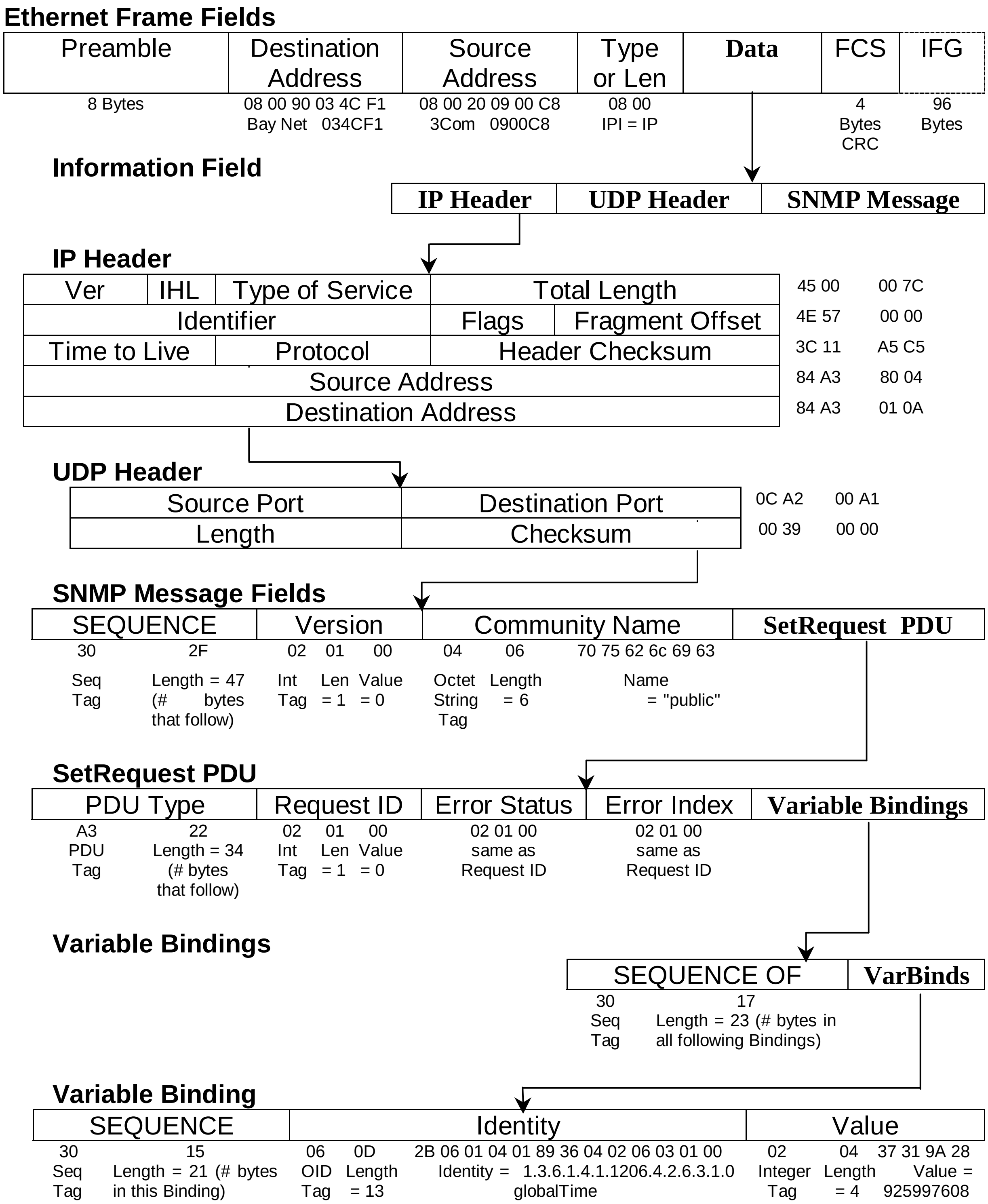
The term UDP/IP may be unfamiliar to transportation personnel. However, if a computer supports TCP/IP or the Internet Protocol Suite, it supports UDP/IP, as well. What this means is that a message that is meant to set the time-of-day in a variable message sign for example, it can be generated by and routed through the computers involved in center-to-center communications. The use of UDP/IP over Ethernet also typifies a real implementation. A traffic signal controller and dynamic message sign system in Toronto, Canada uses SNMP over UDP/IP over a mix of Subnetwork technologies. The current Advanced Transportation Controller – Model 2070 type field controller may use a 10 Mbps Fiber Optic Ethernet Subnetwork, as an example.

The following table summarizes the overhead for the various transport and subnetwork protocols.

Table 5.5 Overhead Estimates

Transport and Subnetwork Protocol	Overhead per Message	Overhead per Exchange
Null over PMPP	7	14
Null over PPP	7	14
UDP/IP over PMPP	35	70
UDP/IP over Ethernet	54	108

Figure 5.3 Set Time operation using SNMP over UDP/IP/Ethernet



Ethernet Frame Fields

Preamble	Destination Address	Source Address	Type or Len	**Data**	FCS	IFG
8 Bytes	08 00 90 03 4C F1 Bay Net 034CF1	08 00 20 09 00 C8 3Com 0900C8	08 00 IPI = IP		4 Bytes CRC	96 Bytes

Information Field

IP Header	**UDP Header**	**SNMP Message**

IP Header

Ver	IHL	Type of Service	Total Length	45 00	00 7C
Identifier			Flags / Fragment Offset	4E 57	00 00
Time to Live		Protocol	Header Checksum	3C 11	A5 C5
Source Address				84 A3	80 04
Destination Address				84 A3	01 0A

UDP Header

Source Port	Destination Port	0C A2	00 A1
Length	Checksum	00 39	00 00

SNMP Message Fields

SEQUENCE		Version			Community Name			**SetRequest PDU**
30	2F	02	01	00	04	06	70 75 62 6c 69 63	
Seq Tag	Length = 47 (# bytes that follow)	Int Tag	Len = 1	Value = 0	Octet String Tag	Length = 6	Name = "public"	

SetRequest PDU

PDU Type		Request ID			Error Status	Error Index	**Variable Bindings**
A3	22	02	01	00	02 01 00	02 01 00	
PDU Tag	Length = 34 (# bytes that follow)	Int Tag	Len = 1	Value = 0	same as Request ID	same as Request ID	

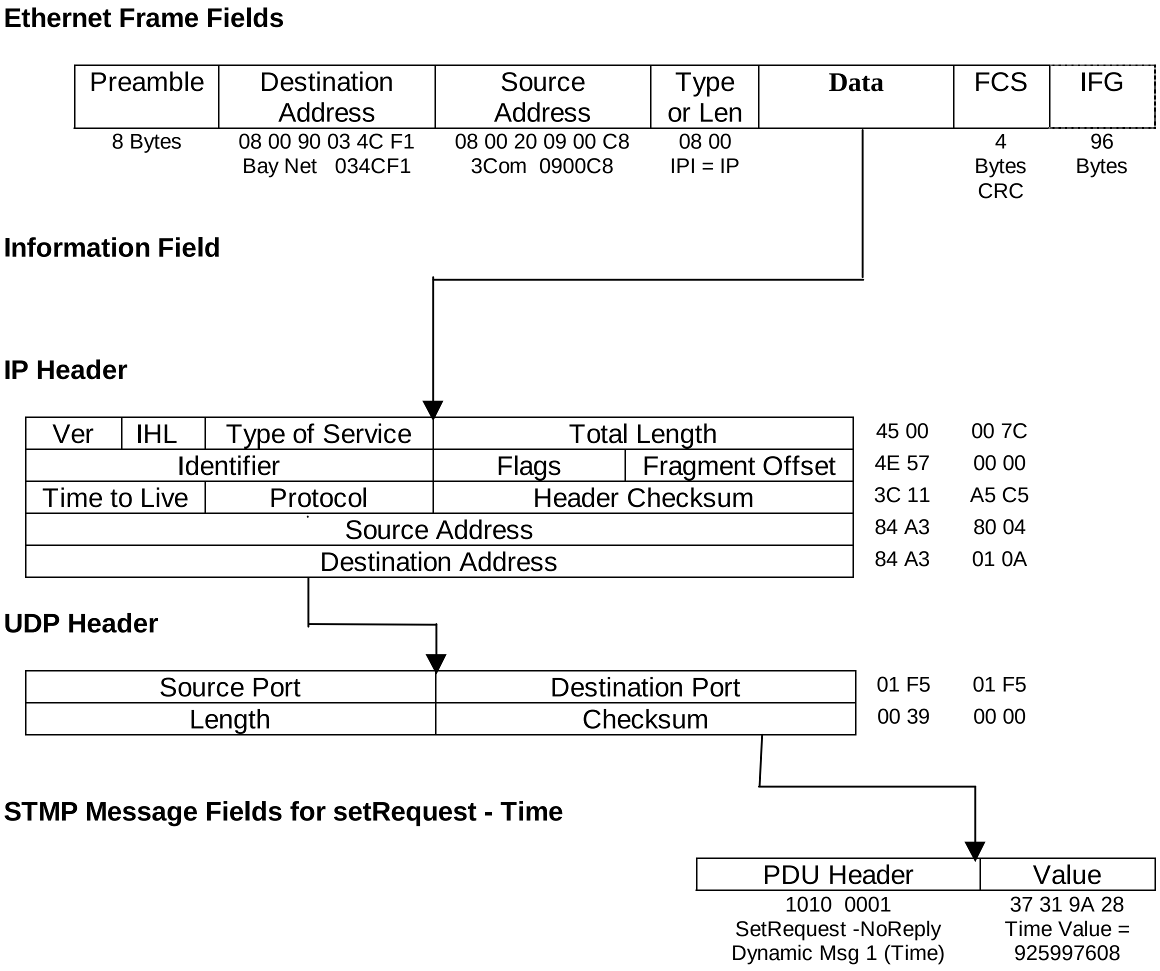
Variable Bindings

SEQUENCE OF		**VarBinds**
30	17	
Seq Tag	Length = 23 (# bytes in all following Bindings)	

Variable Binding

SEQUENCE		Identity			Value		
30	15	06	0D	2B 06 01 04 01 89 36 04 02 06 03 01 00	02	04	37 31 9A 28
Seq Tag	Length = 21 (# bytes in this Binding)	OID Tag	Length = 13	Identity = 1.3.6.1.4.1.1206.4.2.6.3.1.0 globalTime	Integer Tag	Length = 4	Value = 925997608

Figure 5.4 Set Time operation using STMP over UDP/IP/Ethernet

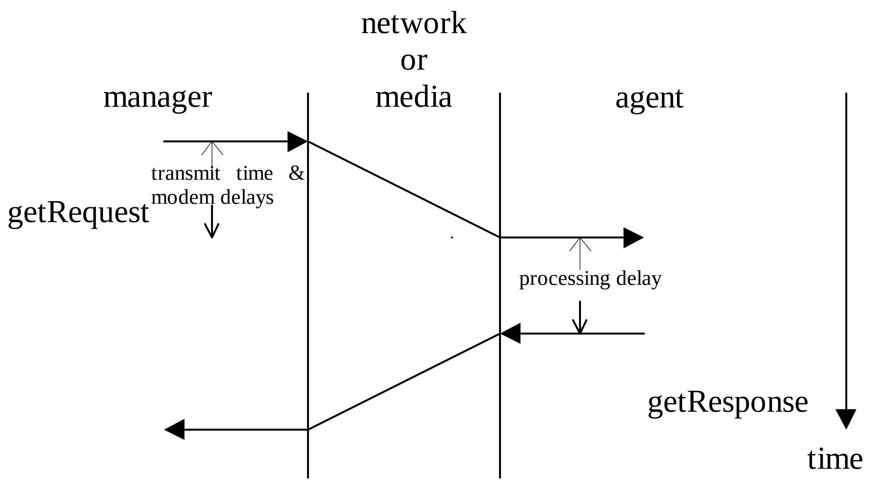


5.2.3.5 Estimate Timing Factors

In performing a bandwidth analysis, there are numerous timing factors that come into play. Processing delays, modem response, and duplexing mode may need to be considered. One can intuitively understand that the response to a command asking for 100 objects will take longer to process than one that only asks for 1 object. Once a message is received, the device will need to parse it in order to understand what is being asked for or what is being sent. Once it understands what, it must then either gather the data or store away each data. It is very important to understand that processing delays will vary according to message content and implementation.

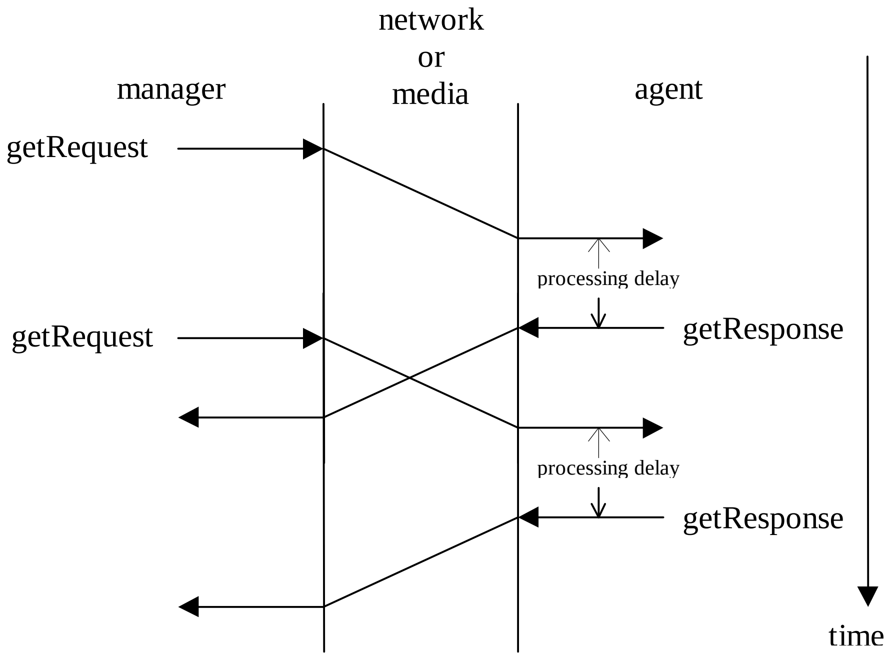
For the sake of this analysis, a processing delay value of 50ms is used. Figure 5.4 shows a graphical representation of the various timing factors to be considered.

Figure 5.4 Timing Factors



Modem detect and turnoff delays can be as high as 2 or 3 seconds. The typical 56Kbps modem that one might use to log into the Internet takes several seconds to "train" or adjust to the wireline characteristics. These may be suitable for point-to-point operation, but in a multi-drop environment, a "fast" turn-on / turn-off type modem is the only practical choice. For the sake of this analysis, it is assumed that a "fast" modem will be used and that the turn-on and turn-off delays are on the order of 10 milliseconds each.

Figure 5.6 Full Duplexing



The duplexing mode of operation can have a significant impact on timing. In full-duplex mode, commands and responses can overlap. A second command can be sent while the response to a previous one is being received. In half-duplex mode, a second command can not be sent until the response to the first is received. Full-duplexing can effectively cut the data rate requirements significantly. The following summarizes the delays that will be used in what follows.

Table 5.6 Delay Estimates

Delays	**Time**
Modem Carrier Turn-on	10 ms
Modem Carrier Turn-off	10 ms
Processing Delay	10 ms
Total	30 ms

5.2.3.6 Modems

Center-to-field communications have traditionally used 1200 bps FSK (Frequency Shift Keying) modems for wireline communications. These modems come in different versions for different applications, such as half or full duplex, leased telephone lines (Bell 3002 voice circuit) or agency-owned twisted pair cable, internal or external to the device, support RS 232 flow control or not, etc. In analyzing bandwidth requirements for copper communications plant and attempting to increase modem bit rate, it is important to remember that not all modems and bit rates may be practical for a given implementation environment. In particular, the following issues need to be considered:

- Consumer modems used for general purpose computer communications (e.g., V.90 56kbps) cannot be used in multi-drop field implementations because they are too slow to reach ready state prior to each transmission (they require "training" time).
- Consumer modems and modems designed for indoor use may not operate reliably in the temperature and humidity extremes encountered in field applications.
- The fastest modems currently available for agency-owned twisted pair multi-drop applications operate at up to 9600 bps.
- Currently, modems suitable for multi-drop operation over leased telephone lines (Bell 3002 analog voice circuits) cannot support 9600 bps unless "a metallic circuit" is provided.
- There is a limit to the distance that a modem can operate on agency-owned twisted pair cable. The maximum distance reduces as the bit rate increases and as the number of devices on the channel increases.
- There is no distance limit on leased telephone lines.
- Modems from different manufacturers can vary greatly in their features and operational characteristics. A thorough test of the actual modem planned for use (in a real-world long distance multi-drop environment) should be made before committing to its use.
- Most field devices do not yet have a 9600 bps internal modem option.
- Modems that are external to the field device (connected by a serial cable) require a dedicated suitable RS 232 port on the field device, in addition to any serial port(s) used for other purposes (e.g., laptop computer connection).
- Asynchronous modems add a start and at least one stop bit for every byte (8 bits) transmitted; synchronous modems do not. This equates to 25% additional overhead.

There are similar but different lists of constraints and considerations for modems or transceivers for other types of plant such as fiber and radio.

5.2.3.6.1 Electrical Limitations

The maximum number of modems on a wireline channel due to electrical limitations is an issue of modem sensitivity, the desired signal-to-noise ratio for a given bit-error-rate, and the characteristics of the wire and interface. The Communications Handbook for Traffic Control

Systems[1] provides an example of the characteristics and calculations for a 1200 bps FSK multi-drop system. The handbook goes into more detail than what is presented here and covers other technologies such as wireless and fiber optic.

Following the example in the handbook, the calculations for any modem technology that uses a wireline (twisted pair) medium would apply. The formula for determining maximum number of drops is:

Number of Drops = (Sensitivity - Cable Loss - S/N Ratio) / Insertion Loss per Drop

The following are hypothetical characteristics of a 9600 bps modem and wiring that is to be used in a multi-drop configuration.

Table 5.7 Modem Parameters

Parameter	Value
Modulation Technique	Some type of Phase and Amplitude Modulation
Operation Mode / Line	Full Duplex / 4 wire (metallic or user owned)
Modem Frequencies	Center Frequency ~ 9600 Hz
Receiver Sensitivity	0 dBM to -39 dBM
Signal-to-Noise Ratio	15 dB for a Bit-Error-Rate of 1 x 10^{-5}
Cable Loss	3.3 dB/mile at 9600 Hz for 19 AWG
Insertion Loss	.5 dB per drop
Distance	8 miles

The modulation technique used by a modem is not necessarily Frequency Shift Keying (FSK). Phase Shift Keying (PSK) and Quadrature Amplitude Modulation (QAM) are typically employed to increase throughput without necessarily increasing the signaling frequency. The operating mode of the 9600 bps modem is assumed to be full duplex using two wire pairs. This configuration minimizes distortion from line reflections and the turnaround times associated with switching from transmit to receive. The signaling frequencies are assumed to be 9600 Hz. The signaling frequencies will vary with modulation techniques but must be quantified because they will determine the cable losses. Receiver sensitivity is an indication of how well a modem is at picking up weak signals and signal-to-noise ratio is the ability of a modem to pick out a signal with back ground noise (static, etc.). Insertion loss comes from a manufacturer's data sheet. There is always some type of loss associated with the connection to the wire. Usually this is due to slight impedance mismatches and physically routing the signal through a connector to the modem electronics. For a given signaling frequency, the size of the interconnect wire will define

[1] Communication Handbook for Traffic Control Systems, Federal Highway Administration Report FHWA-SA-93-052, April 1993

how much signal is lost over some distance. The cable loss is derived from Figure 6-2 in the handbook. The distance from the primary to the farthest secondary is assumed to be 8 miles.

Using the formula given above, we can calculate that:

> Number of Drops = (Sensitivity - Cable Loss - S/N Ratio) / Insertion Loss per Drop
> Number of Drops = (39 dBM - (8 miles x 3.3 dB per mile) - 15 dB) / .5 dB
> Number of Drops = (39 dBM - 19.8 dB - 15 dB) / .5 dB
> Number of Drops = 8.2

Rounding down the value we find that the maximum number of drops for this example is 8, from a purely electrical point of view.

