Communication Plan to Support the
Ten-Year ITS Cost Feasible Plan

Prepared For:

Florida Department of Transportation

ITS Office

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1. 1 Purpose

The purpose of this *Communications Plan* is to identify at a conceptual level the communication needs, requirements and associated standards family required to implement the intelligent transportation systems (ITS) deployments identified in the *Ten-Year ITS Cost Feasible Plan.* The *Ten-Year ITS Cost Feasible Plan* includes the coordinated deployment of nearly $700 million of ITS services on Florida limited-access highways. This *Communications Plan* is needed to ensure the incremental deployments in the *Ten-Year ITS Cost Feasible Plan* are implemented in a coordinated and cost-effective manner.

The work included in this *Communications Plan* represents the combined work of PBS&J, the ITS General Consultant, and PB Farradyne the Telecommunications General Consultant.

1.2 Organization of the Document

This document is organized into five sections.

1. Section 1 provides the introduction, purpose and organization of this document.
2. Section 2 is a summary of the background information for transportation professionals unfamiliar with telecommunication principles.
3. Section 3 is a summary the requirements and alternatives for C2C communications needed to support the *Ten-Year ITS Cost Feasible Plan.*
4. Section 4 is a summary of the requirements for center-to-field communications needed to support the *Ten-Year ITS Cost Feasible Plan.*

2. Background Information

As transportation engineers, we understand the needs, issues, problems and objectives of the transportation users and the issues associated with operations and management of the transportation system. However, communications is a new application for most transportation engineers who make up a dominant part of the ITS marketplace. To assist the reviewers of this document a summary of the basic concepts needed to support the analysis of the telecommunication concepts, analysis and recommendations provided in this *Communications Plan* is provided as follows:

- What are communications for ITS?
- What are the ITS Standards including NTCIP?
- Using the NTCIP Framework For ITS Communication Concept Design

2. 1 What Are Communications For ITS?

Communications for ITS is the process of representing, transferring, interpreting and processing information (data) between people, places and machines. The process involves a sender and a receiver and a transmission medium over which information flows. ITS communications includes, but is not limited to, the transmission of data typically comprised of traffic characteristics, or related information such as weather information, from sensors in the field to a traffic management center. Information about roadway conditions is also transmitted from the traffic management center to roadside devices such as highway advisory radio transmitters or dynamic message signs. Surveillance is also provided through closed-circuit television cameras (CCTV). There are a variety of media that may be used for transmission of this data. The Florida Department of Transportation (FDOT) utilizes leased telecommunication services and also maintains a private network of unshielded twisted pair wire and fiber optic cable systems. These media and the transmission of information over these media currently use several configurations and standards including digital packet switching, asynchronous transfer mode, synchronous optical networks and gigabit Ethernet. Standards for the protocols of the transfer of this information are emerging through ITS Standards including the National Transportation Communication for ITS Protocol (NTCIP) a suite of protocols that provide common standards that can be used by all vendors and system managers to overcome differences in proprietary protocols.

The communications needed for ITS and telecommunications are often used interchangeably. However, in this report the term telecommunications refers explicitly to the purchase of services from a telecommunication service provider, such as a BellSouth.

In the last 30-40 years, communications used for the management of ITS and traffic signal systems have undergone a number of evolutions. Technologies, costs and commercial (pricing) factors have affected this evolution. Table 1 summarizes these trends.

Table 1 – ITS Communications Trends[1]

Period	Type of Requirements	Typical Field Equipment and Communications	Media	Examples
Prior to 1970	System Detectors: Inbound information variables (presence) sampled by central computer at 30 times per second Signal Control: Two outbound control signals, one inbound state signal, all provided by central computer at 1 or 2 times per second	Controllers: Electromechanical or simple electronic with no ancillary data storage capability. Timing changed through intervals or phase command. Communications: Mostly FDM (one channel single signal or two related signals with no data storage capability)	Leased POTS telephone with frequency division multiplexing (FDM)	Chicago Expressway (later some twisted pair wire used)
1970s to Early 1980s	System Detector: 4-8 bits per second Signal Control: Two outbound control signals, one inbound state signal for each major phase, status signals potentially of 8-10 bits once or twice per second.	Controllers: Electromechanical, NEMA, timing through interval or phase command Communications: Mostly fixed byte polled telephone using time division multiplexing (TDM). Short term storage capability in field communication units. Proprietary communication standards, protocols and interfaces.	Owned twisted pair wire with FDM	New Jersey Turnpike Authority

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[1] Adapted from *Communications Handbook For Traffic Control Systems*, FHWA Publication No. FHWA-SA-93-052.

Period	Type of Requirements	Typical Field Equipment and Communications	Media	Examples
Mid 1980s to Mid 1990s	System Detectors: Considerable preprocessing in field (transmission may vary from one time per second to one time per minute) System Control Timing plans downloaded and implemented by field controller.	Controller: Type 170/179. NEMA controllers using proprietary protocols and interfaces. Communications: Mostly fixed using telephone and TDM. Considerable storage and processing in communications unit or controller serving as communications unit.	Leased POTS Telephone FDOT Microwave communications backbone Some single mode fiber optic systems for managing video surveillance	Ontario Highway 401 Ice Warning System in New Mexico Portable DMS for work zone management FDOT Motorist Aid Call Box Systems I-4 SMIS in Orlando Miami FLAMINGO Project
Late 1990s	System Detectors: Considerable preprocessing in field (transmission may vary from one time per second to one time per minute). Video surveillance becomes staple of ITS for incident management. System Control Timing plans downloaded and implemented by field controller.	Controller: Type 2070, 170/179 and NEMA controllers using proprietary protocols and interfaces. Communications: Mostly fixed using telephone and TDM. Considerable storage and processing in communications unit or controller serving as communications unit.	Advancement of DSRC standards for ITS/ETC Multi-mode fiber systems SONET/SDH or SONET/ATM systems for ITS Proliferation of the Internet	Miami Intelligent Corridor System Deployment SunPass™ Electronic Toll Collection (ETC) Jacksonville SunGuide℠ Turnpike SunNav℠

Period	Type of Requirements	Typical Field Equipment and Communications	Media	Examples
Current Trends	System Detectors: Considerable preprocessing in field and storage at devices. Proliferation of new detection devices such as microwave radar, magnetometers (microloops), acoustic and infrared sensors. Video becomes major driver for communication needs and security is increasingly important. System Control Timing plans downloaded and implemented by field controller or computed by the field controller.	Controller: Advanced Traffic Controllers (ATC) using open architecture and NTCIP. Communications: Emergence of NTCIP, use of IP-video, and deployment of Gigabit Ethernet applications for ITS	Wireless (using IEEE Std. 802.11) All other media mentioned before	I-4 SMIS Orlando Upgrade FDOT Microwave Backbone Upgrade *Ten-Year ITS Cost Feasible Plan*

Source: Adapted and expanded from *Communications Handbook for ITS*, FHWA-SA-93-052.

2.2 What Are the ITS Standards?

2.2.1 Overview

ITS Standards define a family of transportation-specific protocols[2] that can be used by many types of computer systems and field devices for transportation management. Of specific interest are the NTCIP suite of protocols. Applications for NTCIP are generally divided into two categories – center-to-field (C2F) and center-to-center (C2C). Additionally, the NTCIP suite of protocols addresses data dictionaries / message sets and underlying communications protocols that transport the data defined in the data dictionaries.

For the C2F, both data dictionaries as well as underlying communications protocols have been developed or referenced. The underlying communications protocols are largely referenced to take advantage of existing and proven information technology/Internet protocols. The data dictionaries on the other hand are transportation-industry specific. C2F standards normally

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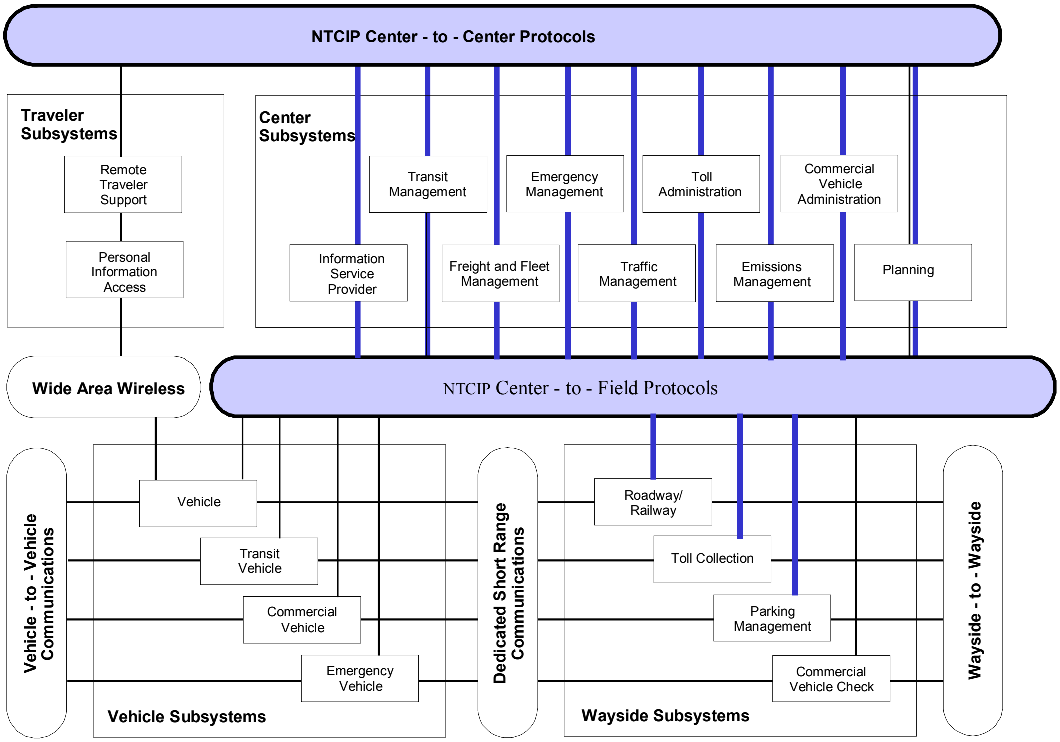
[2] A protocol is a collection of procedures for the initiation, maintenance, and termination of data communications.