5.2.3.6.2 Communications Limitations

The above discussion shows how to calculate the electrical limitations using modem and wireline techniques. It does not address the logical aspects of organizing a system into communications channels, defining what information is sent on each channel, or ensuring each channel can carry the desired information. What follows are the procedures and calculations to define the number of channels and drops per channel based on the message exchange requirements.

What we defined so far is:

1. Size of the message exchanges and how often they will occur.

Table 5.8 Message Frequency and Size

Message Exchange	Frequency	SNMP Exchange (bytes)	STMP Exchange (bytes)
Date and Time	1 per day - all	98	2
Intersection Map Data	1 per second X 24 intersections	512	12
Pattern Command	1 per minute - all	190	4
Detector Data	1 per minute X 8 intersections	282	7
Detailed Status	1 per hour X 8 intersections	144	4
Upload Download	1 per day X 24 intersections	118 - 254	N/A
Tuning	2 per day X 24 intersections	282	N/A

2. Transport and Subnetwork Protocol Overhead.

Table 5.9 Protocol Overhead Estimates

Transport and Subnetwork Protocol	Exchange Overhead (bytes)
Null over PMPP	14
Null over PPP	14
UDP/IP over PMPP	70

3. Processing and Modem Delays.

Table 5.10 Delay Estimates

Delays	Time
Modem Carrier Turn-on	10 ms
Modem Carrier Turn-off	10 ms
Processing Delay	10 ms
Total	30 ms

The processing delay of traffic signal controllers is highly variable, with actual response times varying from 10 ms to 50 ms. Achieving response times at the lower end of this range, as shown in Table 5.10, may require the use of techniques such as asynchronous messaging whereby the response to a request is placed in a buffer for immediate transmission at the next poll.

5.2.3.7 SNMP Timing

At this point, we need to choose specific protocols to analyze and then normalize the data exchanges and delays to some common time interval. For SNMP over Null over PMPP we have:

Table 5.11 Normalized Data using SNMP over NULL over PMPP for 24 drops per channel

Message Exchange	Frequency	Message Exchange Size Bytes	Messages per day	Bytes per day
Date and Time	1 per day - all	112	24	2688
Intersection Map Data	1 per second X 24 intersections	526	2073600	1090713600
Pattern Command	1 per minute - all	204	1440	293760
Detector Data	1 per minute X 8 intersections	296	11520	3409920
Detailed Status	1 per hour X 8 intersections	158	192	30336
Upload Download	1 per day X 24 intersections	268	24	6432
Tuning	2 per day X 24 intersections	296	48	14208
Totals per day			2086848	1094470944

Normalizing the bytes per day to bits per second, we calculate the total system bandwidth required as:

1094470944 bytes per day x 10 bits per byte / 86400 seconds per day = 12667.49 bits in one second

The value 126675 is the average number of bits that are required to transmit all message exchanges to and from the 24 intersection controllers in one second.

Given a specific modem speed, we can calculate a first order approximation of the number of drops per channel and channels. For a 9600 bps modem, this is calculated as:

126670 bits overall / 9600 desired bits per channel = 13.19 channels

And

24 intersections / 13.19 channels = 1.82 drops per channel

Rounding both of these figures downward, the use of 9600 bps modems would only work if there was a single modem and drop dedicated to each intersection. There are some systems that use a dedicated modem and cabling arrangement. If this is feasible, a second order approximation should be performed. A second order approximation accounts for the changes in the number of drops and the need to send broadcast messages on each channel. The impact of any delays must also be considered. Since the steps are same for any protocol combination, only the reiterations for STMP over Null over PMPP using 1200 bps modems will be illustrated.

Clearly, SNMP is not a feasible protocol choice unless each signal has a dedicated channel. In practice, such signal systems will use STMP.

5.2.3.8 STMP Timing

The STMP and PMPP Protocols were designed to be open to address diverse communications need yet be very efficient to meet the limited bandwidth capability of current systems. A typical traffic control system of today that controls 24 intersections uses a proprietary communications scheme, is usually configured as 2 groups of 12 intersections or 3 groups of 8 intersections and uses internal 1200 bps FSK modems. Conversion of these systems to NTCIP may impact the existing configuration and require the use of higher speed modems. The following calculations for STMP over Null over PMPP should help understand what the potential impact may be.

For this NTCIP Stack, Table 5.12 summarizes the messages, frequency, and sizes of the message exchanges. As before, we begin by looking at the system as 24 intersections on a single drop and normalize the total exchanges to a per day basis.

**Table 5.12 Normalized Data
using STMP over NULL over PMPP
for 24 drops per channel**

Message Exchange	Frequency	Message Exchange Size Bytes	Messages per day	Bytes per day
Date and Time (set)	1 per day - all	16	1	16
Date and Time (get)	1 per day X 24intersections	17	24	408
Intersection Map Data	1 per second X 24 intersections	26	2073600	53913600
Pattern Command	1 per minute - all	18	1440	25920
Detector Data	1 per minute X 8 intersections	21	11520	241920
Detailed Status	1 per hour X 8 intersections	18	192	3456
Upload Download	1 per day X 24 intersections	N/A	N/A	N/A
Tuning	2 per day X 24 intersections	N/A	N/A	N/A
Totals per day			2086777	54185320

Normalizing the bytes per day to bits per second,

54185320 bytes per day x 10 bits per byte / 86400 seconds per day = 6271.45 bps

The value 6271.45 bps is the average data rate required to transmit all message exchanges to and from the 24 intersection controllers

For this protocol configuration, let's try a 1200 bps modem. As before, we can calculate a first order approximation of the number of drops per channel and channels by dividing the number of averaged data rate value by the modem speed. For a 1200 bps modem, this would work out to 4.59 drops per channel using 5.23 channels.

These seem to be a reasonable values, so we need to perform a second order approximation. For this iteration, a configuration of 6 channels of 4 drops per channels will be used. The frequency of some of the messages will be adjusted accordingly.

Table 5.13 Normalized Data using STMP over NULL over PMPP for 4 Drops per Channel

Message Exchange	Frequency	Message Exchange Size Bytes	Messages per day	Bytes per day
Date and Time	1 per day - all	16	1	16
Date and Time	1 per day - X 4 intersections	17	4	68
Intersection Map Data	1 per second X 4 intersections	26	345600	8985600
Pattern Command	1 per minute - all	18	1440	25920
Detector Data	1 per minute X 2 intersections	21	2880	60480
Detailed Status	1 per hour X 1 intersections	18	24	432
Upload Download	1 per day X 1intersections	N/A	N/A	N/A
Tuning	2 per day X 24 intersections	N/A	N/A	N/A
Totals per day			349949	9072516

Normalizing the bytes per day to bits per second,

9072516 bytes per day x 10 bits per byte / 86400 seconds per day = 1050.06 bps

The value 1050.06 bps is the average data rate required to transmit all message exchanges to and from the 4 intersection controllers

This appears to be a reasonable value but delays must be taken into account. Any delays will take away from the time that is available to be actually transmitting data. Total delay per second is calculated as:

349949 messages per day X .03 seconds delay per message / 86400 seconds per day = 0.122 sec.

The value 0.122 seconds is the average delay per second. We calculate the modem speed to transmit 1050 bits in the remaining time as:

1050 bits / (1 sec. - 0.122 delay time) = 1195.90 bps

Therefore, 4 drops per channel at 1200 bps is a suitable configuration. If more drops per channel are desired, the data rate can be increased to possibly 4800 or 9600 bits per second, by using faster modems.

5.2.4 Center-to-Field Bandwidth Alternate Analysis

In the previous scenario, the emphasis was on acquiring once-per-second data from all intersections. This may not necessarily apply to all situations. In applications other than traffic signal control this would certainly not be the case. The following scenario addresses the same requirements as before except for map display. In this case, the map display is only for one intersection at a time. In general, this scenario might apply to cases where there is a requirement for real-time (once-per-second) data from a single device but system data can be exchanged on a once-per-minute or longer basis. The communications requirements are summarized as:

1. Synchronize the time and date in all field devices.
2. Provide a map display of the status of **one** intersection.
3. Control the overall timing pattern to be put into effect.
4. Control the operation of 2 lane-closed signs.
5. Monitor all intersections for any abnormal conditions.
6. Accumulate volume and occupancy data for 16 detectors to perform off-line optimization.
7. Provide full upload and download of the complete database or programming data in each field device.
8. Support 24 intersections.

5.2.4.1 Estimate Message Exchanges and Frequency

In this scenario, all the previous messages will be used but a new one will be added. Since the map display information will only be gathered from one intersection, the status of the other intersections will be monitored by an "Intersection Status" set of objects.

To provide indications of what coordination timing pattern is in effect and any abnormal condition at an intersection, the following objects defined in TS 3.5 will be used:

systemPatternStatus - Section 2.5.10
shortAlarmStatus - Section 2.4.9

These are the same objects used in the map display. However, the intersection map display is intended to be gathered from only one intersection at a time. These objects would be used to monitor the other intersections in the system. For the purposes of monitoring, these would be read from each intersection approximately once-per-minute.

The following table summarizes the new set of messages and the how often they occur:

Table 5.14 Message Frequency
Alternate Scenario

Message Exchange	Frequency
Date and Time	1 per day - all
Intersection Map Data	1 per second X 1 intersections
Intersection Status	1 per second X 23 intersections
Pattern Command	1 per minute - all
Detector Data	1 per minute X 8 intersections
Detailed Status	1 per hour X 8 intersections
Upload Download	1 per day X 24 intersections
Tuning	2 per day X 24 intersections

5.2.4.1.1 SNMP Application Message Exchange Sizes

The following table summarizes the messages in the new scenario:

Table 5.15 SNMP Message Sizes
(Alternate Scenario)

SNMP Message Overhead	Objects	Command / Response Size	Exchange Size
Date and Time	1	49	98
Intersection Map Data	10	256	512
Intersection Status	2	72	144
Pattern Command	3	95	190
Detector Data	5	141	282
Detailed Status	2	72	144
Upload Download	1 + bytes	59 - 177	118 - 254
Tuning	5	141	282

The only addition is the intersection status message.

5.2.4.1.2 STMP Application Message Exchange Sizes

The following is an update to Table 5.4. The only difference is the addition of the Intersection Status exchange.

Table 5.16 Derivation of STMP Message Exchange Sizes
(Alternate Scenario)

Dynamic Message	Command	# of Objects	Size		
			Command	Response	Exchange
Date and Time	setRequestNoReply	1	2	-	2
Date and Time	getRequest	1	1	2	3
Intersection Map Data	getRequest	10	1	11	12
Intersection Status	getRequest	2	1	3	4
Pattern Command	setRequestNoReply	3	4	-	4
Detector Data	getRequest	9	1	10	10
Detailed Status	getRequest	2	1	3	3
Upload Download	N/A	-	-	-	-
Tuning	N/A	-	-	-	-

5.2.4.2 Other Estimates

In this example, the estimates for transport and subnetwork protocols remain the same. The timing factors and delays apply, as well.

5.2.4.3 Number and Size of Slots per Channel

The only new topic to be considered in the alternate example is the concept of communications slots. The number of communications slots per channel can best be thought of as the number of opportunities to communicate in any time period. It is not necessarily equal to the number of drops per channel. For example, assume that there are 8 drops per channel. If one needed to communicate with each drop once every minute, there could be 8 slots. The width of each slot in this case would be 7.5 second. An arrangement of 60 slots, each 1 second wide, would be just as suitable if all exchanges took less than 1 second. If this were the case, 52 slots would be available for other uses.

In the alternate example only one message exchange needs to take place on a once-per-second basis. All other exchanges take place on a once-per-minute, once-per-hour, or one-per-day basis. If the once-per-second exchange could be completed in less than one-half second, and all of the other exchanges could each be completed in less than one-half second, the concept sloting arrangement could be used. There could be two slots one-half second wide. The first slot would be reserved for the once per second exchange. The second slot would be used to perform all the other exchanges but on a rotating basis.

5.2.4.4 Communications Drops (Drops per Channel)

At this point we are ready to perform the timing analysis. As before, it necessary to pick a specific NTCIP Stack. In the following examples, the transport and subnetwork protocols are assumed to be Null and PMPP. The following table summarizes the frequency and all overhead associated with the message exchanges.

Table 5.17 Message Frequency and Size

Message Exchange	Frequency	SNMP Message Exchange Bytes	STMP Exchange Bytes
Date and Time	1 per day - all	112	15
Intersection Map Data	1 per second X 1 intersections	526	26
Intersection Status	1 per second X 23 intersections	158	17
Pattern Command	1 per minute - all	204	18
Detector Data	1 per minute X 8 intersections	296	21
Detailed Status	1 per hour X 8 intersections	158	18
Upload Download	1 per day X 24 intersections	268	N/A
Tuning	2 per day X 24 intersections	526	N/A

Since the "system requirements" require communications to 24 intersection controllers, the use of the PMPP and "fast" modems would allow multiple secondary devices to share a communication link. However, the characteristics of wire and the distances between intersections may place an upper limit on how many devices can share a communications link. For the sake of this analysis, the maximum number of drops is assumed to be 9. This would allow a management application and 8 intersections to share a channel. The network of 24 intersections is assumed to be organized into 3 drops of 8. The revised message frequency and size per channel would then be:

Table 5.18 Message Frequency and Size

Message Exchange	Frequency	SNMP Message Exchange Bytes	STMP Exchange Bytes
Date and Time	1 per day - all	112	15
Intersection Map Data	1 per second X 1 intersections	526	26
Intersection Status	1 per second X 7 intersections	158	17
Pattern Command	1 per minute - all	204	18
Detector Data	1 per minute X 2 intersections	296	21
Detailed Status	1 per hour X 1 intersections	158	18
Upload Download	1 per day X 8 intersections	268	N/A
Tuning	2 per day X 8 intersections	526	N/A

5.2.4.5 SNMP Timing

Next, we analyze the exchanges to gauge the impact of multiple secondary devices and the frequency of the exchanges. In this example the assumption is that the user wants to see the Intersection Map Data with some accuracy. Two back-to-back samples of the signal display would not be the same as two spaced exactly one second apart.

Considering this, the Intersection Map Data exchange should take place once every second on the second. Since all other exchanges take place on a minute, hour or day basis, the Intersection Map Data could be requested every second and all other exchanges requested on a rotating basis. To do this would require that the Intersection Map Data and the largest other exchange take place within one second. The largest exchange other than Intersection Map Data is the Tuning exchange. After summing up the size of the exchanges and processing delays, we can then compute the required data rate as:

Data Rate = bytes * 10 / (1 - delay)

[The numbers of bytes is multiplied by 10 because in asynchronous communications, a start and stop bit is added to each byte.]

The following table summarizes the overhead and delays associated with the Intersection Map Data and the Tuning message exchanges.

Table 5.19 SNMP Overhead and Delay Estimate Example

Slot	Exchange	Size (bytes)	Delays and Processing (ms)
1	Intersection Map Data	526	70
2	Tuning	526	70
Totals		1052	140

This results in a requirement to transmit 1052 bytes in one second with 140 ms of delays. The required data rate is computed as:

Data Rate = (1024 +28) *10 / (1 - .140) = 12232.558 bps

This number is too high for readily available "fast" multi-drop modems, so a new approach will be considered. Since the Tuning exchanges are meant to change the timing characteristics of the system and need to be performed manually, we can make the assumption that it does not have to run concurrently with the Intersection Map Data exchange. If we consider the next largest exchange, Detector Data, we come up with:

Table 5.20 SNMP Overhead and Delay Estimate Example (con't)

Slot	Exchange	Exchange Overhead (bytes)	Delays and Processing (ms)
1	Intersection Map Data	526	70
2	Detector Data	296	70
Totals		822	140

Data Rate = (794+28) *10 / (1 - .180) = 10024.39 bps

This value is still too high to consider 9600 bps modems. It is always a good engineering rule of thumb have some margin for error. To gain some margin one could consider the use of fiber optic modems. The carrier turn-on and turn-off delays could be significantly less than 20 ms. If an intersection did not have pedestrian movements, dropping them from the Intersection Map Data Exchange could reduce the data rate to 8341bps. Minimizing carrier turn-on and turn-off delays could be also be accomplished by use of a simple full-duplex operation. The primary's carrier is always on and any secondary turns on it carrier as soon as it recognizes that it needs to send a response. The following table summarizes the overhead and delays for a simple full-duplex operation arrangement.

Table 5.21 SNMP Overhead and Delay Estimate Example (con't)

Slot	Exchange	Exchange Overhead (bytes)	Delays and Processing (ms)
1	Intersection Map Data	526	60
2	Detector Data	296	60
Totals		822	120

Data Rate = 822 *10 / (1 - .120) = 9340.909 bps

Looking at the other exchanges, they could be mapped in to the second slot on a rotating basis as follows:

Table 5.22 SNMP Command and Response Mapping to Third Slot

Interval	Command and Response
1	Date and Time
2	Detector Data - Pair 1
3	Detector Data - Pair 2
4	Detector Data - Pair 3
5	Detector Data - Pair 4
6	Detector Data - Pair 5
7	Detector Data - Pair 6
8	Detector Data - Pair 7
9	Detector Data - Pair 8
10	Status - Intersection 1
11	Status - Intersection 2
12	Status - Intersection 3
13	Status - Intersection 4
14	Status - Intersection 5
15	Status - Intersection 6
16	Status - Intersection 7

Table 5.22 SNMP Command and Response Mapping to Third Slot

Interval	Command and Response
17	Status - Intersection 8
18	Pattern Command - Intersection 1
19	Pattern Command - Intersection 2
20	Pattern Command - Intersection 3
21	Pattern Command - Intersection 4
22	Pattern Command - Intersection 5
23	Pattern Command - Intersection 6
24	Pattern Command - Intersection 7
25	Pattern Command - Intersection 8
26	Spare
…	…
30	Spare

Assuming a total of 30 slots, each of these exchanges would have a resolution of once every 30 seconds. The only concern in this arrangement is that a new pattern command might not transmitted until 29 seconds after it was selected. Since there are spare time slots, one approach could be to send any new Pattern Command as it occurs. In this case, however, it would be sent to all intersections using a group address.

5.2.4.6 STMP Timing

The above example shows that while SNMP could be used for some real-time applications, it may require higher data rates than traditional 1200 bps, FSK modems support. For these applications, STMP is more suited. The following illustrates how to calculate the bandwidth requirements for an STMP over Null over PMPP stack.

In this example, the messages are defined as dynamic objects. The OIDs of the objects that comprise the messages are downloaded to Dynamic Objects 1 - 6 as follows:

Dynamic Object 1 = Time and Date
Dynamic Object 2 = Intersection Map Data
Dynamic Object 3 = Intersection Status
Dynamic Object 4 = Pattern Command
Dynamic Object 5 = Detector Data
Dynamic Object 6 = Detailed Status

Following the same strategy as in the alternate SNMP timing example, the Intersection Map Data and one of the other exchanges could be sent every second. Assuming Detector Data is the largest exchange to be handled in one second, we have:

Table 5.23 STMP Overhead and Delay Estimate Example

Slot	Exchange	Exchange Overhead (bytes)	Delays and Processing (ms)
1	Intersection Map Data	26	60
2	Detector Data	21	60
Totals		47	120

Data Rate = 47 *10 / (1 - .120) = 534.091 bps

Since this is well under the 1200 bps data rate that is typically available, we might want to consider sending a Pattern Command every second, as well. This would result in overhead and delays as follows.

Table 5.24 STMP Overhead and Delay Estimate Example (con't)

Slot	Exchange	Exchange Overhead (bytes)	Delays and Processing (ms)
1	Intersection Map Data	26	70
2	Pattern Command	18	20
3	Detector Data	21	70
Totals		65	160

Data Rate = 65 *10 / (1 - .160) = 773.81 bps

[Note that the Delay and Processing for a Pattern Command is only 20 ms. Since this is sent as a setRequestNoReply, there should not be any internal processing required.]

Since 774 bps provides plenty of margin, one could increase the amount of information being brought back in the Intersection Map Data. For example, if the intersection had a preemption sequence, the preemptState - Section 2.7.2.16 could be added. This object could be used to indicate the state or interval of a preemption sequence. Another object that could be added is phaseStatusGroupPhaseNexts - Section 2.2.4.11. This would indicate the next vehicle phase that is to be serviced at the end of any currently timing phase.