address communications between devices at the roadside and management software on a central computer.

For C2C implementations, the NTCIP only defines the underlying communications protocols such as DATEX-ASN and CORBA, both of which are transmitted over the Internet-developed TCP/UDP/IP standard. The C2C data dictionaries were developed by different efforts such ITE's Traffic Management Data Dictionary and/or SAE's Incident Management effort. C2C 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 1.

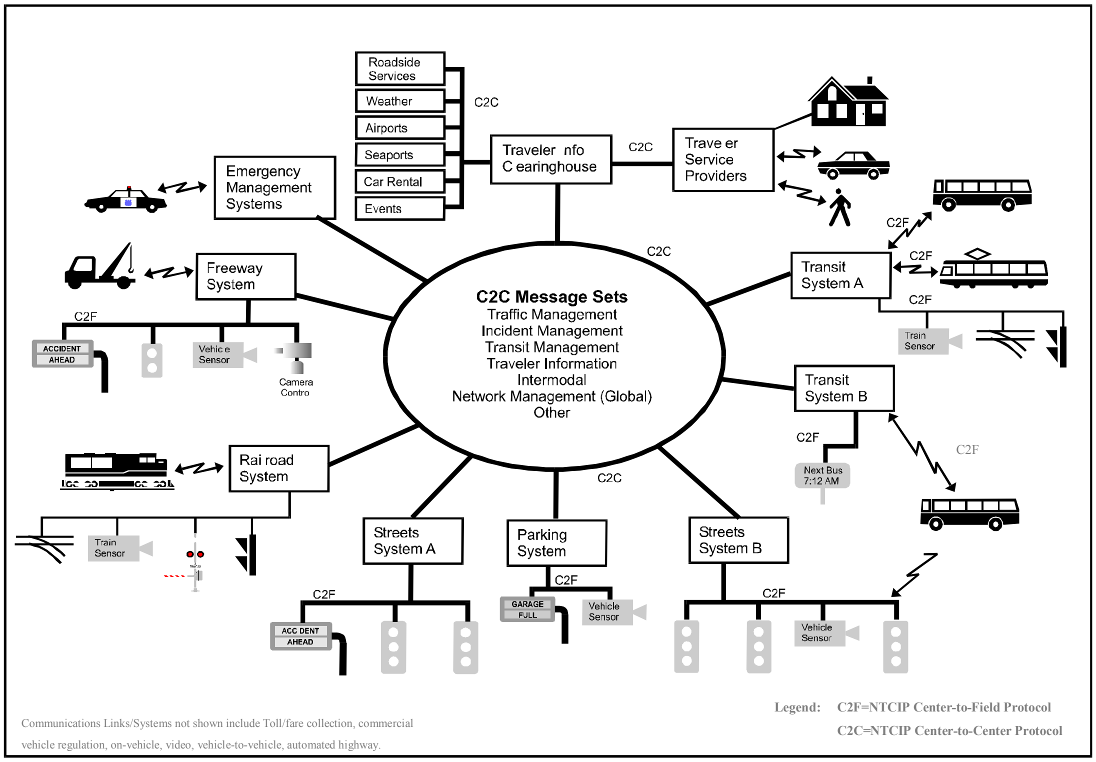
Figure 1 – ITS Standards and the ITS National Architecture



For both C2F and C2C applications, NTCIP supports systems and devices used in traffic, transit, emergency management, traveler information, and planning (data archiving) systems. Figure 2 illustrates how various transportation management systems and devices can be integrated using NTCIP.