As in the SNMP example, the other exchanges could be mapped in to the third slot on a rotating basis as shown in Figure 5.22.

6 IMPLEMENTING NTCIP

6.1 Introduction

This chapter describes the various issues related to implementing the NTCIP in a device or central system. The primary audiences for this chapter are the system/device developers and system implementers. Readers should already be familiar with the concepts presented in Chapters 1-4 of this Guide, especially the concepts related to system design and specification as presented in Chapters 3 and 4.

This chapter contains the following sections:

- Implementation Roadmap
    - Initial Request
    - Investigate Issues
        - Device and/or System Requirements
            - How NTCIP Standards Fit Together
            - Selecting Standards for an Implementation
            - Selecting Manufacturer Extensions
        - Implementation Alternatives
        - Other Factors
            - Stability of the Standard
            - Support of Amendments
            - Interpretation Resolution
            - Client / Developer Understanding
            - Certification Process
            - Integration with Other Components
            - Performance Issues
            - Maintenance / Future Upgrades
    - Development
    - Delivery / Acceptance Testing
        - Unit Testing
        - Integration Testing
        - System Testing
    - Maintenance
- Example Implementation Process
- Example Byte Streams
    - The NTCIP Database
    - Encoding the NTCIP Database for Transmission
        - Encoding an Object with Its Value
        - Encoding the SNMP Data Packet
        - The Transport Profile
        - The Subnetwork Profile
- Defining New Objects
- Examples of Implementation Problems

    - Protocol Related Issues
        - Bit and Byte Order
        - Extended Addresses
        - Maximum Duration Between Successive Bytes
        - Response Time
        - Control Byte
        - Frame Handling
        - CRC Algorithm
        - Invalid Frame
        - STMP Message Type Byte
        - Length Values for Variable Message Fields
    - Systems Integration Issues
        - Carriers
        - Number of Devices on a Channel
        - MIB Issues
- Development Resources
    - Web Sites
    - Sources of Public Domain Software
        - NTCIP Exerciser
        - Field Device Simulator
    - Books
    - Other Resources

This chapter is intended to be germane to all of the NTCIP standards. As such, the concepts are presented at a high level. However, one detailed example is given at the end of the chapter in order to explain the concepts more fully.

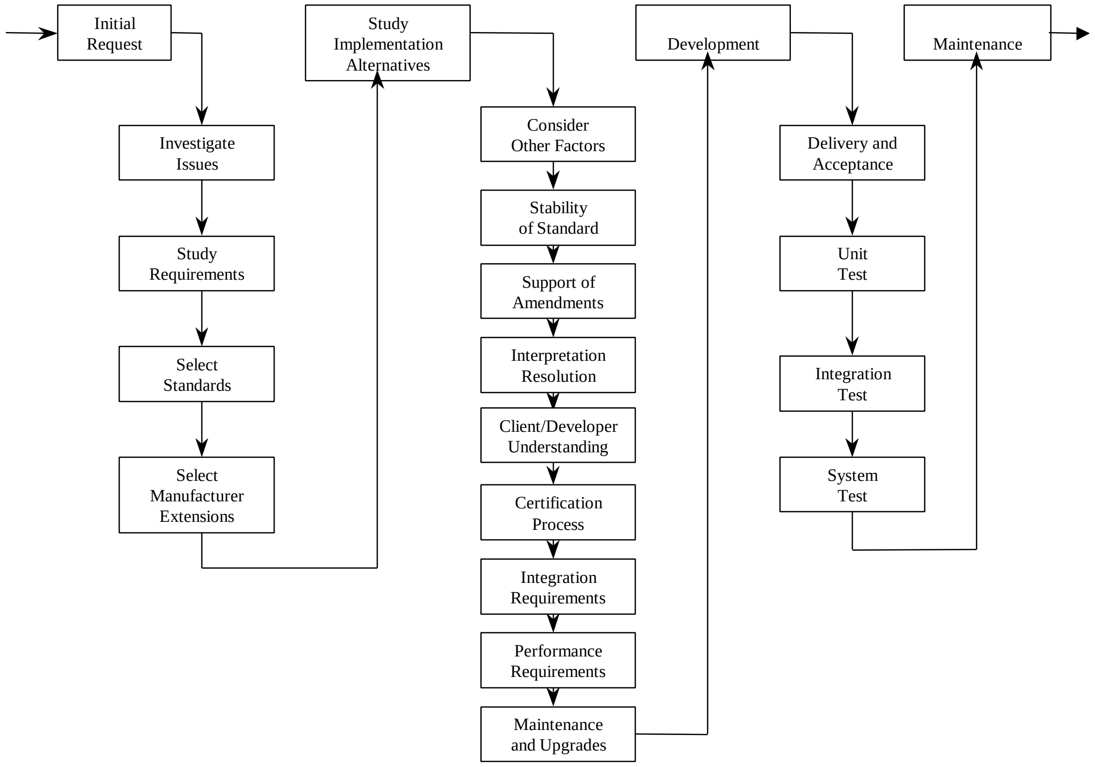
The reader is warned not to rely on this interpretation of the NTCIP for development purposes. A system or device developer will need to review the relevant NTCIP standards in order to implement them properly.

This document is updated from time to time to reflect changes in NTCIP. To check whether this is the current version of this document, access the NTCIP home page on the World Wide Web at *http://www.ntcip.org.*

6.2 Implementation Roadmap

There are certain steps that should be taken in any systems development project. It is especially critical to follow these steps when developing systems that are intended to meet standards. Figure 6.1 summarizes some of the more important steps that should be followed by any organization considering the development of NTCIP software.

Figure 6.1 Roadmap for Implementing NTCIP



6.2.1 Initial Request

Software projects are initiated by an individual or organization (client) requesting a certain product from a developer. The client and developer may be a part of the same organization or might represent two distinct organizations. For example, a manager may wish to develop an NTCIP device using internal resources in order to be the first NTCIP compliant device on the market. Alternatively, the request may come from an agency wishing to procure such a device, even though the device is not currently available on the market. In either case, it is wise to perform a full investigation of the issues surrounding the request prior to submitting the proposal.

6.2.2 Investigate Issues

The developer must ensure that there is an adequate understanding of the request. Some requests may be very ambiguous (i.e., "The device shall be NTCIP-compliant."), others may be very detailed and precise, and some may have precise statements that conflict with each other. Thus, the developer must first perform an investigation to ensure a proper understanding of the client's needs. This is then followed by an investigation of how the system may be implemented while recognizing the development risks that may be encountered.

It should be realized that this process works best in an iterative fashion. This allows the client and the developer to work together in developing a list of requirements and a proposal that best matches everyone's needs. However, this is not always possible due to the procurement regulations of some organizations.

6.2.2.1 Device and/or System Requirements

The first aspect of the investigation should be to determine the exact requirements for the system. This will often require expanding the original request. For example, if the request is simply for an "NTCIP compliant device", the developer must determine what functionality the device is supposed to support and then determine what NTCIP options might be appropriate.

The developer may also need to modify or limit the original request in order to meet safety, schedule, budget, market or other concerns. For example, the request may be for a signal controller and require "support for the full range of all objects." However, for safety and liability reasons, the developer may want to develop his software to limit the valid values for the yellow clearance interval to 3.0 to 5.0 seconds. It is important to identify any such variances from the request as early as possible so that the expectations for the resulting product are properly managed.

The result of this effort should be a detailed requirements document with which both the client and developer can be satisfied. Additional details of this investigation are given below. As a minimum, the document should address those issues identified in Chapter 4 of this Guide.

6.2.2.1.1 How NTCIP Standards Fit Together

Ideally, there would only be one NTCIP standard that met everyone's needs. However, reality requires a large number of options to meet the unique needs of specific sites. For example, some agencies have a large amount of twisted pair copper that they want to continue to use. Other agencies are installing new systems and want to take advantage of fiber optic cable and other technologies. Likewise, some agencies have fairly simple data exchange needs with field devices, whereas other centers need to exchange large amounts of information with other centers. The NTCIP accommodates these various needs by providing a suite of standards, each providing unique features.

NTCIP standards are based on a layered approach that is similar to those used by the International Organization for Standardization (ISO) and the Internet community. There are four primary levels of the NTCIP stack:

- Information – Information Profiles define the meaning of data and messages and generally deal with ITS information (rather than information about the communications network). This is similar to defining a dictionary and phrase list within a language. These standards are above the traditional ISO seven layer stack.

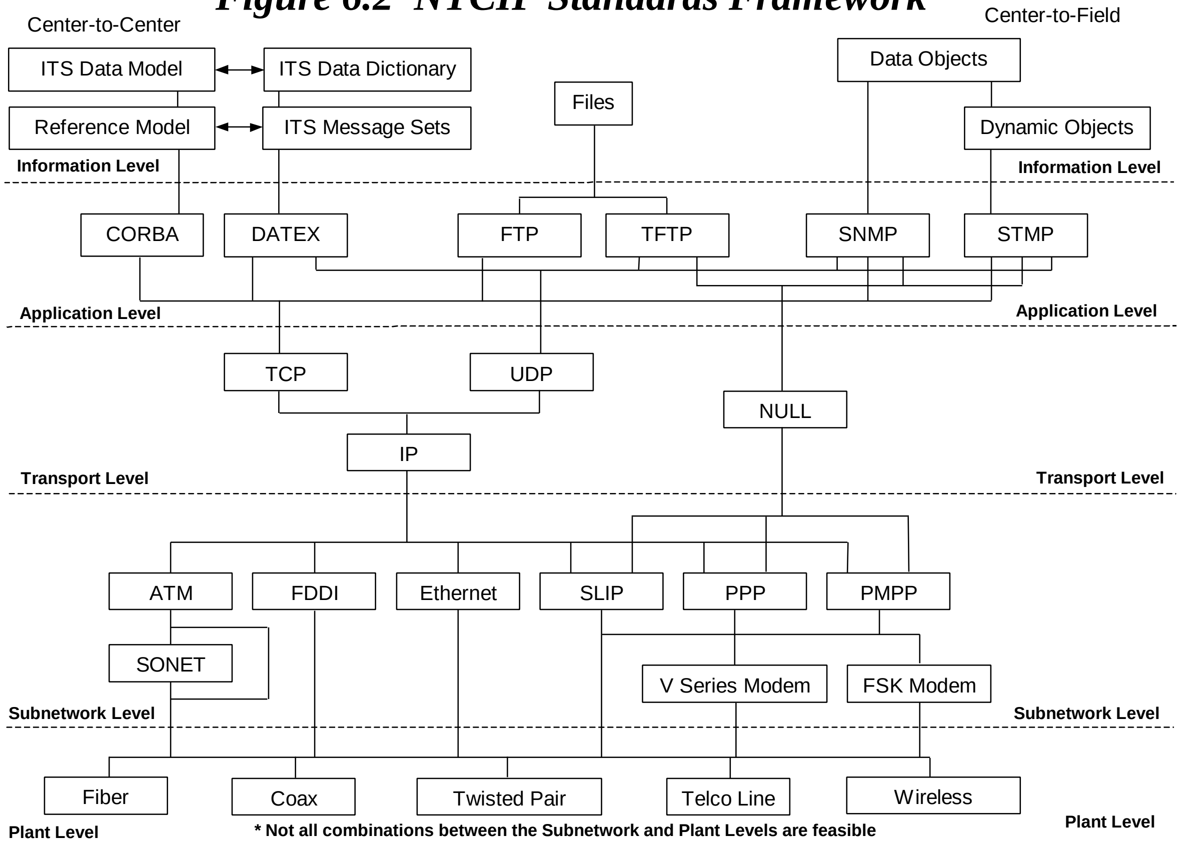
- Application – Application Profiles define the rules and procedures for exchanging information data. The rules may include definitions of proper grammar and syntax of a single statement as well as the sequence of allowed statements. This is similar to combining words and phrases to form a sentence or a complete thought and defining the rules for greeting each other and exchanging information. These standards are equivalent to the Session, Presentation and Application Layers of the ISO seven layer stack.

- Transport – Transport Profiles define the rules and procedures for exchanging the Application data between point 'A' and point 'X' on a network. This includes any necessary routing, message disassembly/re-assembly and network management functions. This is similar to the rules and procedures used by the telephone company to connect two remotely located phones.

- Subnetwork – Subnetwork Profiles define the rules and procedures for exchanging data between two 'adjacent' devices over some communications media. This is equivalent to the rules used by the telephone company to exchange data over a cellular link versus the rules used to exchange data over a twisted pair copper wire.

Any data exchange requires the use of one standard taken from each of the four levels. In theory, a profile from one level should be designed such that it can be combined with any profile from another level; however, in practice, profiles will often require certain services from other levels. Thus, only certain combinations are desirable and recognized by the NTCIP effort. These combinations are depicted in Figure 6.2.

Figure 6.2 NTCIP Standards Framework



6.2.2.1.2 Selecting Standards for an Implementation

The client may inform the developer which standards to use in the request; however, even in this case, the developer must be familiar with the standards enough to ensure that the request is consistent with the intended purpose of the standard. For example, the CORBA standard is not intended for field device communications using the "object definition standards." If a developer receives such a request, he should contact the client to ensure that there is an appropriate understanding of what is required.

During this phase of the investigation, the developer should also consider the general market applicability of the selected standards. For example, if the developer believes that the marketplace will seldom request the selected combination, the bulk of the implementation costs will have to be borne by the one client. Thus, it may be appropriate to suggest a more common combination of standards in order to spread the development costs over multiple clients.

6.2.2.1.3 Selecting Manufacturer Extensions

Finally, the developer must determine whether or not the standard supports all of the features supported by the manufacturer's device. The NTCIP has been explicitly designed to allow for innovations and it is recognized that the NTCIP standards do not currently define standardized objects for every feature of every device. Thus, the developer must determine if there are special features of the subject device that are not standardized by the NTCIP. If such features are present, then the developer will need to determine precisely how these features will be supported without conflicting with the standardized implementations. Usually, this is simply defining additional objects under a developer specific node. Once defined, the developer may want to publish these objects to the transportation community in order to promote this design as the defacto standard for the given feature.

6.2.2.2 Implementation Alternatives

Once there is a clear understanding of the project requirements, the developer can investigate ways to implement the desired features. For example, the developer may be able to acquire off-the-shelf software to minimize the effort required to implement the features. A layered design will minimize the effort required to maintain the code and to implement different profiles in the future. However, these benefits may impose other constraints on the system.

The NTCIP has used widely recognized standards whenever possible. For example, the NTCIP standards reference the Transmission Control Protocol (TCP), Internet Protocol (IP), Simple Network Management Protocol (SNMP), Common Object Request Broker Architecture (CORBA), and High Level Data Link Control Protocol (HDLC) standards to name just a few.

In many cases, the private industry has developed off-the-shelf tools to aid system developers in implementing these protocols. Being aware of what products are available and for what costs will allow the developer to provide a more realistic estimate of development costs. For example, most developers use an off-the-shelf implementation of TCP/IP rather than creating their own. Standards for which there are known products include:

- File Transfer Protocol (FTP)
- Trivial File Transfer Protocol (TFTP)
- SNMP
- CORBA
- Data Exchange in ASN.1 (DATEX-ASN)
- TCP/IP and UDP/IP
- Point-to-Point Protocol (PPP)
- Ethernet

While off-the-shelf software can save a considerable amount of development time and greatly simplify maintenance of the software; it may not always provide the most efficient implementation. Off-the-shelf software has generally been designed in a very layered fashion for easy maintenance and fully generic use; however, real-time system performance can frequently be improved by violating the rules of a true layered design and by embedding customized code for a specific purpose. The system developer should consider the benefits and detriments of each approach before determining the development approach and cost estimate.

It should also be recognized that the availability of off-the-shelf tools may affect the selection of features to be included in the requirements document.

6.2.2.3 Other Factors

There may be a variety of other factors that may need to be considered in order to finalize a proposal. Each of these issues may impact the proposed budget, schedule, and/or scope. Therefore, they should be explicitly addressed in the proposal in order to manage expectations. Without the management of expectations early in the process, a product, which the developer believes is compliant, may be perceived to be lacking by the client. A sample of these issues is provided in the following subclauses.

6.2.2.3.1 Stability of the Standard

The NTCIP standards are still relatively new and all standards are subject to amendments. Amendments typically result from developers attempting to implement the subject standard and recognizing either a technical problem with the specification or ambiguous wording. Thus, new standards are frequently amended to solve these problems and the standards become more and more stable over time. Thus, from a developers perspective, there is greater risk in implementing new standards; however, typically the first manufacturers to implement are the manufacturers who establish the greatest market share. Thus, these trade-offs must be considered in any implementation.

6.2.2.3.2 Support of Amendments

Because the standards are relatively new, the developer must consider what will happen if an amendment to the standard is approved during the development period of the product. As a general rule, it may be difficult to support amendments that are made after the product design is finalized and coding has begun. However, many times, a draft amendment may be present during design and the issues identified in the draft can be incorporated. In any case, the proposal should explicitly state whether or not amendments will be included for the proposed price and whether or not there is a cut-off date for such amendments.

6.2.2.3.3 Interpretation Resolution

If a developer is implementing a relatively new standard, he should ensure that there is a clear understanding of how interpretation problems will be addressed. For example, one could propose that any interpretation compliant with the wording is valid for acceptance. This would minimize the risk undertaken by the developer, but may not result in a product that is interoperable with other "standard" devices. Another approach would be to have the respective NTCIP Working Group provide an interpretation of the standard; this would increase the risk assumed by the developer but would also increase the probability for interoperability.

6.2.2.3.4 Client/Developer Understanding

Another factor to consider is whether or not the client has realistic expectations. While the NTCIP provides a standardized interface that is flexible enough to meet various needs, it may be more bandwidth intensive than what the client's previous systems and/or it may use a slightly different database design. It is important to make sure that the client has realistic expectations at the start of the project in order to ensure that the project will be perceived as a success. A thorough understanding of the expectations on the part of both the client and developer is important to the success of any project.

6.2.2.3.5 Certification Process

The developer must also consider the certification process for the product. While a rigid certification process will undoubtedly provide a greater assurance to the client, it will also increase costs. These costs are especially important to consider if the developer is responsible for any testing costs (e.g., through hiring an independent lab).

6.2.2.3.6 Integration with other components

The developer may also be required to ensure that his device works with other components within a larger system. Such integration may reveal problems that do not appear during product certification and thus may also affect the project costs.

6.2.2.3.7 Performance Issues

The developer should also realize that the flexibility of NTCIP also comes at the price of a more complex system than the industry has traditionally used. Therefore, the system may require more sophisticated processors or better communication facilities than traditional systems in order to achieve the same performance level (e.g., response times, etc.). If the developer overlooks these issues at the design time, there could be significant costs imposed at the end of the project in order to provide the necessary performance. The client should also be informed of performance tradeoffs.

6.2.2.3.8 Maintenance / Future Upgrades

A final issue to consider is whether or not the client desires extended maintenance or future upgrades. Such services may be very appropriate given that the standards may change based on other deployment projects; but clearly such a service will increase the costs associated with the project.

6.2.3 Development

If the proposal is accepted, the development phase will begin. This will include finalizing the development approach, building the prototypes and internally testing the units.

6.2.4 Delivery / Acceptance Testing

Once the developer is satisfied with the quality of his implementation, it is ready for delivery to the client. At this point, the client will perform an acceptance test. The type of acceptance test should be specified in the proposal process as this may affect the cost of the delivered product. It should be realized that the NTCIP is a very complex set of standards and it is impractical to perform comprehensive testing. However, well designed test plans can be produced to provide a high level of confidence for a reasonable cost.

In general, there are three levels of testing: unit testing, integration testing, and system testing.

6.2.4.1 Unit Testing

Unit testing focuses on comparing an implementation against the standard. This may be performed by inspecting the code or with the use of "proven" software to send test messages to the device. This process should be formalized by documenting a specific test procedure that will be followed and during the test, the result of each step of the procedure should be recorded.

Unit testing provides a basic level of assurance that a product is compliant to a standard. Many times, the test plan will be designed such that the failure of one procedure will provide a clear indication of what problem resides within the implementation; thereby minimizing the cost of finding the 'bug'. A device that fails such a test plan would almost certainly not be able to interoperate with other systems. A device that passes such a test has a reasonable probability of interoperating.