Some computers involved in C2C communications may be located in the field (e.g., kiosks, field masters, advanced controllers). NTCIP's center-to-field and C2C protocols have options to support dial-up, Ethernet, and serial communications links. The following are examples of systems and devices that can take advantage of ITS Standards and especially the NTCIP standards:

Figure 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

Center-to-Field (data dictionaries and message sets only)
- Dynamic message signs – NTCIP 1203
- Traffic signals – NTCIP 1202
- Environmental sensors – NTCIP 1204
- Ramp meters – NTCIP 1207
- Vehicle detectors (intrusive and non-intrusive) – NTCIP 1209 and NTCIP 1206
- Closed circuit television cameras (PTZ control only) – NTCIP 1205 and 1208
- Any mix of the above

C2C (data dictionaries and message sets only)
- Traffic management (freeway/surface street, urban/rural) – ITE TM1.03 and TM2.01
- Transit management (bus/rail/other) – NTCIP 1401 to NTCIP 1409
- Emergency management – IEEE 1512
- Parking management – partially covered in NTCIP 1404
- Traveler information (all modes) – SAE J2353 and J2354
- Commercial vehicle operations regulation – ASTM TS284 to TS286

- Any mix of the above

Many applications using ITS Standards are related to near real-time communications and involve continuous, automated transmissions of data or commands. ITS Standards also support human-to-remote-machine/system transmissions. Historical data can also be sent using ITS Standards, but other communication standards, especially electronic mail and file transfer protocols developed for the Internet (and referenced in NTCIP standards such as NTCIP 2302, NTCIP 2303, NTCIP 2202, NTCIP 2103 and NTCIP 2104), 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 by the NTCIP C2C protocols.

2.2.2 What Is Not Covered by the Above ITS Standards?

Some of the data transfers involved in ITS have special needs that are the subject of other standards development efforts. The above ITS Standard efforts are coordinated with the activities of these other groups to the extent practical. The 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, which is be covered by the Dedicated Short Range Communications (DSRC) standard. However, NTCIP is suited to communications between the roadside tag reader and a central computer[3].

- Any video (slow scan to full motion) 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 within the Information Technology industry. However, there are special NTCIP standards to transmit video camera (NTCIP 1205) and switch control (NTCIP 1208) 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 (such as the FM Subcarrier protocol defined in EIA 795) or cellular radio. However, NTCIP is suited to sending the information from various data sources to the traveler information service provider. While NTCIP standards such as NTCIP 2202 (TCP/IP) and NTCIP 2104 (Ethernet) could be used to transmit the data, SAE standards J2353 and J2353 define the data dictionary and message set to transmit data from a TMC to a traveler ISP.

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[3] NTCIP provides communications protocols such as TCP/IP and Ethernet that transport the data; however, the data dictionaries and message sets covering this type of end-application are not defined within the NTCIP suite of standards.

- Communications for financial transactions. This involves special security measures and data sets developed by the financial industry. ITS implementations will need to support these secure standards to facilitate and interface with financial institutions.

- 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 such as the SAE J2355 (ITS Data Bus (IDB) Architecture Reference Model), SAE J2366 (ITS Data Bus (IDB) Protocol), SAE J1760 (ITS Data Bus (IDB) Data Security Services Recommended Practice), and SAE J2395 (ITS In-Vehicle Message Priority Recommended Practice)**.**

- 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. There are several ITS Standards currently under development that address this aspect such as the ITE 9603-3 (Advanced Transportation Controller) standard.

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

2.2.3 The Levels or Modules Involved in ITS Standards Communications

ITS Standards use 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., NTCIP 140x (Transit Communications Interface Protocols), NTCIP 1202 (advanced signal controller), ITE TM 1.03 and TM2.01 (MS/ETMCC), etc.). The ITS Standards on this level are not specific to the NTCIP suite of protocols.

- Application Level – This level provides standards for the data packet structure and session management. (e.g., SNMP, STMP, DATEX, CORBA, FTP, etc.). The ITS Standards on this level are largely defined and/or referenced in NTCIP Standards.

- Transport Level – This level provides standards for data packet subdivision, packet reassembly, and routing when needed (e.g., TCP, UDP, IP). The ITS Standards on this level are largely defined and/or referenced in NTCIP Standards.

- 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.). The ITS Standards on this level are largely defined and/or referenced in NTCIP Standards.

- 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 mostly unique to the transportation industry; however, there are some communications standards-related data elements developed by and used in the IT industry that are applicable to ITS systems. 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 and/or message sets or interface specifications/dialogs 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 (except for low-speed, high-frequency, multi-drop serial systems such as signal control networks), 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.

2.2.4 Focus of the NTCIP

The application level is the primary focus of the NTCIP. Although some existing standards are useful, 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, 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 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.

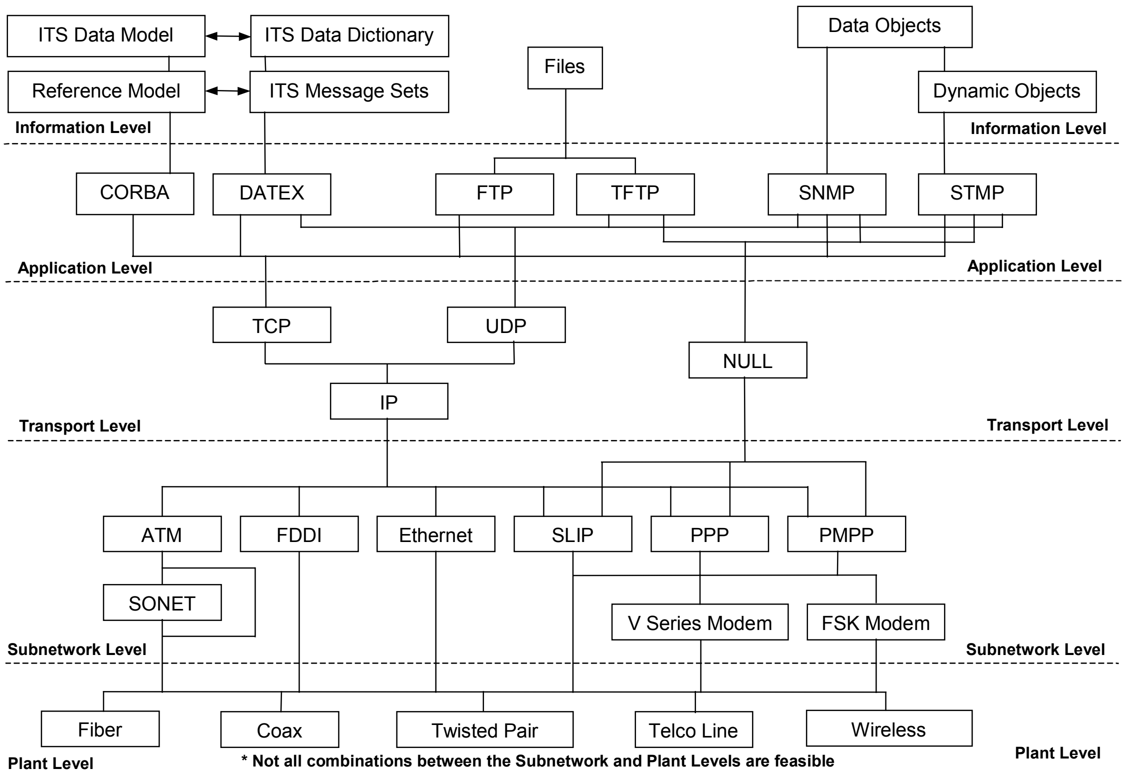
2.2.5 The NTCIP Framework

Figure 3 illustrates the framework for the NTCIP. The diagram shows the different standards that can be chosen at each level (boxes) and which ones are compatible (lines connecting boxes).

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 (but unusual) 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, 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. A dashed line shows interrelated standards, i.e., the ITS Data Dictionaries and ITS Message Sets are basically the same as the ITS Data Model and ITS Reference Model, but the former are used in conjunction with DATEX while the latter are used in conjunction with CORBA.

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, which are not defined in the ISO OSI Reference Model. The levels and terminology used in NTCIP were chosen for simplicity and ease of understanding by lay readers, and for 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 - NTCIP Standards Framework



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

2.3 Using the NTCIP Framework for ITS Communication Concept Design

In this communication plan, the five layers of the NTCIP Framework for ITS communications are used as basis for the outline of the plan. In each subsequent section of this report, the alternatives analysis and standards associated with each element of the framework are discussed and provided to compose the ultimate recommendation of the *Communications Plan*.

This *Communications Plan* also relies heavily on the recommendations of the *NTCIP Guide* (NTCIP 9001 v3 (Draft) Section 5. Designing NTCIP), which provides an overview of the communication design considerations for designing a communications system using the NTCIP suite of standards.

2. Communication Alternatives

The following basic communication scenarios are needed to support the *Ten-Year ITS Cost Feasible Plan*. These scenarios are based on two basic types of communications as defined by the NTCIP (C2C and center-to-field). Three basic assumptions were also made that relate to the backbone communications media. The three basic alternatives considered in this plan are to use a fiber optic backbone that is constructed either by FDOT or with a partner through a shared-resource project; use the FDOT's microwave backbone; or for a information service provider to provide communications to support advanced traveler information services (ATIS). Table 2 summarizes these basic scenarios.