6.2.4.2 Integration Testing

Integration testing consists of connecting two or more devices together and having them exchange data. Assuming the individual devices have previously passed a sufficiently designed unit test plan and the two devices support the same features, the devices should integrate together fairly easily. However, there are a few problems that may arise during this phase. Examples include two different interpretations of a specific requirement (typically a problem of newer standards) and problems related to system timing between the two implementations.

In theory, the unit test should be thorough enough to prevent any problems in integration testing; however, the integration testing provides a higher level of confidence that nothing has been overlooked.

6.2.4.3 System Testing

A final level of testing is system testing. At this level, each device on the system is integrated together to form the final system. This level of testing could identify problems such as modem carriers being left on (i.e., preventing other devices from talking) or system timing issues (e.g., too many signals on a channel to maintain a desired once-per-second poll rate).

Once again, in theory, devices that successfully pass unit testing and integration testing should pass this level as well as long as the system was properly designed. However, the final check is only provided when this test is performed and it is not infrequent that problems arise at this stage.

6.2.5 Maintenance

The developer should also be aware of any requirements for maintenance and upgrades as these will affect the overall costs of the project. In general, it should be recognized that the NTCIP standards are still relatively new and thus changes may occur to the standards. Further, as there are relatively few implementations available, ambiguities may still be discovered in the standard and the standards may be modified in order to correct these problems. Any such change may require a modification to deployed equipment if the equipment is to maintain compatibility with the new version of the standard.

6.3 Example Implementation Process

This section provides an example of the various decisions that must be made during an implementation project. In the following example represents a procedure that a manufacturer or developer might use to develop an NTCIP compliant device. In this case, the device is a dynamic message sign.

6.3.1 The Request

For the purposes of this example, we will assume that the client has issued an Invitation For Bid for a dynamic message sign and controller (DMS) containing the following statements:

A. The DMS shall be a full matrix capable of displaying three lines of text with 20 characters per line when 18 inch characters are utilized. Full matrix display shall be capable of displaying other size characters and other number of lines depending on the height of characters utilized. The sign shall be designed to provide 2 pixels of spacing between lines of text when displaying the characters and lines of text as indicated herein.

B. The DMS shall be provided with a temperature sensor to monitor the interior temperature of the sign.

C. The DMS shall be capable of the following types of displays.
   1. Signs shall be able to display each line as either static or flashing, as described below.
      a) **Static Message** - The line shall be displayed constantly on the sign face until the sign controller is instructed to do otherwise.
      b) **Flashing Message** - A selected line shall be displayed and blanked alternately at durations separately controllable in 0.5-second increments.
   2. The DMS shall be capable of displaying up to three different pages (each page consisting of up to three lines of text) alternately at duration's separately controllable in 0.5-second increments.
   3. The sign shall be able to display text as centered, right justified, or left justified
   4. The sign shall be able to display a message in a specific font (e.g., single-stroke or double stroke).
   5. In the event of communication errors or controller lock-ups, the sign shall retain the current message. In the event of a power failure, sign shall display the current message upon restoration of power.

D. The DMS shall display a message composed of any combination of the following characters and shapes:
   1. "A" thru "Z"- All upper case letters.
   2. "0" thru "9"- All decimal digits.
   3. A blank or space.
   4. Punctuation marks shown in brackets [. , ! ? - : ; " ' / ( )]
   5. Special characters shown in brackets [# & * + < >]
   6. graphic displays

E. All communications between the DMS and central computer shall be NTCIP compliant in one of the following modes, which shall be user selectable:
   1. Polled Operation in which the sign controller informs the central computer of its current status in response to a query from the central computer; or;
   2. Event-Driven Operation in which the sign controller not only responds to queries from the central computer but also calls the central computer by telephone whenever it detects: restoration of AC power at the sign controller and/or internal DMS temperature exceeds programmed safety limit. If the line is busy, it shall retry the call at an interval that can be selected by the operator until it connects with the central computer.

F. The DMS shall contain a computer-readable time-of-year clock with a lithium battery backup. Battery shall keep the clock operating properly for at least 10 years without external power. Clock shall automatically adjust for daylight saving time and leap year through hardware or software or a combination of both. It shall be set by the sign controller's microprocessor. Clock shall be accurate to within 1 minute per month.

G. The DMS shall be provided with an eight character (minimum) password, for access to sign controller.

H. In the absence of instructions to the contrary from the remote control port, the DMS shall implement a display selected from those stored in its memory based upon date and time as specified in the schedule.

I. The DMS shall incorporate fail-safe procedures to check messages received and shall not change a message stored in memory, the display currently on the sign, the schedule stored in memory, or the current time unless the message is received correctly.

J. The DMS shall associate a priority level with each message. If the priority status is higher than the status of the message that it is to replace, the new message shall be posted.

K. The DMS shall include a system which shall sense the background ambient light level and provide a minimum of sixteen field adjustable intensities (dimming).

L. An 8 byte ID code shall be assignable to each DMS.

6.3.2 The Investigation

While the above request provides a fair amount of detail as to the required functionality of the sign, the information is not presented in a format that directly relates to NTCIP requirements and there are several issues on which the request is silent. The first task of the investigation is to determine exactly what the requirements are and to then investigate the other related issues. The discussion presented here only focuses on the NTCIP issues; however, a real investigation would clearly have to investigate hardware issues as well.

6.3.2.1 Requirements

The first task is to provide an interpretation of each requirement of the request. In this case, there is a fair description of the desired functionality, thus, this task is a matter of mapping the functions to specific NTCIP features. In other cases, the developer may have to work more closely with the client to develop the functional requirements. Once the initial interpretation is performed, the developer may have a list of questions for the client.

6.3.2.1.1 Interpretation

The list below interprets the above requirements into specific NTCIP requirements. Normal text indicates the original statement. Text in italics indicates the NTCIP interpretation. Text in bold indicates significant statements that may impact costs and/or may impact the user's expectations.

A. The DMS shall be a full matrix capable of displaying three lines of text with 20 characters per line when 18 inch characters are utilized. Full matrix display shall be capable of displaying other size characters and other number of lines depending on the height of characters utilized. The sign shall be designed to provide 2 pixels of spacing between lines of text when displaying the characters and lines of text as indicated herein. *The DMS shall be a full matrix display consisting of 120 pixels wide by 27 pixels high. Pixels shall be evenly spaced both vertically and horizontally. A 5 x 7 pixel matrix shall form a standard fixed width 18" high character.* ***The DMS shall support five fonts, as defined by the NTCIP font table.***

B. The DMS shall be provided with a temperature sensor to monitor the interior temperature of the sign. *The Temperature Status Conformance Group shall be supported.* ***This also requires two additional sensors: one to monitor the ambient temperature and the other to monitor controller cabinet temperature.***

C. The DMS shall be capable of the following types of displays.
   1. Signs shall be able to display each line as either static or flashing, as described below. *This shall be achieved through the use of the* 'fl' *MULTI Tag.*
      a) **Static Message** - The line shall be displayed constantly on the sign face until the sign controller is instructed to do otherwise.
      b) **Flashing Message** - A selected line shall be displayed and blanked alternately at durations separately controllable in 0.5-second increments.
   2. The DMS shall be capable of displaying up to three different pages (each page consisting of up to three lines of text) alternately at duration's separately controllable in 0.5-second increments. *This shall be achieved through the use of the* 'np' *and* 'p' *MULTI Tags.*
   3. The sign shall be able to display text as centered, right justified, or left justified. *This shall be achieved through the use of the* 'jl' *MULTI Tag.*
   4. The sign shall be able to display a message in a specific font (e.g., single-stroke or double stroke). *This shall be achieved through the use of the* 'fo' *MULTI Tag.*
   5. In the event of communication errors or controller lock-ups, the sign shall retain the current message. In the event of a power failure, sign shall display the current message upon restoration of power. *This shall be achieved by storing the currentBuffer row of the message table in non-volatile memory and configuring the appropriate Default Message objects to point to the currentBuffer.* ***This is one interpretation of the standards****.*

D. The DMS shall display a message composed of any combination of the following characters and shapes: *These shall be stored in the default fonts as their respective ASCII character codes. Other character codes can be used for graphics. There will also be one font reserved for graphics* ***(true graphics are not currently standardized by NTCIP).*** *Alternatively, a manufacturer specific graphic capability can be provided.*
   1. "A" thru "Z"- All upper case letters.
   2. "0" thru "9"- All decimal digits.
   3. A blank or space.
   4. Punctuation marks shown in brackets [. , ! ? - : ; " ' / ( )]
   5. Special characters shown in brackets [# & * + < >]
   6. graphic displays

E. The DMS shall permit the communication with an NTCIP compliant central computer in either of the following modes which shall be user selectable: ***The DMS shall provide <u>minimal</u> support for the PPP Subnetwork Profile (i.e., Dial-up Modem, RS-232, PPP), the Internet Transport Profile (i.e., UDP/IP), the STMF Application Profile (i.e., SNMP), and the DMS Information Profile (as defined in Sections 4 and 5 of TS 3.6). The temperature***

safety limit shall be a manufacturer specific object and the notification shall be achieved through a manufacturer specific trap.

1. Polled Operation in which the sign controller informs the central computer of its current status in response to a query from the central computer; or;
2. Event-Driven Operation in which the sign controller not only responds to queries from the central computer but also calls the central computer by telephone whenever it detects: restoration of AC power at the sign controller and/or internal DMS temperature exceeds programmed safety limit. If the line is busy, it shall retry the call at an interval which can be selected by the operator until it connects with the central computer.

F. The DMS shall contain a computer-readable time-of-year clock with a lithium battery backup. Battery shall keep the clock operating properly for at least 10 years without external power. Clock shall automatically adjust for daylight saving time and leap year through hardware or software or a combination of both. It shall be set by the sign controller's microprocessor. Clock shall be accurate to within 1 minute per month. *The sign shall support the globalTime, globalTimeDifferential, and globalDaylightSavings parameters.*

G. The DMS shall be provided with an eight character (minimum) password, for access to sign controller. *The DMS shall support the security (community name) objects defined in the amendment to TS 3.4. This password will also be required when accessing the controller locally.*

H. In the absence of instructions to the contrary from the remote control port, the DMS shall implement a display selected from those stored in its memory based upon date and time as specified in the schedule. *The DMS shall support the Timebase Event Schedule conformance group from TS 3.4 and the Scheduling conformance group from TS 3.6.*

I. The DMS shall incorporate fail-safe procedures to check messages received and shall not change a message stored in memory, the display currently on the sign, the schedule stored in memory, or the current time unless the message is received correctly. *The DMS shall provide this feature by using the CRC-16 algorithm of PPP.*

J. The DMS shall associate a priority level with each message. If the priority status is higher than the status of the message that it is to replace, the new message shall be posted. *The DMS shall use the run-time and activation priorities as identified in TS 3.6.*

K. The DMS shall include a system which shall sense the background ambient light level and provide a minimum of sixteen field adjustable intensities (dimming). *The DMS shall support the Illumination and Brightness control conformance group.*

L. An 8 byte ID code shall be assignable to each DMS. *Each DMS will be associated with an IPv6 address in addition to the IPv4 address and physical addresses that it will support.*

6.3.2.1.2 Questions Arising from Requirements Review

During the above analysis, there were three significant issues that should ideally be clarified prior to providing a bid estimate. However, in some cases it may not be possible to ask such questions. In these cases, the developer may wish to prepare a bid that documents other options.

The three questions that arose from this analysis are:

- How many fonts must the sign support?
- Should graphics be handled as a font or as a manufacturer specific feature?
- Is support for subnetworks other than PPP required?

A second iteration through this process would include questions arising from the text below, namely:

- How will the sign be tested to ensure compliance?
- Who is going to supply the central software?
- Are there any other devices in the system?
- What are the performance requirements of the system?
- Is the developer expected to provide maintenance of the software and/or upgrade the software if the standards change? If so, until what date?
- How many messages must the sign support and of what type?

6.3.2.2 Implementation Alternatives

Once the initial requirements are known, the developer can determine the best approach to developing the system; this in turn will allow the developer to start estimating the costs associated with the project.

Products are readily available from multiple vendors for a standard implementation of SNMP, UDP/IP, and PPP; thus, in this case, the developer would likely choose to use a great deal of off-the-shelf software. This would allow the developer to focus on the actual functionality of the objects rather than spending a large amount of time on the protocols.

6.3.2.3 Other Factors

As mentioned above, there are a variety of other factors to consider as well. The following text describes how these factors might affect the example project.

6.3.2.3.1 Stability of the Standard

In this case, the developer will have to implement the following standards:

- PPP Subnetwork Profile, which includes
  - AT Command Set
  - RS 232
  - PPP
  - LCP
  - CHAP

- Internet Transport Profile, which includes
  - UDP
  - IP
- STMF Application Profile, which includes
  - SNMP
  - BER
- Global Object Definitions
- Object Definitions for Dynamic Message Signs

These standards are somewhat stable, but could change to some degree. The standards referenced by these standards (i.e., the protocols) are widely deployed and are very stable.

6.3.2.3.2 Support of Amendments

Given this design, the developer would probably want to state that the project will use off-the-shelf software for the protocols and will be compliant with the current version of the Profiles. Given the stability of these base standards, this design should be fully compatible with the final version of the Profile documents. If, however, amendments are made to the profiles that are not compatible to the traditional use of the base standards, additional costs may be incurred.

The developer would need to develop the software for the objects internally. As such, the developer would probably indicate that he will support all defined features and all approved amendments up to a certain date (perhaps six months after award). If an amendment is approved after this date, additional costs may be incurred.

6.3.2.3.3 Interpretation Resolution

In this case, the developer would probably want protocol issues to be resolved by the Internet community and object definitions to be resolved by the NTCIP community. Thus, the proposal should include a statement indicating that the relevant working group shall be contacted to provide any necessary clarification of the standard. If the resolution is simply a clarification and does not require a normative change to the standard, the decision of the working group shall be implemented. If the decision results in an effort to amend the standard and the amendment is not approved by the indicated date, the client and developer will negotiate what the appropriate solution might be and how that solution might impact the schedule and budget of the project.

6.3.2.3.4 Client / Developer Understanding

Given the initial set of requirements provided by the client, it is likely that the client is only aware of the NTCIP and is unfamiliar with the details. Thus, the developer should budget resources during the project to ensure that he is able to properly manage expectations. This may include a meeting during the initial stages of the project to clearly present the features of the end product and how this may be different than what the client expects.

6.3.2.3.5 Certification Process

The initial requirements did not indicate any certification process. However, it is likely in the developer's best interest to indicate what sort of compliance testing would be appropriate. In the case of this project, the proposal might suggest that the developer also prepare a test plan, to be approved by the client, and the test will be performed in front of the client.

6.3.2.3.6 Integration with Other Components

The initial requirements did not indicate whether this sign would be integrated with other components, but one would assume that a management station would be used. Thus, the developer may wish to suggest that the procurement will include a central system to control the sign.

6.3.2.3.7 Performance Issues

The original specification did not include any requirement for performance. The developer may want to provide a statement in the proposal that the sign will produce a response to a get global time request within one second and a set activate message request within two seconds (measured from last byte in to first byte out). However, ideally, the client should specify the performance requirements [this can be an important issue for traffic signal systems].

6.3.2.3.8 Maintenance / Upgrades

The initial requirements are silent as to maintenance and upgrades. The developer may decide to minimize risks and not include any such features in the proposal, or the developer may decide that the product will have to be maintained for other clients anyway and thus include the estimate in the proposal. In the latter case, the developer would likely want to encourage the client to include maintenance and upgrades in the requirements for the bid by asking a question to that effect.

6.3.3 Proposal

Once all of these issues are resolved, the developer is able to prepare a proposal. For this example, the following text may be included in the proposal.

> **Display Requirements**
>
> The DMS display shall be full matrix and contain 120 pixels wide by 27 pixels high. The pixels shall be evenly spaced both horizontally and vertically.

The display will be configurable to support different size fonts and the number of lines supported shall be determined based on the selected font. When displaying a 5x7 font, a character shall be 18" high and the sign will display 3 lines, each separated by two pixels, with 20 characters per line, each separated by one pixel.

The sign shall be equipped with three temperature sensors: one for the interior of the sign, one for the interior of the cabinet, and one for the ambient air temperature.

An internal clock shall be provided to support the globalTime object. It shall have a lithium battery backup, which will last a minimum of ten years. The controller shall adjust for daylight savings (according to the NTCIP mechanisms) and leap years. The clock shall be accurate to within one minute per month.

The sign shall include a system of light sensors and adjust the illumination/brightness according to the mechanisms defined in TS 3.6.

NTCIP Functional Requirements

The DMS shall support the following NTCIP conformance groups.

- Configuration, as defined in NEMA TS 3.4-1996 and Amendment 1
- Time Management, as defined in NEMA TS 3.4-1996 and Amendment 1
- Timebase Event Schedule, as defined in NEMA TS 3.4-1996 and Amendment 1
- Security, as defined in NEMA TS 3.4 Amendment 1
- Sign Configuration, as defined in NEMA TS 3.6-1997
- Font Configuration, as defined in NEMA TS 3.6-1997
- Message Table, as defined in NEMA TS 3.6-1997
- Sign Control, as defined in NEMA TS 3.6-1997
- Default Message Control, as defined in NEMA TS 3.6-1997
- MULTI Error Control, as defined in NEMA TS 3.6-1997
- Illumination/Brightness Control, as defined in NEMA TS 3.6-1997
- Scheduling, as defined in NEMA TS 3.6-1997
- Status Error, as defined in NEMA TS 3.6-1997
- Temperature Status, as defined in NEMA TS 3.6-1997

In addition, the sign will support the following objects, as defined in NEMA TS 3.6-1997:

- defaultFlashOn
- defaultFlashOff
- defaultFont
- defaultJustificationLine
- defaultPageOnTime
- defaultPageOffTime

The full range of each object shall be supported, except as noted in the table below.

Table 6.2 Range Values Supported

Object	Values Supported
TS 3.4-1996	
Max Time Base Schedule Entries	7
Max Day Plans	7
Max Day Plan Events	7
TS 3.6-1997	
Number Fonts	5
Max Font Characters	127
Default Background Color	0
Default Foreground Color	9
Default Justification Line	2, 3, 4
DMS Num. Permanent Msg	0
DMS Max. Changeable Msg	21
DMS Max. Volatile Msg	0
Non-Volatile Memory	5 KB
DMS Control Mode	2, 4, and 5
Number Action Table Entries	15

The current buffer of the message table shall be stored in non-volatile memory. This will enable the controller to redisplay the last message after a power outage, if so selected by the dmsShortPowerRecoveryMessage and/or dmsLongPowerRecoveryMessage.

In addition, the sign shall support the following manufacturer-specific objects:

- Maximum Allowed Sign Housing Temperature
- Sign Housing Temperature Exceeded Trap
- IP v6 Address

The software shall implement the following tags (opening and closing where defined) of MULTI as defined in NEMA TS 3.6-1997.