Table 2 - Basic Communication Scenarios Considered

Type of Communication/ Basic Assumption	Using a fiber optic network constructed by FDOT or through a shared-resource project	Using the FDOT's microwave communication network	Telecommunications provided by a partner information service provider (ISP) for advanced traveler information services (ATIS)
C2C	●	●	●
Center-to-Field	●	●	●

In addition to the C2C and center-to-field scenarios identified in this plan, special consideration is given to the approach for the management of video for traffic management and ATIS applications. Common questions and issues arise over a centralized approach to video, such as a single National Television System Committee (NTSC) centralized server or a decentralized approach with multiple video servers in the field. Both approaches are currently used in Florida.

3. Center-to-Center Communications Network

The issues associated with network connectivity between traffic management centers involve complex environments using multiple media, multiple protocols and services, and interconnection to networks outside any single traffic management center's domain of control. Carefully designing the network can reduce the hardships associated with growth as the networking environment evolves.

This chapter provides an overview of planning and design issues for C2C communications. Discussions are divided into the following general topics:

- C2C communications requirements
- Communications plant
- Subnetwork standard
- Transport-level network standards
- Application protocols

3.1 Center-to-Center Communication Requirements

The following is a generalized list of requirements for Center to Center (C2C) communications based on the efforts completed as part of the *Ten-Year ITS Cost Feasible Plan* and preliminary work completed by ITS standards organizations. This is not intended to be a comprehensive list of requirements. A separate project is ongoing to develop C2C standards and an NTCIP migration plan. This list is a guideline for developing general requirements in support of the *Ten-Year ITS Cost Feasible Plan.*

The overriding assumption of this list is that the Regional Traffic Management Centers (RTMC) in Florida will need the ability to share electronic information regarding traffic conditions between their jurisdictions. This may include traffic sensor data, video data, and event data among others. This list also assumes that there will be a requirement for some degree of ability for one center to accept or pass control of certain traffic control devices to other centers.

3.1.1 Functional Requirements

The following functional requirements for C2C were developed as part of the *Technical Memorandum No. 4.1 – ITS Corridor Master Plans: Concept of Operations for ITS Deployments along Florida's Principal FIHS Limited-Access Corridors* (herein after referred to as the *ITS Concept of Operations*).

<u>Minimum Requirements</u>

- Coordination with all law enforcement, fire/rescue, and emergency management personnel
- Support operations and management during natural or manmade disasters or evacuations

- Provide secondary control of operations normally managed by other RTMCs during natural or man-made disasters

Desirable Requirements

- Coordination with local traffic operation centers
- Coordination with county emergency management centers and the SEOC when appropriate
- Coordination with a freeway incident management team involving major stakeholders
- Reporting of data needed for performance monitoring and deployment evaluation including HPMS requirements through coordination with the TranStat Office
- Traffic data archiving and data warehousing including regional data sharing capabilities
- C2C communications to support major incidents that effect multiple jurisdictions including evacuation
- Integration with computer aided dispatch systems for incident detection with regional communications centers (RCCs) and emergency operations centers through co-location, communications links, and software or provision of operation stations in the TMC
- Support Advanced Public Transit Systems information needs such as transit, port and airport
- Provide data to information service providers (ISP) who are providing Advanced Traveler Information Services (ATIS)

Some the requirements above that may have been anticipated to be minimum requirements are desirable since the level of maturity and development of ITS is different in each District. Each District agreed to achieve the desirable requirements once mature systems are complete.

3.1.2 Administrative Requirements

These requirements are those needed for the operational needs of C2C communications and would be definitional in nature. Administrative items will require maintenance to be sent between centers but likely a very low data transmission requirement once established. Items will include:

- Agency/Organization definition
- Key contact information
- Security procedures (login, password, control levels, etc.)
- Reporting – sharing of administrative status

3.1.3 Planned Event Reporting

This requirement pertains to maintenance and notification of planned events, such as construction, parades, sporting events, etc that may have an inter-jurisdictional impact on traffic. Planned Events will require maintenance and status reporting but likely a low data transmission requirement.

These requirements will include:

- Creating and sharing report data
- Updating and maintaining report data
- Coordination and maintenance of action or incident management plans

3.1.4 Unplanned Event Reporting

These events are those associated with deteriorating traffic conditions due to accidents, bad weather, or other unexpected road conditions. Depending upon severity and location this type of incident may have a heavy data transmission requirement including but not limited to Video transmissions. For purpose of C2C communications this paper assumes that each RTMC will "pass" the information to the appropriate EMS or police agencies, preferably through joint use of the same center.

These requirements will include:

- Creating and sharing report data
- Updating and maintaining report data
- Coordination and maintenance of action or incident management plans

3.1.5 Device Sharing and Control

This requirement represents the largest potential requirement for data transmission between centers. In most cases this requirement will be highest in times of an emergency or severe traffic situation. For purposes of this paper it is assumed that the sharing of raw detection data will only be needed in the case of video. In other cases the detection data will be processed by the "owning" center and the "results" shared with the other centers.

Passing control of a device between centers will require resolution of the many administrative issues that can be envisioned. However this is not a major technical issue and the requirement for data transmission must be looked at closely. The most likely devices to be used in a C2C control situation would be Dynamic Message signs (DMS) and video. The data requirements for DMS are very low with capability of several DMS signs to be controlled over a single 9600 bps line.

However the data requirements for full motion compressed video of reasonable quality is ball parked at one T1 circuit per camera. While there are certainly technical considerations regarding the sharing of video and control, this guideline should suffice for planning purposes at this time. The question then becomes how many cameras will need to be simultaneously shared between centers. That assumption will determine the primary bandwidth requirement.

The data requirement for actual control functions is very small compared to the requirement for actual video. It is a fair assumption to make that if the Video requirements can be met, the other data transmission requirements should fit within that range. Device sharing requirements include:

- Device database inventory (device type, location, status)
- Device sharing procedure – request/accept
- Device data format/reports

3.1.6 Other Potential Requirements

There exists the potential for sharing other types of ITS data between centers. This could include Highway Advisory Radio (HAR)[4], signal control information, ramp metering information, and parking information. The main requirements for these would be inventory and some limited control functions and they are not seen to have a significant impact on data transmission requirements between centers.

The Traffic Management Data Dictionary Working Group also recently published a *Draft Concept of Operations* that documents the following functions as needs for C2C communications.

- User Need to Control Devices That Control Traffic
- User Need to Manage Information
- User Need to Manage Assets
- Provide Control Sharing
- Provide Status Sharing
- Provide Inventory Sharing
- Provide Traffic Signal Control
- Provide Ramp Meter Control
- Provide DMS Control
- Provide Gate Control
- Provide Lane Control
- Provide Response Plan Control
- Provide Incident Report Information Sharing
- Provide Historical Information About An Incident
- Provide Construction Project Plan Information Sharing
- Provide Construction Progress Information Sharing
- Provide Historical Information About Construction
- Provide Special Event Plan Information Sharing
- Provide Special Event Progress Information Sharing
- Provide Historical Information about a Special Event
- Provide information Sharing on Agencies, Operations Organizations, and Centers
- Provide Information on the Status of Traffic Signals
- Provide Information on the Status of Ramp Meters
- Provide Information on the Status of Dynamic Message Signs
- Provide Information on the Status of Highway Advisory Radio

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[4] Note that there is currently no Center to Field (NTCIP) Standard covering HAR.

- Provide CCTV Camera and Video Switch Status and Control
- Provide Environmental Sensor Station (ESS) Data and Status
- Provide Traffic Section Definition
- Provide Traffic Network Definition
- Provide Information on the Status of Traffic Detectors
- Provide Traffic Detector Data
- Provide Vehicle Detector Data
- Provide Parking Lot Information
- Provide System Alarms
- Provide C2C User Information
- Establish and Maintain C2C Security Credentials
- Provide Traffic Signals Inventory
- Provide Ramp Meter Inventory
- Provide CCTV Camera and Video Switch Inventory1
- Provide Dynamic Message Sign (DMS) Inventory
- Provide Highway Advisory Radio (HAR) Inventory
- Provide Environmental Sensor Station (ESS) Inventory
- Provide Traffic Detector Inventory
- Provide Vehicle Detector Inventory
- Provide System Alarm Inventory
- Provide Controllable Lanes and Gates Inventory
- Provide Response Plan Inventory

These functions are being addressed in greater detail through the *Center-to-Center Communications Standards Project* and the *Statewide TMC Software Library Project.*

3.1.7 Relationships Between Traffic Management Centers

FDOT has identified four (4) types of TMCs that will connect to each other to provide data backup and temporary assumption of responsibilities in times of disaster. There are ten (10) RTMCs defined in *Technical Memorandum No. 4.1 – ITS Corridor Master Plans: Concept of Operations for ITS Deployments along Florida's Principal FIHS Limited-Access Corridors* (hereinafter referred to as the *ITS Concept of Operations* and available at http://floridaits.com) and each RTMC will connect to satellite (or secondary) transportation management centers (STMCs) and local TMCs, depending on the needs. Communications links identified as needs in the *ITS Concept of Operations* between RTMCs are grouped by districts. There are eight (8) districts identified in the *ITS Concept of Operations*

.