- Flash ('fl')
- Font ('fo')
- Justification Line ('jl')

- New Line ('nl')
- New Page ('np')
- Page Time ('p')

NTCIP Protocol Requirements

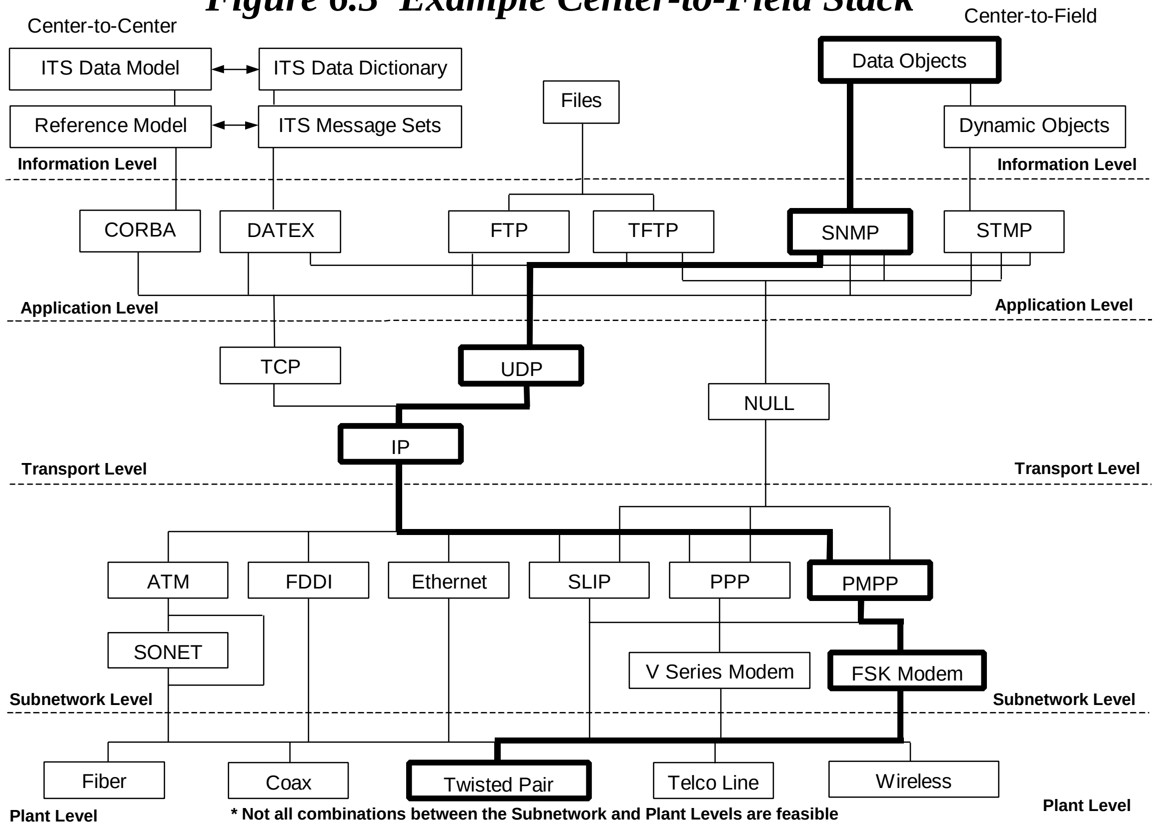
The sign shall comply with the minimum requirements of the PPP Subnetwork Profile.

The sign shall comply with the minimum requirements of the Internet Transport Profile.

The sign shall comply with the minimum requirements of the STMF Application Profile.

The following figure, Figure 6.3, depicts the protocols that will be supported:

Figure 6.3 Example Center-to-Field Stack



Initial Configuration

The controller will be shipped with a four standard font sets: an 18" (5x7) single stroke, an 18" double stroke, a 13" (3 or 4 x5) single stroke, and a 36" double stroke. The stored characters shall include all of the upper case letters (A-Z), digits (0-9), a blank, and the following marks: [. , ! ? - : ; " ' / ( ) # & * + < > $]. All characters will be stored according to their ASCII character codes. The character entries for all other ASCII character codes shall be left empty for the user to define. The fifth font shall contain a sampling of common graphics.

Acceptance

A test plan shall be provided to the client for approval. Upon delivery of the sign, the test plan will be performed in the presence of the client to demonstrate conformance to the standard.

Maintenance / Upgrades

This contract does not include maintenance or upgrade support.

6.4 Example Byte Streams

This section will provide the reader with a basic understanding of how the NTCIP works in a center-to-field environment.

6.4.1 The NTCIP Database

Transportation devices need to store and communicate constants, parameters, and collected data. Examples include minimum cycle time for a traffic signal, text for a dynamic message sign, vehicles per hour for a count station, and current wind speed from a weather station.

NTCIP is intended for many types of transportation devices, each with different database requirements. NTCIP relies on the SNMP approach to database management. SNMP uses an industry-standard get/set paradigm to read and write data in a database. Data elements in the database are called “managed objects” or just “objects” for short. The database is a group of related objects and is called a “management information base” or MIB. The entity that manages the MIB within a device is called an agent. The concept is that a management application sends messages to the agent to fetch or modify the values of objects stored within the MIB. When MIB values change, the transportation device responds as defined in its programming. The agent works at the application layer in the protocol, but is itself not the application. The agent does not care whether the MIB represents a traffic controller or dynamic message sign or any other device.

STMP works in the same way as does SNMP and uses the same objects. STMP simply provides a more bandwidth efficient, but more processor intensive, solution to the same problem.

An object is a type of data. Within an agent, one or more instances of the object may exist. Different instances are identified by their index, as discussed below. An object instance must be transported as a whole. As an example, an object may define the current time, say 12:15:30. Since this object is defined as hours, minutes and seconds, it can not be used to transport just seconds. Alternatively, time could be defined as three separate objects, one each for hours, minutes, and seconds; in this case, a request could deal with any one of the three objects or simultaneously access all three. A third alternative would be to define both of these representations of time (for a total of four objects). It may be convenient to have access to different forms of the same data in the same MIB but it is not very efficient, since extra objects require more computer memory. Thus, when designing objects, the designer must consider the trade-offs of each approach.

To standardize some of the commonly needed objects, the NTCIP defines a global objects MIB module. The global MIB module contains definitions of commonly needed objects that are basic to the NTCIP, such as the name and versions of the MIBs supported by an agent.

A MIB and its objects are defined using Abstract Syntax Notation One (ASN.1). "Abstract syntax" means that the manner used to define the data is independent of the procedure for encoding the data into binary form. The MIB is a text document that can be read by a human and compiled by computer. A management application must have a copy of the MIB employed by the managed agent. The MIB is transferred to a management application via a text file on a floppy disk. This is usually performed when the device is first installed. However, other methods could be used for MIB transfer.

> ***Example 6.1:***
>
> *Consider the example above where the device includes a clock. The management application will need to set the clock periodically to ensure that all devices are synchronized. The MIB defined in Global Object Definitions (TS 3.4-1996 and Amendment 1), includes an object called "globalTime." Below is the ASN.1 definition of this object.*

```
globalTime OBJECT-TYPE
SYNTAX       Counter
ACCESS       read-write
STATUS       mandatory
DESCRIPTION “The current time in seconds since the epoch 00:00:00
(midnight) January 1, 1970 UTC (a.k.a. Zulu).”
::={globalTimeManagement 1}
```

The first line is the name of the object, followed by the formal invocation of the OBJECT-TYPE macro.

The SYNTAX line defines the variable type. In this example, the type is a Counter. The SNMP standards define a Counter to be an INTEGER with a range of 0 to 4294967295 that performs a counting operation. Upon reaching the maximum value, the Counter rolls over and starts at zero.

The STATUS line is provided to simplify conformance statements. At the end of each object standard, conformance groups are defined. For a device to claim conformance to a conformance group, it must support all "mandatory" objects within that group. It may also support "optional" objects within the group. For a device to claim conformance to a standard, it must support all "mandatory" conformance groups defined by the standard, and may optionally support "optional" conformance groups.

The Description line provides a human readable description of the object. This object represents the current time as represented in seconds since midnight January 1, 1970 in Greenwich, England. Many objects specify some sort of functionality; in this case, this object requires the device to increment the value of this object by one at a rate of exactly once a second.

The last line indicates that the location of this object on the ISO Global Naming tree. In this case, the object is the first node under the globalTimeManagement node. Earlier within the standard, the globalTimeManagement node was defined to be underneath the global node. This referencing continues within the standard all the way back to the ISO root node.

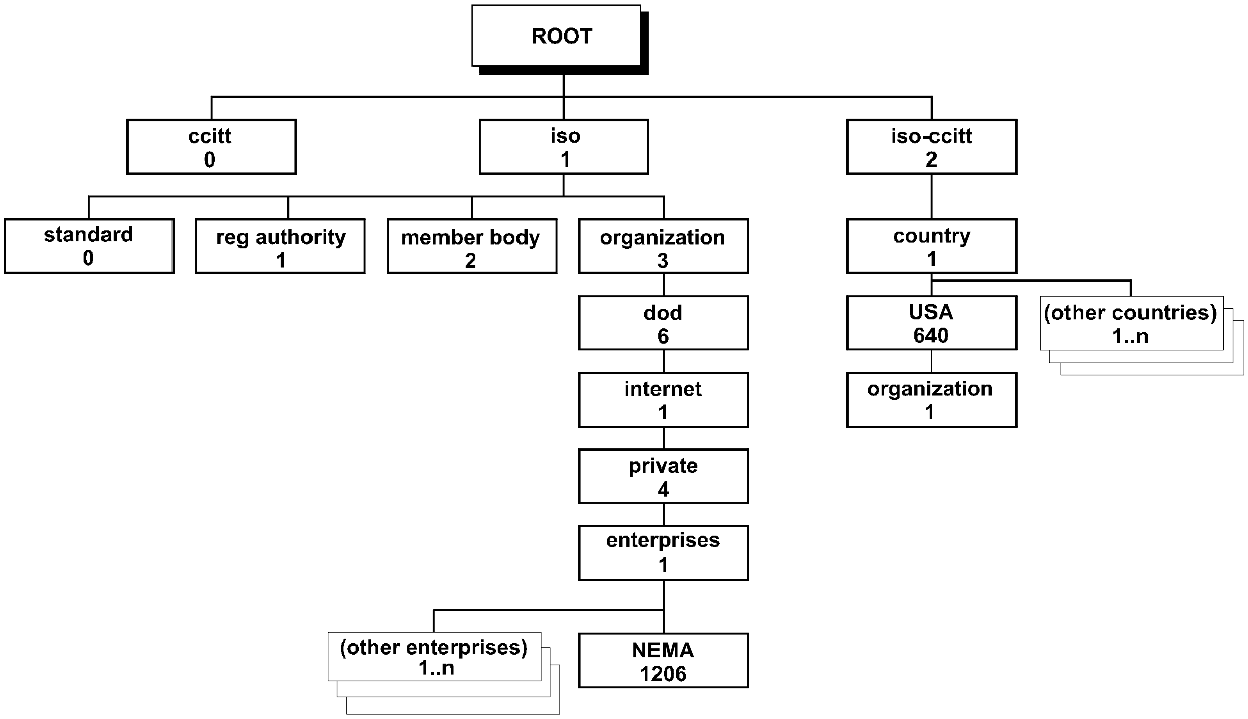
Table 6.3 Some Common ASN.1 / NTCIP Terms for Object Definitions

ASN.1 Tag	Description	Some Options
OBJECT-TYPE	Alphanumeric string that names the object	
SYNTAX	Object data type	**INTEGER (-128..127)** **INTEGER (0..255)** **INTEGER (0..4294967295)** **OCTET STRING** - a string of bytes, such as ASCII text
ACCESS	Determines read/write capabilities	**read-only** **read-write** **not-accessible**
STATUS	Determines whether this object is required.	**mandatory** - must be supported **if** a conformance group containing this object is supported. **optional** - not mandatory. **deprecated** - use of the object is discouraged, however, management stations should support the object as it may be encountered in a deployed device; future releases of the standard may mark the object obsolete. **obsolete** - the object has been deleted or replaced; management stations and agents are not required to implement it.
DESCRIPTION	Explanation of what the object represents and how to interpret it	Anything you want to write to describe object

Table 6.3 lists some common ASN.1 terms used for object definitions. Since this is an incomplete list, refer to ISO 8824 and the NTCIP documents for more information. The NTCIP also defines additional limitations to ASN.1. These limitations are defined in a section called the NEMA Structure and Identification of Management Information (NEMA_SMI). The NEMA_SMI is not a MIB but is added to all NTCIP MIBs.

The ASN.1 macro language is very powerful, even with the restrictions imposed by SNMP. A MIB may define a new syntax by combining basic (primitive) data types. Likewise, a MIB can define a one or multi-dimensional table using the SEQUENCE operator. Default values and ranges for objects can also be defined in the MIB. The robustness of the ASN.1 language allows for the modeling of virtually any database likely to be encountered in ITS field devices.

Figure 6.4 Tree Structure of MIB Objects
(Source: NEMA Standards Publication TS 3.2)

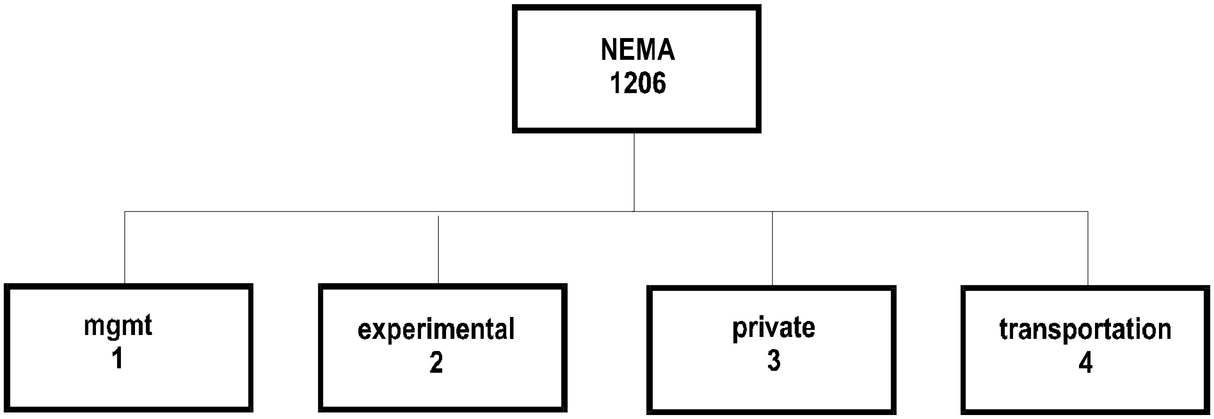


The MIB objects are related by device type (e.g., a traffic controller MIB or a message sign MIB). These device MIBs are called modules. NTCIP has MIB modules for actuated traffic controllers (ASC), dynamic message signs (DMS), closed circuit television control (CCTV) and environmental sensor stations (ESS) to name but a few. It is desirable to use a standard MIB wherever possible, but as new device features require additional objects, new versions of a MIB can be created. NTCIP also supports proprietary and experimental MIBs. Experimental MIBs are kept under a separate node and users know that the MIB is subject to change. Proprietary MIBs can exist under nodes registered to either private firms or public agencies.

Objects in the MIB are arranged in a tree structure, and objects are named by the path along the branches of the tree to the object. The path starts at the trunk of the tree, and a node identifier is added at each branch until the object is reached. The node identifiers are unsigned integers and are frequently documented in text as dot separated (e.g., "1.3.6.1.4.1.1206"). The tree structure is formally defined by ISO and CCITT. An entire MIB module will hang off this global name tree. Below is a diagram showing the tree structure from its root to the NEMA node. All standardized NTCIP MIB modules will be attached to the NEMA node.

All objects in the NEMA NTCIP MIB modules will start with 1.3.6.1.4.1.1206 or (*iso.org.dod.internet.private.enterprises.nema*). NEMA has further divided the 1206 node into four subgroups.

Figure 6.5 NEMA 1206 Node and Subgroups
(Source: NEMA Standards Publication TS 3.2)



Everything below the transportation node constitutes the TMIB. Within the TMIB there are protocol, device, and tcip object groups. The device group has subtrees for each of the supported devices: asc, ramp meter, dms, cctv, ess, global, etc. Branches are added as new devices are included in NTCIP.

> ***Example 6.2:***
>
> *Consider our globalTime object in example 6.1. The object identifier for globalTime is defined as* globalTimeManagement 1. *GlobalTimeManagement is previously defined as* global 3. *Finally, the header of the MIB contains the following:*
>
> nema OBJECT IDENTIFIER ::= {iso(1) org(3) dod(6) internet(1) private(4) enterprises(1) 1206}
>
> transportation OBJECT IDENTIFIER ::= {nema 4}
> devices OBJECT IDENTIFIER ::= {transportation 2}
> global OBJECT IDENTIFIER ::= {devices 6}

Thus, the Object Identifier (OID) for global is 1.3.6.1.4.1.1206.4.2.6 or (iso.org.dod.internet.private.enterprises. nema.transportation.devices 6). The OID for globalTimeManagement is 1.3.6.1.4.1.1206.4.2.6.3 and the OID for globalTime is 1.3.6.1.4.1.1206.4.2.6.3.1. As mentioned above, each object is instantiated by the agent. In the case of globalTime, there is only one instance (i.e., the object is not contained in a table) and thus, its instance number is zero (0). Thus, the full OID for the instance of globalTime within our DMS would be 1.3.6.1.4.1.1206.4.2.6.3.1.0.

When using STMP, this 13-node identifier (OID) can be pre-configured to minimize bandwidth consumption on frequently transmitted messages.

The databases for NTCIP devices are defined using ASN.1, which provides a standard method for object definition, organization, and identification. We have examined how to define an object and identify the path to the object using this standard. Next, we examine how the object identifier or path and the value of the object are encoded into binary data for transmission.

6.4.2 Encoding the NTCIP Database for Transmission

To transmit an object we first need to select the protocols that we will use for transmission. In the DMS example, we indicated that we would support the minimal requirements of the STMF, Internet and PPP profiles; these protocols were identified in Figure 6.3. Thus, in this example, we use an application layer of SNMP.

6.4.2.1 Encoding an Object with Its Value

For SNMP, we need to encode the object’s identifier (data type, length, and value) and the object's value (data type, length, and value). SNMP uses a standard set of rules for encoding called, Basic Encoding Rules (BER) (ISO 8825-1).

Example 6.3:

Using the object from example 6.1, we need to encode the object's identifier and value

Identifier

Type	OBJECT IDENTIFIER
Length	The number of octets (i.e., bytes) used to encode the value of the identifier
Value	1.3.6.1.4.1.1206.4.2.6.3.1.0

Value

Type	Counter
Length	The number of octets used to encode the value of the identifier
Value	915148800 (i.e., 00:00:00, 1 January 1999 UTC)

According to the rules of BER, the first two components of an OBJECT IDENTIFIER are combined using the formula (40X)+Y to form the first subidentifier. Each subsequent component forms the next subidentifier. Each subidentifier is encoded as a non-negative integer using as few seven bit blocks as possible. The blocks are packed into octets, with the first bit of each octet set to a 1 except for the last octet of each subidentifier. Thus, the object identifier (OID), {1.3.6.1.4.1.1206.4.2.6.3.1.0} is encoded as follows:

Table 6.4 Object Component, Subidentifier and Octet Sequence Hex

Component	Subidentifier	Octet Sequence Hex
1.3 (iso org)	43	[2B]
6 (dod)	6	[06]
1 (internet)	1	[01]
4 (private)	4	[04]
1 (enterprises)	1	[01]
1206 (nema)	1206	10010110110 bin [89][36]
4 (transportation)	4	[04]
2 (devices)	2	[02]
6 (global)	6	[06]
3(globalTimeManagement)	3	[03]
1 (globalTime)	1	[01]
0 (instance 0)	0	[00]

Note that [xx] represents a number in hexadecimal format.

Adding the OBJECT IDENTIFIER type of [06] and a length of [0D] or (13 decimal) yields the following byte sequence:

[06][0D][2B][06][01][04][01][89][36][04][02][06][03][01][00]

Next, we encode the data value, which is 915148800. BER encodes Counters in the same way as it encodes INTEGERs, with a two's complement representation using the minimum number of octets (note - this means the value 255 would be encoded in two bytes, [00][FF], so that the high order bit is set to zero indicating a positive number). Thus, the byte sequence of would be:

[36][8C][10][00]

A Counter has a type code of [41].

Thus, our object value with a type of [41] and a length of [04] would become:

[41][04][36][8C][10][00]

The combined byte SEQUENCE (Type [30]) for the OID and value has a length of 21 ([15]). Thus, the entire encoding for this object is:

[30][15][06][0D][2B][06][01][04][01][89][36][04][02][06][03][01][00][41][04][36][8C][10][00]

If STMP was used, a dynamic object could be configured to include this object. In this case, only the object identifier would not be transmitted (because each end of the link would already be aware of what data to expect next). Further, the data value would be encoded using Octet Encoding Rules (OER), which is more efficient than BER. Thus, an STMP dynamic object would encode the above information in 4 bytes instead of the 23 bytes shown (i.e., 21 plus type and length of the sequence). However, STMP only supports thirteen dynamic objects; thus, this benefit is not achieved on every exchange.

Example 6.3 examined only two data types that can be encoded with BER. BER contains encoding rules for all ASN.1 types.

6.4.2.2 Encoding the SNMP Data Packet

We have created an object using ASN.1, placed it in a tree structure, gave it a real value, and finally encoded the object and its value using BER. Now this information must be given in a context. For example, is this a request to set the time, or is it a response to a get request? The context is given by the surrounding structure of the data packet, as defined by the rules of SNMP.

SNMP uses a get/set/trap paradigm. The table below lists the SNMP message types, purposes and originators.

Table 6.5 SNMP Message Type, Purpose, and Originator

Message Type	Purpose	Originator
Get Request	Contains a list of objects, the agent is to return the values	Management Application
Get Next Request	Contains a list of objects, the agent is to return the values of the next sequential object from those indicated.	Management Application
Set Request	Contains a list of objects and values, the agent is to set the values in its MIB per this message	Management Application
'Get' Response	Agent response to either a Get or a Set request	Agent Application
Trap	An Agent initiated transmission to indicate that a defined event has occurred.	Agent Application

The SNMP Message structure is given by the following ASN.1 structure:

```
Message ::= SEQUENCE {
        version         INTEGER { version-1(0) },
        community       OCTET STRING,
        data            CHOICE {
                get-request             GetRequest-PDU,
                get-next-request                GetNextRequest-PDU,
                get-response            GetResponse-PDU,
                set-request             SetRequest-PDU,
                trap                    Trap-PDU
                }
        }
```

All of the PDU structures have essentially the same structure, as follows, with a different Tag.

```
GetRequest-PDU ::= [0] IMPLICIT SEQUENCE {
        request-id              RequestID,
        error-status            ErrorStatus,
        error-index             ErrorIndex,
        variable-bindings       SEQUENCE OF SEQUENCE {
                name                    OBJECT IDENTIFIER,
                value                   ObjectSyntax -- i.e., the SYNTAX of the selected object
                }
        }
```

The 23 byte data stream produced above forms the following sub-structure in the above structure.

```
SEQUENCE {
        name                    OBJECT IDENTIFIER,
        value                   ObjectSyntax -- i.e., the SYNTAX of the selected object
        }
```

Thus, we now have to add the rest of the components of the data packet. In this case, we will assume the data packet is a get response for a get request of both the globalTime object as well as the globalDaylightSavings object, as follows:

Table 6.6 Example of Get Response

Field	Byte Stream
SEQUENCE - Type and Length (Value is below)	[30][45]
version - INTEGER of 1 byte, value 0	[02][01][00]
community - OCTET STRING of 6 bytes ("Public")	[04][06][50][75][62][6C][69][63]
data - Type and Length (Value below)	[A2] [38]
request-id - In this case we use 1	[02][01][01]
error-status	[02][01][00]
error-index	[02][01][00]
variable-bindings SEQUENCE OF	[30] [2D]
SEQUENCE	[30][2B]
name	[06][0D][2B][06][01][04][01] [89][36][04][02][06][03][01][00]
value	[41][04][36][8C][10][00]
SEQUENCE	[30][12]
name	[06][0D][2B][06][01][04][01] [89][36][04][02][06][03][02][00]
value	[02][01][03]

The Get Request would be nearly identical. The data type would be [A0] rather than [A2] and the value fields would be NULL (i.e., Type 5 and zero length, [05][00]).

6.4.2.3 The Transport Profile

The above structure defines the encoding of the Application Layer. This data must now be prepared for transmission through the network. In general, this consists of transmitting the data from one device (IP Address) to another device (IP Address). The data stream defined above is then packaged into the network datagram required for transmission across this network. Based on the decision to use the Internet Transport Profile, this will entail placing the above data stream into an UDP datagram and then placing the UDP datagram into an IP packet.

6.4.2.4 The Subnetwork Profile

Once the IP packet is ready for transmission, it must be prepared for transmission across the next link (i.e., the subnetwork). Based on the decision to use the PPP Subnetwork Profile, this entails encapsulating the IP packet into a PPP frame and ensuring that the PPP session is properly established before the frame is transmitted. Likewise, at some point after transmission, the link should be closed.

6.5 Defining New Objects

AASHTO, ITE and NEMA have defined an open and expandable protocol. NTCIP permits completely open database definitions without precluding completely proprietary (closed) ones. NTCIP will serve both open and closed databases on the same network. Users are encouraged to review the existing MIB object definitions before attempting to add new ones.

The creation of a new MIB module can be quite easy. This is especially true if the device to be supported already has a list of defined requirements and database. Start by rewriting the existing database using ASN.1. Next, define the necessary objects for the device and attempt to organize them in a subtree. Obtain from NEMA, a root node for the subtree under the NEMA private or experimental node. Seek comments from NEMA, manufacturers, and users of similar devices. In the early stages of NTCIP development, it may be sufficient to list the needed objects by name and proposed data types (submit them to the Joint NTCIP Standards Committee for further development). Above all, try to use the existing object definitions as much as possible; this will further compatibility between devices.

6.6 Examples of Implementation Problems

A number of issues arose during the integration of the various components of the NTCIP demonstration, which was unveiled at TRB in January 1996. These issues are documented here to provide future implementers and integrators information for their design consideration.

6.6.1 Protocol-Related Issues

Implementing a standard requires careful examination of a large amount of text within the standards. A number of the problems discovered during the integration work related to invalid interpretation of the specifications, especially relating to those clauses that reference other specifications without providing significant detail. In order to minimize the number of these conflicts in the future, a discussion of some of these issues is provided below.

6.6.1.1 Bit and Byte Order

Bit and byte order in a computer are not necessarily the same as the bit and byte order on the transmission medium. The transmission order varies in accordance with the guidelines of international standards. Implementations should ensure that the representation of the most and least significant bits and bytes in the computer accurately reflect what is sent and received on the transmission media.

6.6.1.2 Extended Addresses

There has been some confusion about how large of a high-level data link control (HDLC) address must be supported. For both of the PMPP and PPP Subnetwork Profiles, NTCIP devices are required to fully support one-byte addresses and to accept incoming frames with two-byte addresses to the device address. Production of frames with two-byte addresses is optional as is support for configuring the device to an address greater than 63.

All addresses are odd; if the first byte of an address is even, then the address is multibyte.

6.6.1.3 Maximum Duration Between Successive Bytes

Many existing field devices use proprietary protocols that expect incoming messages to be a series of bytes with minimal delay between the bytes. They will time out as an end of message when a byte is not received in 15 ms for 1,200-bps communications. This means that consecutive messages must be separated by about 30 ms at 1,200 bps. With the simultaneous use of soft carrier turnoff this gap must be increased by the soft carrier turnoff time. At higher transmission rates these times are proportionally reduced.

Because of the desire for full-duplex communications, devices conforming to the PMPP Profile should be designed to support much greater durations between successive bytes as suggested in the NTCIP documents. In short, the only distinguishing limit of a message is the 0x7E flag.

6.6.1.4 Response Time

The public domain code that is available was developed using DOS and Windows; in both cases the serial port interrupt is only checked every 50 ms. Thus, these systems do not perform quite as well as desired; however, this was not an issue for the demonstration.

A real product should use a serial port driver to achieve the desired performance. The desired performance is system dependent and is stored in the T2 [the maximum time that a device is allowed to take before starting to send a response] object. In a multi-drop environment it is desirable to minimize the duration of the T2 timer. A T2 value of 20 ms or less is desirable, but not always achievable. According to NTCIP standards, the secondary is not allowed to respond after its T2 timer expires.

6.6.1.5 Control Byte

PMPP includes support for three control byte values. A primary can transmit an unnumbered poll (0x33), an unnumbered information command with the poll bit set (0x13), or an unnumbered information command without the poll bit set (0x03). The secondary must respond to every frame received with the poll bit set (i.e., either 0x33 or 0x13); the response frame must be an unnumbered information response with the final bit set (0x13). The secondary may not transmit at any other time. (Note that these values are presented according to Internet encoding rules.)

PPP devices are peer devices (i.e., either the management station or the field device may communicate at any time because they are the only devices on the 4-wire link). In this environment, there is no need to give permission to the other device, nor is there a need to force a data link response. As such, the PPP Profile only uses the unnumbered information command without the poll bit set for both ends of the link. This byte may be omitted, if such operation has previously been negotiated (see the PPP Subnetwork Profile and the PPP RFC).

6.6.1.6 Frame Handling

In PMPP systems, the primary may constantly poll each device in order to determine whether it has any information to report. If the primary station has information to transmit with this poll (e.g., a request), it encapsulates this data in an unnumbered information command with the poll bit set. If there is not any information to send, it sends an “empty” frame of six bytes called an unnumbered poll frame. If the primary station has information to send, but does not want to give the opportunity for the receiving device to respond (e.g., a broadcast), it sends the data in an unnumbered information frame without the poll bit set.

When a secondary station receives an unnumbered information frame with the poll bit set or an unnumbered poll, it responds with an unnumbered information frame with the final bit set. If the secondary has any data to send with this frame, it is encapsulated within the frame. If the secondary does not have any data to send, it should send an empty frame.

When a secondary station receives an information command without the poll bit set (e.g. a broadcast message), it does not respond.

It should be further noted that these rules only deal with the data link layer. For example, a central system may send a broadcast message without a poll at the data link layer, while requesting a response at the application layer. The remote device would prepare a response at the application layer that would then be stored in the device’s data link layer. This response could only be sent out after the device has received a frame with the poll bit set.

For example, if dynamic object 1 had been defined to be the time object, central could send the following byte stream:

```
Flag Addr Ctrl  IPI STMP   ----SET Time----     CRC     Flag
 7E   FF   03   C1   91   31   E6   E7   00   XX   XX   7E
```

The address indicates that it is received by everyone and the control byte prevents anyone from responding on the wire; however, the STMP byte is a SET with response. Thus, all of the devices generate responses at the application layer and they are sent to the data link layer to be transmitted. Then, the data link layer waits until permission is granted for the device to speak (e.g., an unnumbered poll frame). In this way, a central system can broadcast the time and then go back and ensure that all the devices received the message.

If the secondary has a pending response waiting at the data link layer, it should send the response immediately upon receiving a frame with the poll bit set. If the incoming frame contains information, the information should be processed. This might entail producing a new response that will be sent to the data link layer, where it will reside until the next poll is received.

A device is responsible for storing one response frame at the data link layer. If a second response is generated before the first is sent, the first response should be overwritten.

6.6.1.7 CRC Algorithm

Examples of how to code the cyclical redundancy check (CRC) algorithm can be found in the AB3418 code and the FHWA code used the demonstration. This same algorithm is used in both PMPP and PPP.

6.6.1.8 Invalid Frame

In both PMPP and PPP, when a device receives an invalid frame it should just discard the frame. Invalid frames include those with invalid CRCs, invalid initial protocol identifiers, etc. Devices should not provide any response to invalid frames.

6.6.1.9 STMP Message Type Byte

To see how the STMP Message Type Byte is coded and used, see NEMA Standards Publication TS 3.2, National Transportation Communications for ITS Protocol, Simple Transportation Management Framework, page 5-1.

6.6.1.10 Length Values for Variable Message Fields

The exact meaning of this field (i.e., which bytes are included in the count) has led to some confusion. The count value does not include the count byte in the count (i.e., the count starts the byte after the count byte).

6.6.2 Systems Integration Issues

In addition to those issues raised about the interpretation of the specifications, there were also issues over how systems should be designed and what should be required in procurement specifications to achieve the goal of systems interoperability. This section provides some guidance on how to approach these issues.

6.6.2.1 Carriers

It is very important that secondary stations on multidrop lines turn off their modem carriers when not sending data. After responding to a poll, the carrier must be removed from the line so that other stations may respond.

6.6.2.2 Number of Devices on a Channel

The input impedance of the transmission output circuit in the field device modems limits the maximum number of field devices that can reliably be supported on a single modem channel. Each of these outputs is a load on the field device transmission line. A practical upper limit is somewhere around 15 field devices for the current technology 202 modems. Advanced 202 modems can be used that will isolate the individual transmission circuits unless the modem is actively transmitting. In a system with only four to seven field devices per channel this consideration can usually be neglected, since communications timing is usually the determining factor in the maximum number of devices per channel. Section 5 provides a more detailed explanation for determining the maximum number of devices per channel.

6.6.2.3 MIB Issues

All NTCIP procurements should specify that the manufacturers/developers must provide the devices' MIB module(s) to the purchasing agency, with rights to distribute to their agents (e.g., those persons acting on behalf of the agency). The MIBs should be provided in ASCII format on the medium of the procuring agency's choice. The MIBs should include all Simple Network Management Protocol (SNMP)/Simple Transportation Management Protocol (STMP) objects that the device(s) support.

6.7 Development Resources

There are a wide variety of resources available that relate to the NTCIP. This section lists some of the resource materials that have been used in the development process and early implementations, as well as the location of developed materials.

6.7.1 Web Sites

A wide range of documentation is available on the World Wide Web NTCIP Home Page located at: *http://www.ntcip.org*

The site currently includes such items as these:

- NTCIP Profile documents
- NTCIP object definitions for a variety of devices
- Various white papers written during the development of the initial standards
- FHWA-sponsored software packages (e.g., NTCIP demonstration and NTCIP Exerciser).

Other web sites of interest are shown in the following table.

Table 6.7 NTCIP Related Web Sites

Web Site	Address	Description
NTCIP	http://www.ntcip.org/	The official web site for NTCIP and related documents and information.
DATEX-ASN	http://www.viggen.com/ntcip/datex/index.htm	The web site for DATEX-ASN documents and information
DATEX-Net	http://www.datex.org/	The official web site of the DATEX-Net Standard currently in use in Europe.
IANA	http://www.iana.org/numbers.html	The Internet Assigned Numbers Authority web site.
IEEE ITS Page	http://stdsbbs.ieee.org/groups/scc32/index.html	Links to all of the IEEE standards efforts, including ATIS, Incident Management, Data Dictionaries, and Data Registries.
ISO	http://www.iso.ch/	The official ISO home page.
ISO TC204	http://www.sae.org/TECHCMTE/204.htm	The home page for ISO Technical Committee 204 (i.e., the committee for ITS standards).
ITE	http://www.ite.org/	ITE web site.
ITS America	http://www.itsa.org/	The home page for ITS America.
NEMA Standards	http://www.nema.org/nema/standards/	Site for ordering NTCIP standards.

Table 6.7 NTCIP Related Web Sites

Web Site	Address	Description
RFC Index	http://www.nexor.com/public/rfc/index/rfc.html	A search engine for all of the Internet RFCs.
TCIP	http://www.tcip.org	The home page for the Transit Communications Interface Profiles.

6.7.2 Sources of Public Domain Software

There are two basic prototype implementations of NTCIP software. Neither of these packages were designed to operate a real system; rather, they were designed to provide tools to the industry to test equipment submitted as being compliant to a specific protocol. Unfortunately, there is no ongoing program to maintain these packages.

6.7.2.1 NTCIP Exerciser

This NTCIP Exerciser is able to read in any properly formatted management information base (MIB) from a floppy disk and support the exchange of fully compliant NTCIP messages under the direction of the operator. The package supports the creation of simple macros to enable the user to perform a number of operations sequentially and to record the results. The current version supports the simulation of either a management station (funded by the FHWA) or an agent (funded by Virginia DOT). It currently supports the STMF Application Profile (SNMP only, the STMF portion is out of date), Null Transport Profile, and both the PMPP-232 Subnetwork Profile and the PPP Subnetwork Profile. The most recent version of this software is available for free on the NTCIP Web Site. It is designed for Windows NT.

6.7.2.2 Field Device Simulator

The FHWA also developed a DOS based program to emulate a field device that supports the objects contained in the Global Object Definitions. This program supports the STMF Application Profile (SNMP-only, the STMF code is out of date), the Null Transport Profile, and the PMPP-232 Subnetwork Profile.

6.7.3 Books

During the development of the standards and prototypes, a number of books were consulted; including the following:

- Stevens, W. R., *TCP/IP Illustrated, Volume 1, The Protocols*: Reading, Massachusetts: Addison Wesley Publishing Co. 1994
- Wright, G. R. and Stevens, W. R., *TCP/IP Illustrated, Volume 2, The Implementation*, Reading, Massachusetts: Addison Wesley Publishing Co. 1995
- International Technical Support Center Raleigh N. C., *TCP/IP Tutorial and Technical Overview*, Document Number GG24-3376-01, IBM Corp, Armonk, N.Y.: June 5, 1990, 2nd Edition
- Rose, M. T., *The Open Book*, Englewood Cliffs, N.J.: Prentice Hall, 1990
- Stallings, W., *SNMP, SNMPv2, and CMIP The Practical Guide to Network Management Standards*, Reading, Massachusetts: Addison Wesley Publishing Co. 1993
- Perkins, D. and McGinnis, E., *Understanding SNMP MIBS*, 1997, Upper Saddle River, New Jersey: Prentice Hall, Inc., 1997.

6.7.4 Other Resources

In addition, there are articles in the December 1995, January 1996, and April 1996 issues of the *ITE Journal*. There are periodic releases of *NTCIPNews*, a newsletter produced by the NTCIP Joint Committee. Finally, there are updates of ITS standards in each Journal.

6.8 Summary

Transportation devices, like any other computer device, require databases, processors, and interfaces. If the device intends to share its data with other devices, a communication protocol is required. NTCIP fulfills the requirement for a set of communication protocols that are flexible enough to support the variety of fixed-point communications systems within ITS.

7 GLOSSARY

7.1 Acronyms

Table 7.1 Glossary

Acronym/Abbreviation	Definition
AASHTO	American Association of State Highway and Transportation Officials
ASC	Actuated Signal Controller
ASN.1	Abstract Syntax Notation One
ATIS	Advanced Traveler Information System
ATMS	Advanced Traffic Management System
BER	Basic Encoding Rules
bps	bits per second
C2C	Center to Center
C2F	Center to Field
CCTV	closed-circuit television
CORBA	Common Object Request Broker Architecture
CRC	Cyclical Redundancy Check
DATEX	Data Exchange Between Systems
DMS	Dynamic Message Sign
ESS	Environmental Sensor Systems
FCS	Frame Check Sequence (see Cyclic Redundancy Check)
FHWA	Federal Highway Administration
FSK	Frequency Shift Keying
FTP	File Transfer Protocol
HAR	Highway Advisory Radio
HDLC	High-Level Data Link Control
IANA	Internet Assigned Numbers Authority
IEEE	Institute of Electrical and Electronic Engineers
IP	Internet Protocol
IPI	Initial Protocol Identifier
ISO	International Organization for Standardization
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation Systems
MIB	Management Information Base

Table 7.1 Glossary

Acronym/Abbreviation	Definition
NEMA	National Electrical Manufacturers Association
NTCIP	National Transportation Communication for ITS Protocol
OER	Octet Encoding Rules
OSI	Open Systems Interconnection
PDU	Protocol Data Unit
PER	Packed Encoding Rules
PICS	Protocol Implementation Conformance Statement
PMPP	Point-to-Multi Point Protocol
PPP	Point-to-Point Protocol
RFC	Request For Comment
SLIP	Serial Line Internet Protocol
SNMP	Simple Network Management Protocol
SNMPv2	Simple Network Management Protocol version 2
STMF	Simple Transportation Management Framework
STMP	Simple Transportation Management Protocol
TCIP	Transit Communications Interface Protocol
TCP	Transmission Control Protocol
TCP/IP	Transmission Control Protocol/Internet Protocol
TEA-21	Transportation Equity Act for the 21st Century
TFTP	Trivial File Transfer Protocol
TMC	Transportation Management Center
TMIB	Transportation MIB
TMS	Transportation Management Systems
TOC	Transportation Operation Center
UDP	User Datagram Protocol
UDP/IP	User Datagram Protocol/Internet Protocol
VMS	Variable Message Sign

7.2 Definitions

Table 7.2 Definitions

Term/Abbreviation Acronym	**Definition**
agent	An STMF entity that receives commands and transmits responses to the received commands.
ANSI	American National Standards Institute, a standardization group that develops or adopts standards for the United States.
application services	The services collectively offered by the upper four layers of the OSI model.
Applications Programmer Interface (API)	A set of calling conventions defining how a service is invoked through a software package.
ASCII	American Standard Code for Information Interchange. A 7-bit binary code representation of letters, numbers, and special characters. It is universally supported in computer data transfer.
ASN.1	Abstract Syntax Notation One, a formal language for describing information to be processed by computer, an ISO standard.
asynchronous	Data transmission in which the actual data is preceded by a start bit and followed by a stop bit since the time between transmitted characters varies. Compare with Synchronous.
authentication	The process whereby a message is associated with a particular originating entity.
authorization	The process whereby an access policy determines whether an entity is allowed to perform an operation.
bandwidth	The range of frequencies that can be used for transmitting information on a channel, equal to the difference in Hertz (Hz) between the highest and lowest frequencies available on that channel. Indicates the transmission-carrying capacity of a channel.
Basic Encoding Rules (BER)	A series of procedures for describing transfer syntax of types specified with ASN.1. Transfer syntax is the actual representation of octets to be sent from one network entity to another.
Baud Rate	The number of discrete signal events per second occurring on a communications channel. It is often interchanged with bits per second (bps), which is technically inaccurate but widely accepted for slower bit rates.
bit	Binary digit. A single basic computer signal consisting of a value of 0 or 1, off or on.
Bit error rate (BER)	The number of bits transmitted incorrectly. In digital applications it is the ratio of bits received in error to bits sent.
bps	Bits per second, transmission rate (speed) of data
bridge	A means for connecting two networks at the data link layer.
broadcast address	An address referring to all stations on a medium.
byte	A group of bits acted upon as a group, which may have a readable ASCII value as a letter or number or some other coded meaning to the computer. it is commonly used to refer to 8-bit groups.
(AB3418) California Assembly Bill No. 3418	A bill that requires all new or upgraded traffic signal controllers installed in California after January 1, 1996, to incorporate a standard communications protocol. Caltrans has published this specification for developers.
carrier	A continuous frequency capable of being either modulated or impressed with another information-carrying signal. Carriers are generated and maintained by modems via the transmission lines of the telephone companies.
checksum	An arithmetic sum used to verify data integrity.
Cyclical Redundancy Check	Cyclical Redundancy Check. An error-detection technique consisting of a cyclic algorithm performed on each “block” of data at the sending and receiving end of the transmission. As each block is received, the CRC value is checked against the CRC value sent along with the block.
data	Information before it is interpreted.
data dictionary	An organized listing of all data elements that are essential to the system, with precise, definitions so that both the user and the system developer will have a common understanding of input, output, components of storage, and intermediate calculations.
data flow	The description of information movement and the transforms that are applied as the data moves from input to output.
Data Link Layer	Layer 2 of the OSI Reference Model; it is responsible for transmission, framing, and error control over a single communications link.
datagram	A self-contained unit of data transmitted independently of other datagrams.

Table 7.2 Definitions

Term/Abbreviation Acronym	Definition
DTE	Data Terminal Equipment. The device that is the originator or destination of the data sent by a modem. (An EIA/TIA – 232 – E signal)
DTR	Data Terminal Ready. A signal generated by most modems indicating a connection between the DTE (computer) and the modem. When DTR is high, the computer is connected. (An EIA/TIA – 232 – E signal)
EIA/TIA-232-E	Electronic Industries Association/Telecommunications Industries Association specification that defines the serial port on a PC.
end-to-end services	The services collectively offered by the lower three layers of the OSI model.
flow control	A mechanism that compensates for differences in the flow of data to and output from a modem or computer. Either hardware or software can be used for this control to prevent data loss. Hardware flow control using the modem makes use of a buffer to store data to be sent and data received. Flow control is necessary if the communications port is locked at a higher rate than the connection rate.
FSK modem interface	Typical method of traffic control system communications, phone line, or twisted wire based.
full duplex	Signal flow in both directions at the same time. It is sometimes used to refer to the suppression of on-line local echo and allowing the remote system to provide a remote echo.
gateway	A router and translater between protocols; also, (imprecise usage) an entity responsible for complex topology mappings.
half duplex	Signal flow in both directions, but only one way at a time. It is sometimes used to refer to activation of local echo which causes a copy of sent data to be displayed on the sending display.
HDLC	Generalized network approach: high-level data link control
Highway Advisory Radio (HAR)	Low-powered AM or FM stations that broadcast brief messages to standard car radios from small transmitters placed near highways.
host	(Internet usage) an endsystem.
IETF	lnternet Engineering Task Force, a group chartered by the IAB to develop certain RFCs for standardization .
indirect routing	The process of sending a network message to a router for forwarding.
infrastructure	This refers to all fixed components to a transportation system such as rights of way, tracks, equipment, stations, parking/park-n-ride lots, signalization equipment, maintenance facilities.
Intelligent Transportation Systems (ITS)	A major national initiative to improve information, communication, and control technologies in order to improve the efficiency of surface transportation. Technological innovations that apply direct communications and information processing to improve the efficiency and safety of surface transportation systems. These include on-board navigation for vehicles, emergency communications systems, electronic toll/fare collections, traffic management centers, etc.
intermediate system	A network device performing functions from the lower three layers of the OSI model. Intermediate systems are commonly thought of as routing data for end systems.
Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA)	Federal authorizing legislation for highways, transit, and other surface transportation programs. Established intermodal objectives for national transportation system to achieve efficiency, air quality, and environmental quality.
intermodalism	The use and coordination of more than one mode of transportation.
International Organization for Standardization (ISO)	An international standards organization. ANSI is the primary interface to ISO within the United States. Often thought to be International Standards Organization because of the usage ISO for short.
Internet	A large collection of connected networks, primarily in the United States, running the Internet suite of protocols. Sometimes referred to as the *DARPA Intemet, NSF/DARPA, Intemet, or* the *Federal Research Intemet.*
Internet Protocol (IP)	The network protocol offering a connection less mode network service in the Internet suite of protocols.
Internet suite of protocols	A collection of computer-communication protocols originally developed under DARPA sponsorship.
IP address	A 32-bit quantity used to represent a point of attachment in an internet. An Internet Protocol Address.
lAB	Internet Activities Board, group in charge of authorizing RFCs for the purpose of standardizing Internet operations.
IANA	Internet Assigned Numbers Authority, group in charge of assigning Internet addresses.
Local Area Network (LAN)	Any one of a number of technologies providing high speed, low-latency transfer and being limited in geographic size.
Management Information Base (MIB)	A collection of objects defined using Abstract Syntax Notation One (ASN.1) that can be accessed via a network management protocol. (See Structure of Management Information.)
manager	The entity that sends commands to entries and processes their responses.
maximum transmission unit	The largest amount of user data that can be sent in a single frame on a particular medium.
network	A collection of subnetworks connected by intermediate systems and populated by end systems.
network identifier	That portion of an IP address corresponding to a network in an internet.

Table 7.2 Definitions

Term/Abbreviation Acronym	Definition
Network Layer	That portion of an OSI system responsible for data transfer across the network, independent of both the media comprising the underlying subnetworks and the topology of those subnetworks.
network management	The technology used to manage a network. Usually referring to the management of networking specific devices such as routers. In the context of the NTCIP, refers to all devices including end systems that are present on the network or inter network.
NTCIP	National Transportation Communication for ITS Protocol, communications protocol under development. The development effort is being spearheaded by FHWA, NEMA, and the NTCIP Joint Standards Committee.
NTCIP Home Page	Site on the World Wide Web where one may obtain the latest NTCIP information. The address is http://www.ntcip.org
NTCIP Steering Group	A public/private advisory group composed of ITS experts that guides the development of the NTCIP.
object	A representation of a data element that is managed.
object identifier	A unique name (identifier) that is associated with each type of object in a MIB. This is a defined ASN.1 type.
OBJECT-TYPE	The macro defined in RFC-1212 which is the format used to define SNMP objects. In STMF, the OBJECT-TYPE macro consists of five fields: Object Name Syntax Description Access Status.
Open Systems Interconnection (OSI)	An international effort to facilitate communications among computers of different manufacture and technology.
parity	A simple error detection method used in both communications and computer memory checking to determine character validity.
PER	Packed Encoding Rules, a variation of BER developed for use on low bandwidth communications links, specified in NEMA TS-3.2.
physical address	The address of a physical interface.
Physical Layer	That portion of an OSI system responsible for the electro-mechanical interface to the communications media.
Point-to-Point Protocol (PPP)	Transmission of data between two and only two stations on a point to point link.
Point-to-Multi-Point Protocol (PMPP)	Transmission of data between multiple stations or nodes (i.e., one primary and multiple secondaries).
port number	Identifies an application-entry to a transport service in the Internet suite of protocols. The concept of ports are often present in OSI literature, however, ports are not Internet standard, but exists as local network conventions only.
Presentation Layer	That portion of an OSI system responsible for adding structure to the units of data that are exchanged.
primary	A node on a link which controls the polling to and from secondary nodes on that link and controls the communications from the secondary nodes on that link.
profile	The defined protocol at each of the seven OSI layers.
protocol	A formal set of conventions governing the format and relative timing of message exchange between two communicating processes. A system of rules and procedures governing communications between two devices.
Protocol Data Unit (PDU)	A part of transmitted data that contains information used by the protocol at a particular layer in the OSI stack.
proxy agent	A device which receives and responds to network management commands on behalf of another entity.
RFC	Request for Comments, the name given to correspondence and standards by the IAB.
router	A level 3 (network layer) relay
secondary	A node on a link that is controlled by the primary node in terms of polling and communications.
service primitive	An artifact modeling how a service is requested or accepted by a user
Session Layer	That portion of an OSI system responsible for adding control mechanisms to the data exchange.
Simple Transportation Management Framework (STMF)	Simple Transportation Management Framework, describes the organization of the information within devices and the methods of retrieving or modifying any informaiton within the device. STMF also explains how to generate and utilize computer readable information organization descriptions.
Simple Transportation Management Protocol (STMP)	Simple Transportation Management Protocol, a variation of SNMP developed by NEMA to address low bandwidth communication links and real time device monitoring.
SMI	Structure of Management Information, a definition of how to create management objects and a hierarchical (tree like) definition of nodes where management objects will be attached for unique identification.

Table 7.2 Definitions

Term/Abbreviation Acronym	Definition
SNMP	Simple Network Management Protocol, a communications protocol developed by the IETF, used for configuration and monitoring of network devices.
SNMPv2	Simple Network Management Protocol version 2, recent modification of SNMP that is undergoing evaluation by the Internet community.
socket	A pairing of IP address and a port number
TCIP	Transit Communications Interface Protocol – A subset of NTCIP protocols which are specific to the transit community.
TCP/IP	Transmission Control Protocol/Internet Protocol (protocol addressing both the network and transport layers)
TLV	Tag, Length, Value – the form used in SNMP encoding.
Traffic Management Experimental Protocol (TMC E1)	Based on the AB3418, TMC E1 is a specified protocol that allows basic communication messages to be sent between TMCs on the same communications channel.
Traffic Management Experimental Protocol (TMC E1.2)	An enhancement of TMC E1, TMC E1.2 is a specified protocol that allows basic communication messages to be sent between multiple TMCs using IP for routing services.
Transmission Control Protocol (TCP)	The transport protocol offering a connection-oriented transport service in the Internet suite of protocols.
Transport Layer	That portion of an OSI system responsible for reliability and multiplexing of data transfer across the network (over and above that provided by the network layer) to the level required by the application.
transport-stack	The combination of protocols, at the transport layer and below, used in a given context.
user data	Conceptually, the part of a protocol data unit used to transparently communicate information between the users of the protocol. Prefixed by the protocol control information.
User Datagram Protocol (UDP)	The transport protocol offering a connectionless mode transport service in the Internet suite of protocols.
Variable Message Sign Experimental Protocol Version 1.0 (VMS E1)	Based on AB3418, a specified protocol that allows basic communication messages to be sent to and from multiple VMS on the same communications channel, even if the signs are from different manufacturers.
Variable Message Sign Experimental Protocol Version 1.2 (VMS E1.2)	An enhancement of VMS E1, a specified protocol that allows the VMS messages to be routed using the IP protocol.
Wide Area Network (WAN)	Any one of a number of technologies that provide geographically distant transfer.

8 BIBLIOGRAPHY

8.1 Selected Reading List

Table 8.1 Selected Reading List and References

Subject	Reference
Object Definition	Understanding SNMP MIBS, 1997, D. Perkins and E. McGinnis, Prentice Hall, Inc., ISBN 0-13-437708-7 ASN.1: The Tutorial & Reference, 1993, D. Steedman, Technology Appraisals Ltd., ISBN 1-871802-06-7
SNMP Protocol	SNMP, SNMPv2, and CMIP, 1993, W. Stallings, Addison-Wesley Publishing Company, Inc., ISBN 0-201-63331-0 SNMP, SNMPv2 and RMON, 1996, W. Stallings, Addision-Wesley Publishing Company, Inc., ISBN 0-201-63479-1 Managing Internetworks with SNMP, 1995, M. Miller, M&T Books, ISBN 1-5581-304-3 SNMP: A Guide To Network Management, 1995, S. Feit, McGraw Hill, Inc., ISBN 0-07-020359-8
TCP,UDP, IP and PPP Protocols	Internetworking with TCP/IP, 1995, D. Comer, Prentice Hall, Inc., ISBN 0-13-216987-8 TCP/IP: Architecture, Protocols, and Implementation, 1993, S. Feit, McGraw Hill, Inc., ISBN 0-07-020346-6 TCP/IP Illustrated, Volume 1, The Protocols, W. R. Stevens, 1994, Addison Wesley Publishing Co. TCP/IP Isslustrated, Volume 2, The Implementation, G. R. Wright and W. R. Stevens, 1995, Addison Wesley Publishing Co. TCP/IP Tutorial and Technical Overview, International Technical Support Center, Raleigh, NC, 1990, Document Number GC24-3376-01, IBM Corp.
Network Interfaces	The Ethernet Management Guide, 1995, M. Nemzow, McGraw-Hill, Inc., ISBN 0-07-046380-8 The Token-Ring Management Guide, 1995, M. Nemzow, McGraw-Hill, Inc, ISBN 0-07-046321-2
OSI Network Management	Telecommunications Network Management into the 21st Century, 1994, S. Aidarous and T. Plevyak, IEEE Press, New York, NY
OSI	Understanding OSI, 1994, J. Larmouth, http://www.salford.ac.uk/iti/books/osi.htm, 1997
CORBA	CORBA for Dummies, J. schettino, L. O'Hara, R S. Hohman, IDG Books, 1998 Instant CORBA, R. Orfali, D. Harkey, and J. Edwards, et al, John Wiley & Sons, 1997, ISBN 0471183334 CORBA Fundamentals & Programming, J. Siegel, Object Management Group, Inc., 1996 Object-Oriented Systems Design: An Integrated Approach, E. Yourdon, Yourdon Press Computing Systems (Prentice Hall), 1994, ISBN 0136363253 Object Lessons: Lessons in Object-Oriented Development Projects, SIGS Books, 1993, ISBN 0962747734
Profiles	Guide to Open System Specifications, European Workshop for Open Systems, http://www.ewos.be/goss/top.htm, 1997 US-DOD Internet Related Standardized Profiles, DISA Internet Librarian, http://www-library.itsi.disa.mil/org/mil_std.html, 1997 The Open Book, 1990, M. T. Rose, Prentice Hall

9 EXAMPLE NTICP IMPLEMENTATIONS

Several potential NTCIP Implementations are presented in this section as examples of how the various Information, Application, Transport, Subnetwork, and Plant Levels may be combined.

The following examples will occasionally make reference to legacy terminology such as Class Profiles. Rather than developing a different Class Profile for each possible combination of alternative selections at the various NTCIP Stack Levels, the NTCIP Joint Committee has chosen to deprecate the use of alphanumeric class profile designations in lieu of individual standards at each level. The user is now able to create an NTCIP Stack by selecting the appropriate standards at each Level that is applicable for the application and system design. This approach enables the user to better specify choices specific to the system being deployed.

9.1 Center-to-Field

Two examples are provided for center-to-field communications.

9.1.1 Example Center-to-Field Implementation Without Routing

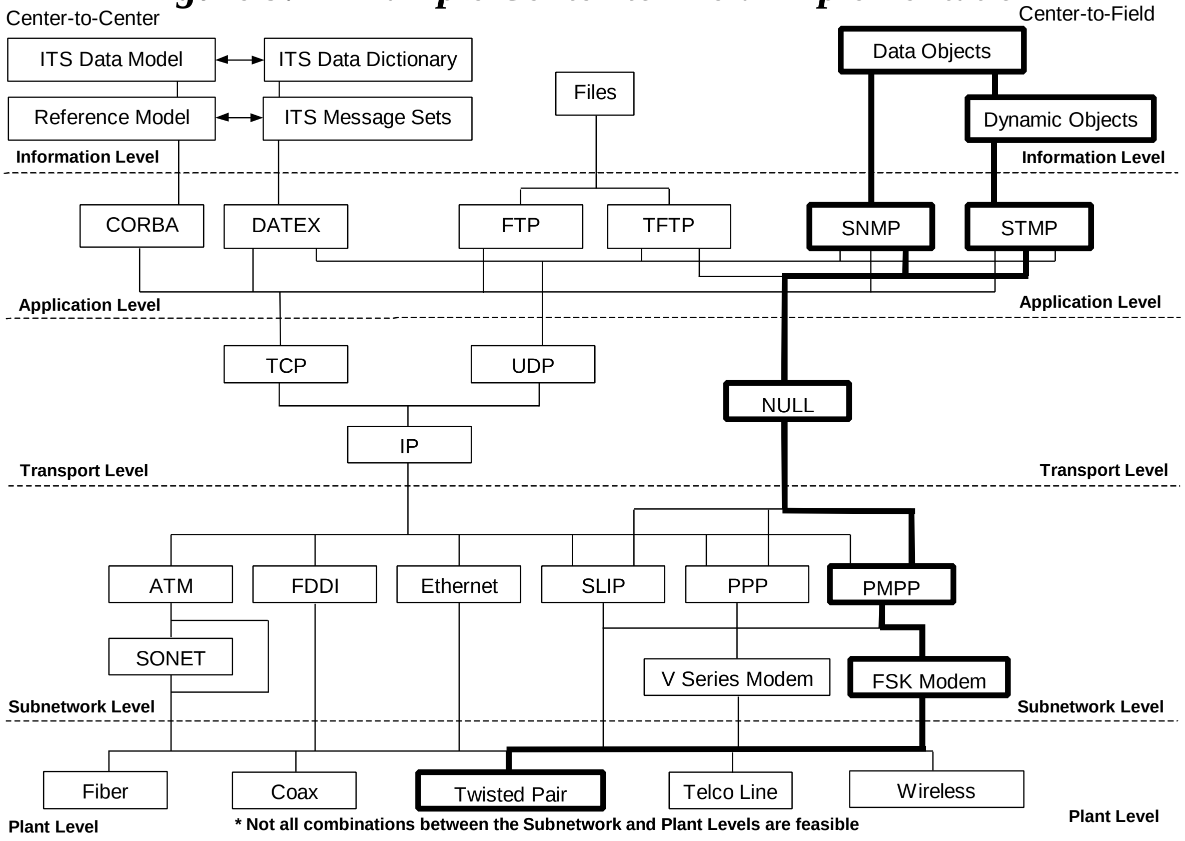
> *Example 9.1 Example of a Center-to-Field Implementation Without Routing*
>
> *This example shows one possible implementation of NTCIP center-to-field communications where routing through an intermediate device is not needed.*

Figure 9.1 depicts a common example of a center-to-field NTCIP Implementation where routing through an intermediate device is not needed. In this example the Transport Level is NUL because there is no need for a routing protocol.

The example NTCIP implementation illustrated in Figure 9.1 highlights one implementation subset of the NTCIP Framework. The figure shows the standard(s) implemented at each NTCIP Framework Level. The example shows the implementation of both STMP and SNMP at the Application Level and NULL at the Transport Level. Together, these standards provide services for an NTCIP system, such as a traffic signal system, that does not involve routing through intermediate devices. The example shows the selection of both STMP and SNMP at the Application Level within the NTCIP Stack since this will be a common implementation many systems, such as traffic signal systems, that use dynamic objects.

The implementation subset of the NTCIP Framework shown in this example is similar to that once known as the Class B Profile. It should be noted that the trend is moving away from denoting the various stacks with alphanumeric characters and is moving towards the designation of specific standards at each level within the NTCIP Framework. As a result, Class B should be regarded as a legacy term that will ultimately be abandoned in-lieu of an array of specific NTCIP Framework level standards.

Figure 9.1 Example Center-to-Field Implementation



The Subnetwork Level standard selected in this example is Point to Multi-Point, FSK modems. The Plant Level in this example NTCIP implementation is shown to be agency owned twisted pair wire, but any suitable media can be used.

9.1.2 Example Center-to-Field Implementation With Routing

Example 9.2 Example of a Center-to-Field Implementation With Routing

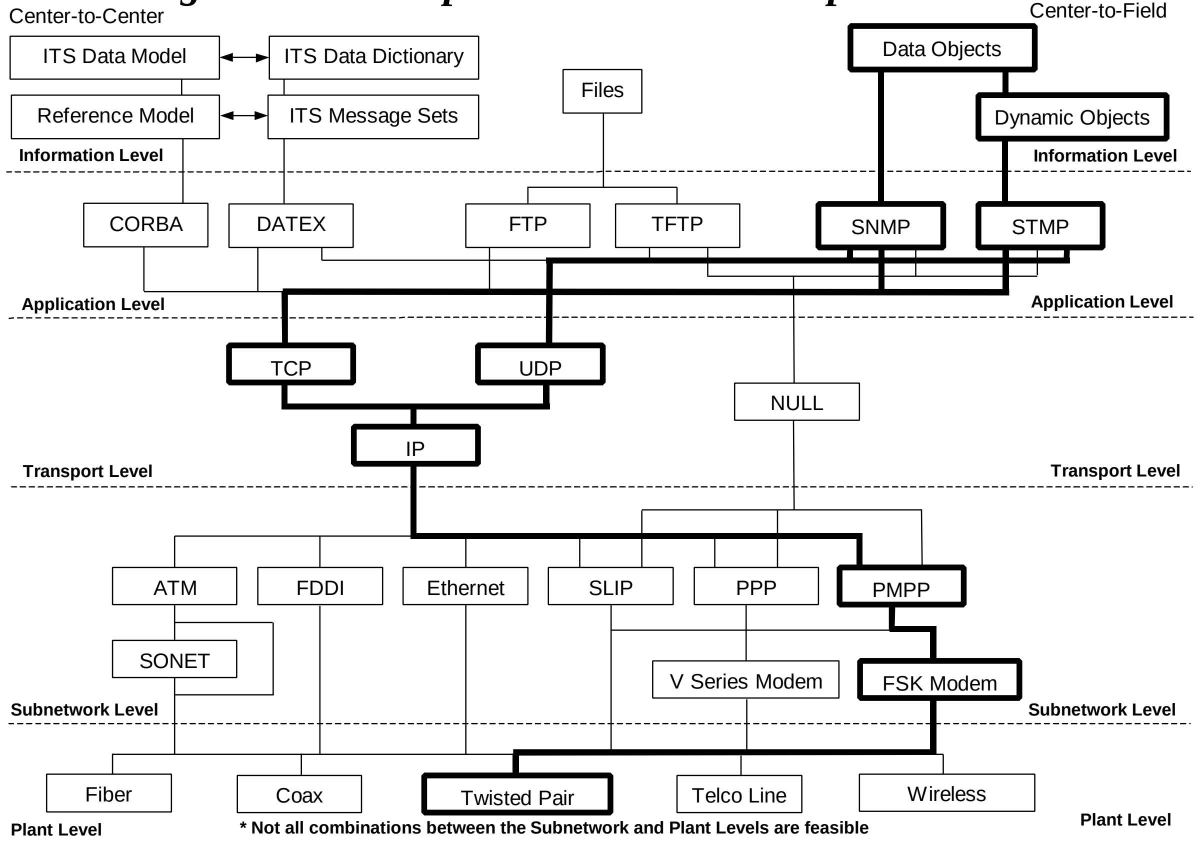
This example shows one possible implementation of NTCIP center-to-field communications where routing through one or more intermediate devices is needed.

Figure 9.2 depicts a common example of a center-to-field NTCIP Implementation where routing through an intermediate device is needed. The routing can take either the form of connectionless or connection-oriented transport delivery services depending on the selection at the Transport Level. For connectionless transport delivery services, the selection of User Datagram Protocol over Internet Protocol (UDP/IP) should be made at the Transport Level. For connection-oriented transport delivery services, Transmission Control Protocol over Internet Protocol (TCP/IP) should be selected as the appropriate Transport Level.

The example NTCIP implementation illustrated in Figure 9.2 highlights one implementation subset of the NTCIP Framework. The figure shows the standard(s) implemented at each NTCIP Framework Level. The example shows the implementation of both STMP and SNMP at the Application Level and TCP, UDP/IP at the Transport Level. Together, these standards provide services for an NTCIP system, such as a traffic signal system, that involves intermediate routing.

The implementation subset of the NTCIP Framework shown in this example is similar to that once known as the Class C Profile. It should be noted that the trend is moving away from denoting the various stacks with alphanumeric characters and is moving towards the designation of specific standards at each level within the NTCIP Framework. As a result, Class A and Class C should be regarded as a legacy term that will ultimately be abandoned in-lieu of an array of specific NTCIP Framework level standards.

Figure 9.2 Example Center-to-Field Implementation



* Not all combinations between the Subnetwork and Plant Levels are feasible

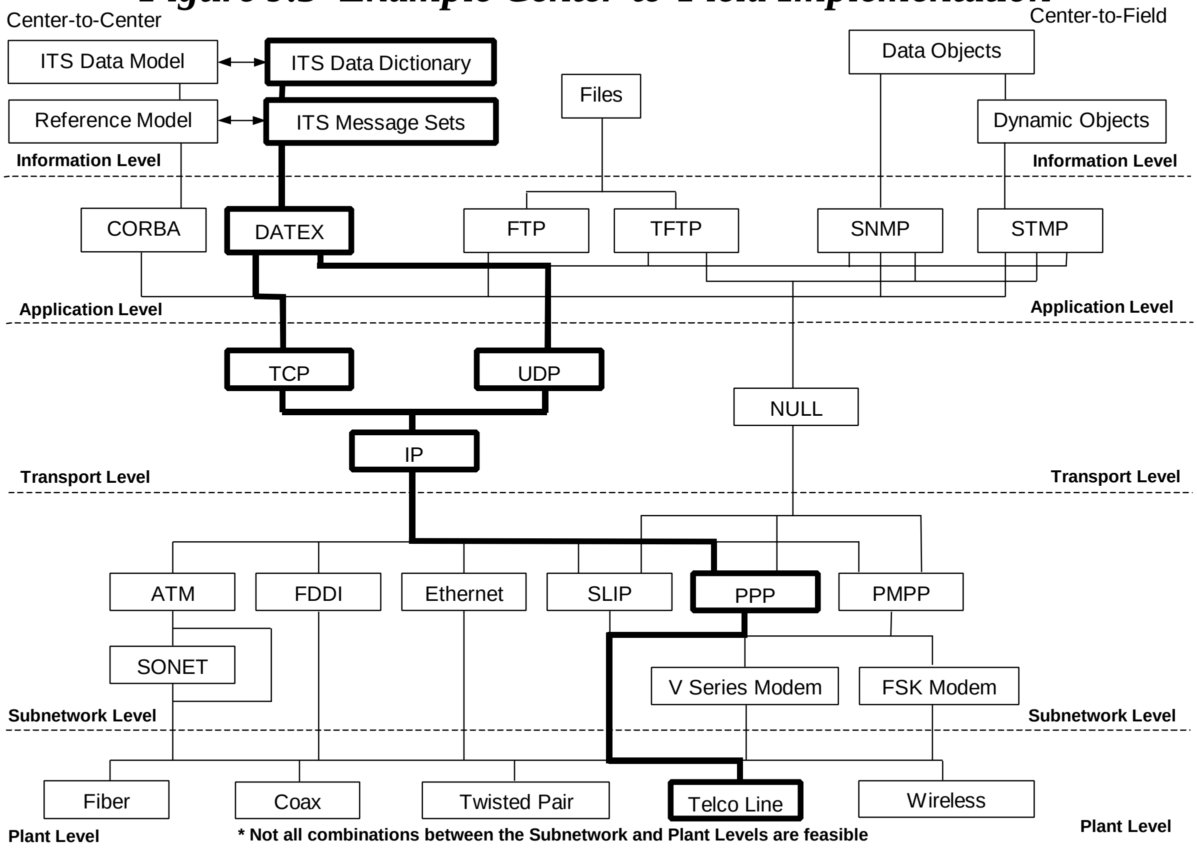
The Subnetwork Level standard selected in this example is Point to Multi-Point, FSK modems. The Plant Level in this example NTCIP implementation is shown to be agency owned twisted pair wire, but any suitable media can be used.

9.2 Center-to-Center

Two examples are provided for center-to-field communications.

9.2.1 Example Center-to-Center Implementation using DATEX

Figure 9.3 Example Center-to-Field Implementation



Example 9.3 Example of a Center-to-Center Implementation using DATEX

This example shows one possible implementation of NTCIP center-to-center communications using DATEX.

Figure 9.3 depicts an example center-to-center NTCIP implementation and is one variation of an approach using DATEX. This NTCIP implementation example is intended for connection-oriented transport delivery services from a transportation management center to field devices.

The example NTCIP implementation illustrated in Figure 9.3 highlights one implementation subset of the NTCIP Framework for center-to-center communications. The figure shows the standard(s) implemented at each NTCIP Framework Level for using DATEX at the Application Level within the NTCIP Framework.

For center-to-center communications, the choices that are offered at the Application Level include DATEX and CORBA. The choices that are defined for the Transport Level are the User Datagram Protocol over Internet Protocol (UDP/IP) for connectionless transport services and Transmission Control Protocol over Internet Protocol (TCP/IP) for connection-oriented transport delivery services. The Subnetwork Level options include a variety of high bandwidth options, such as ATM, FDDI, Ethernet, and PPP. In this case, an example might be to use Frame Relay with a Point-to-Point Protocol (PPP) at the Subnetwork Level. The Plant Level can include a variety of options such as telco lines, as in this example, or fiber.

9.2.2 Example Center-to-Center Implementation using CORBA

Example 9.4 Example of a Center-to-Center Implementation using CORBA

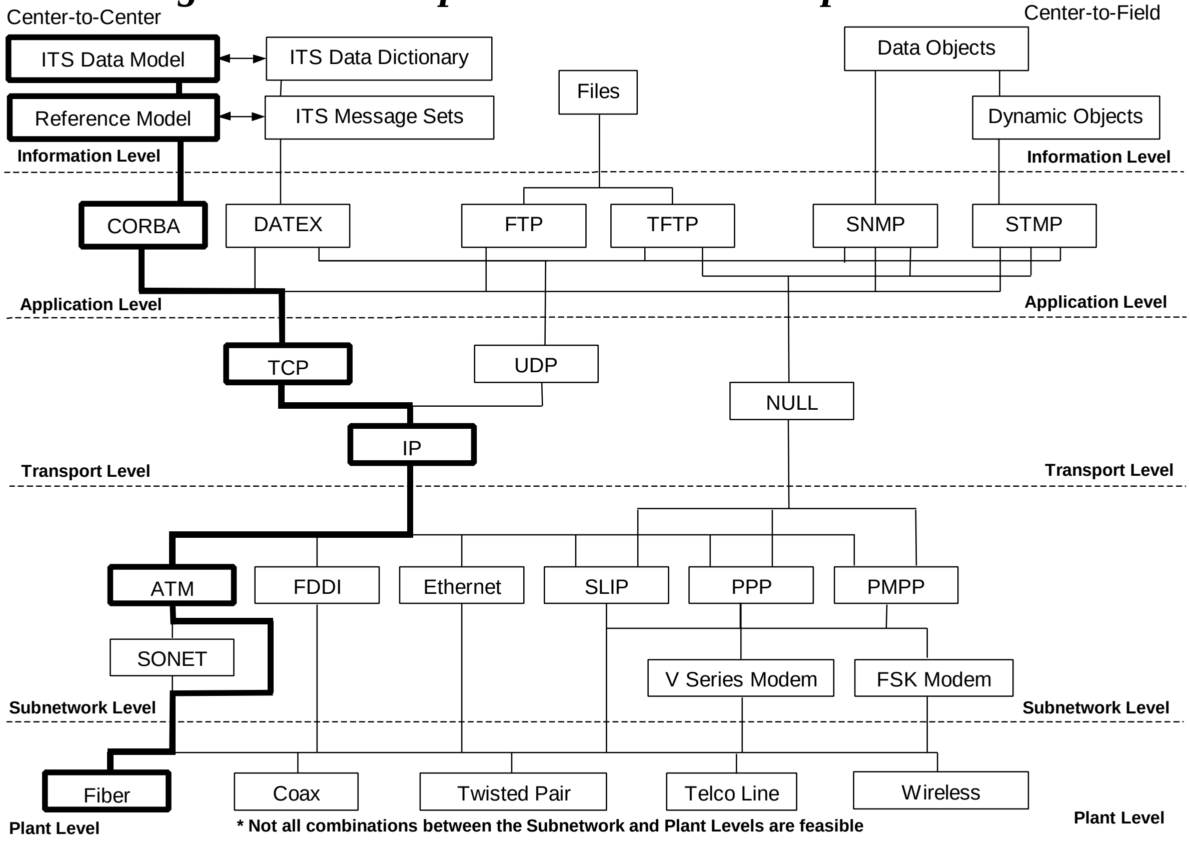
This example shows one possible implementation of NTCIP center-to-center communications using CORBA.

Figure 9.4 depicts an example center-to-center NTCIP implementation and is one variation of an approach using CORBA. This NTCIP implementation example is intended for connection-oriented transport delivery services from a transportation management center to field devices.

The example NTCIP implementation illustrated in Figure 9.4 highlights one implementation subset of the NTCIP Framework for center-to-center communications. The figure shows the standard(s) implemented at each NTCIP Framework Level for using CORBA at the Application Level within the NTCIP Framework.

For center-to-center communications, the choices that are offered at the Application Level include DATEX and CORBA. The choices that are defined for the Transport Level are the User Datagram Protocol over Internet Protocol (UDP/IP) for connectionless transport services and Transmission Control Protocol over Internet Protocol (TCP/IP) for connection-oriented transport delivery services. The Subnetwork Level options include a variety of high bandwidth options, such as ATM, FDDI, Ethernet, and PPP. In this case, an example might be to use ATM at the Subnetwork Level, although other options might also be appropriate. The Plant Level can include a variety of options such as fiber, as in this example, or telco lines.

Figure 9.4 Example Center-to-Field Implementation



* Not all combinations between the Subnetwork and Plant Levels are feasible

10 NTICP DOCUMENTS

The following list of NTCIP documents is dated August 20, 1999.

10.1 Listing of NTCIP Documents

Table 10.1 Listing of Current and Planned NTCIP Documents

Number	Old Number	Title	Type	Status
1101	TS 3.2-1996	NTCIP Simple Transpn. Mgmt. Framework (STMF)	Base Standard	Published with NEMA cover; Amended
1102	OER	NTCIP Octet Encoding Rules (OER)	Base Standard	User Comment Draft
1103	STMP	NTCIP Simple Transpn. Mgmt. Protocol (STMP)	Base Standard	WG Draft
1201	TS 3.4-1996	NTCIP Global Object (GO) Definitions	Device Data Dictionary	Published with NEMA cover; Amended
1202	TS 3.5-1996	NTCIP Objects for ASC	Device Data Dictionary	Published with NEMA cover; Amended
1203	TS 3.6-1997	NTCIP Objects for Dynamic Message Signs (DMS)	Device Data Dictionary	Approved by 3 SDOs
1204	TS 3.7-1998	NTCIP Objects for Environmental (ESS)	Device Data Dictionary	Approved by 3 SDOs
1205	TS 3.CCTV	NTCIP Objects for CCTV Camera Control	Device Data Dictionary	Recommended Standard
1206	TS 3.DCM	NTCIP Objects for Data Collectn. (DCM)	Device Data Dictionary	WG Draft
1207	TS 3.RMC	NTCIP Objects for Ramp Meter Control (RMC)	Device Data Dictionary	WG Draft
1208	TS 3.SWITCH	NTCIP Objects for Video Switches	Device Data Dictionary	User Comment Draft
1209	TS 3.TSS	NTCIP Objects for Transp. Sensor Sys. (TSS)	Device Data Dictionary	User Comment Draft
1400	TCIP-FRAME	TCIP Framework Standard	Process & Control	Recommended Standard
1401	TCIP-CPT	TCIP Common Public Transpn. (CPT) Objects	Device Data Dictionary	Recommended Standard
1402	TCIP-IM	TCIP Incident Management (IM) Bus. Area Std.	Device Data Dictionary	Recommended Standard
1403	TCIP-PI	TCIP Passenger Information (PI) Bus. Area Std	Device Data Dictionary	Recommended Standard
1404	TCIP-SCH	TCIP Scheduling/Runcutting (SCH) Bus. Area St	Device Data Dictionary	Recommended Standard
1405	TCIP-SP	TCIP Spatial Representation (SP) Bus. Area S	Device Data Dictionary	Recommended Standard
1406	TCIP-OB	TCIP On-Board (OB) Objects	Device Data Dictionary	Recommended Standard
1407	TCIP-CC	TCIP Control Center (CC) Objects	Device Data Dictionary	User Comment Draft
1408	TCIP-FC	TCIP Fare Collection (FC) Objects	Device Data Dictionary	User Comment Draft
2001	TS 3.3-1996	NTCIP Class B Profile	Profile - Other	Published with NEMA cover; Amended
2002	CP-CLA	NTCIP Class A and C Profiles	Profile - Other	Withdrawn
2101	SP-PMPP/RS232	NTCIP SP-PMPP/RS232	Subnet Profile	User Comment Draft
2102	SP-PMPP/FSK	NTCIP SP-PMPP/FSK	Subnet Profile	Proposed New Work Item
2103	SP-PPP/RS232	NTCIP SP-PPP/RS232	Subnet Profile	WG Draft
2104	SP-Ethernet	NTCIP SP-Ethernet	Subnet Profile	WG Draft
2201	TP-Null	NTCIP TP-Null	Transport Profile	Proposed New Work Item
2202	TP-INTERNET	NTCIP TP-Internet (TCP/IP and UDP/IP)	Transport Profile	Recommended Standard
2301	AP-STMF	NTCIP AP-STMF	Application Profile	Recommended Standard
2302	AP-TFTP	NTCIP AP-TFTP	Application Profile	Recommended Standard

Table 10.1 Listing of Current and Planned NTCIP Documents

Number	Old Number	Title	Type	Status
2303	AP-FTP	NTCIP AP-FTP	Application Profile	Recommended Standard
2304	TS 3.AP-DATEX	NTCIP AP-DATEX-ASN	Application Profile	User Comment Draft
2305	TS 3.AP-CORBA	NTCIP AP-CORBA	Application Profile	User Comment Draft
2500	InP-C2C	NTCIP EP-C2C	Center Information Profile	WG Draft
2501	InP-DATEX	NTCIP EP-DATEX	Center Information Profile	Proposed Work Item
2502	InP-CORBA	NTCIP EP-CORBA	Center Information Profile	Proposed Work Item
7001	NAN-1	NTCIP Assigned Numbers (NAN) - Part 1	Registry	WG Draft
7002	NAN-2	NTCIP Assigned Numbers (NAN) - Part 2	Registry	WG Draft
8001	White Paper	NTCIP Standards Development Process	Process & Control	WG Draft
8002	None	NTCIP Standards Publications Format	Process & Control	Committee Draft
8003	TS 3.PRO	NTCIP Framework and Classification of Profile	Process & Control	Approved by Joint Committee
8004	SMI	NTCIP Structure and Ident. of Mgmt. & Info. (SMI)	Process & Control	Proposed New Work Item
9001	Guide	NTCIP Guide	Information Report	Published; Revision Drafted
9002	None	NTCIP VDOT Case Study on VMS	Information Report	Project Draft
9003	None	NTCIP WashDOT Case Study on VMS	Information Report	Project Draft
9004	None	NTCIP Phoenix Case Study on Signal Control	Information Report	Project Draft