RTMCs will provide center-to-center communications between each other as shown in Table 3. The following information was extracted from the *Concept of Operations* dated May 8, 2002.

Table 3 – Regional Transportation Management Center (RTMC) Communications Links

FLORIDA REGIONAL TRAFFIC MANAGEMENT CENTERS	Broward County RTMC	Ft. Myers RTMC	Jacksonville RTMC	Miami RTMC	Orlando RTMC	Palm Beach County RTMC	Pompano Beach RTMC	Tallahassee RTMC	Tampa RTMC	Turkey Lake RTMC
Broward County RTMC		●		●		●	●			
Ft. Myers RTMC	●								●	
Jacksonville RTMC					●			●	●	
Miami RTMC	●						●			
Orlando RTMC			●			●			●	●
Palm Beach County RTMC	●				●		●			
Pompano Beach RTMC	●			●		●				●
Tallahassee RTMC			●							
Tampa RTMC		●	●		●					●
Turkey Lake RTMC					●		●		●	

The RTMC communications links for Districts 1 through 8 are shown in Tables 4 through 11, consecutively and their location and proposed coverage of facilities is illustrated in Figures 4.

Table 4 – District 1's Regional Transportation Management Center (RTMC) Communications Links

DISTRICT 1 REGIONAL TRAFFIC MANAGEMENT CENTERS	Charlotte County TMC	City of Bradenton TMC	City of Cape Coral TMC	City of Ft. Myers TMC	City of Naples TMC	City of Sarasota TMC	City/County Police/Fire	Collier County TMC	Collier County TMC	County Emergency Management	FHP Troop F	Ft. Myers TMC	Lee County TMC	LEETRAN Transit Management Center	Manatee County TMC	MCAT Transit Management Center	Punta Gorda TMC	Road Rangers Service Patrol Dispatch	Sarasota County TMC	Sarasota STMC	SCAT Transit Management Center	SunPass Service Center
Charlotte County TMC												●					●					
City of Bradenton TMC															●							
City of Cape Coral TMC													●									
City of Ft. Myers TMC													●									
City of Naples TMC								●														
City of Sarasota TMC																			●			
City/County Police/Fire												●										
Collier County TMC					●							●										
Collier County TMC					●							●										
County Emergency Management												●										
FHP Troop F												●										
Ft. Myers TMC	●						●	●		●	●		●					●		●		●
Lee County TMC			●	●								●		●								
LEETRAN Transit Management Center													●									
Manatee County TMC		●														●				●		
MCAT Transit Management Center															●					●		
Punta Gorda TMC	●																					
Road Rangers Service Patrol Dispatch												●										
Sarasota County TMC						●														●	●	
Sarasota STMC												●			●	●			●		●	
SCAT Transit Management Center																			●	●		
SunPass Service Center												●										

Table 5 – District 2's Regional Transportation Management Center (RTMC) Communications Links

DISTRICT 2 REGIONAL TRAFFIC MANAGEMENT CENTERS	City of Gainesville TMC	City of Jacksonville TMC	City of Lake City TMC	City/County Fire and Police	Clay County TMC (For ATIS Only)	County Emergency Management	FHP Troop B	FHP Troop D	FHP Troop G	FHP Troop H	Gainsville Regional Transit Authority	Jacksonville RTMC	Jacksonville Transit Authority Transit Management Center	Lake City VTMC at District 2 Headquarter	St. Augustine TMC	St. Augustine TMC
City of Gainesville TMC												●				
City of Jacksonville TMC												●				
City of Lake City TMC												●				
City/County Fire and Police												●				
Clay County TMC (For ATIS Only)																
County Emergency Management												●				
FHP Troop B												●				
FHP Troop D												●				
FHP Troop G												●				
FHP Troop H												●				
Gainsville Regional Transit Authority												●				
Jacksonville RTMC	●	●	●	●		●	●	●	●	●	●		●	●	●	●
Jacksonville Transit Authority Transit Management Center												●				
Lake City VTMC at District 2 Headquarters												●				
St. Augustine TMC												●				
St. Augustine TMC												●				

Table 6 – District 3's Regional Transportation Management Center (RTMC) Communications Links

DISTRICT 3 REGIONAL TRAFFIC MANAGEMENT CENTERS	City of Pensacola TMC	City of Tallahassee Traffic Control Center	City/County Fire and Police	Escambia County Area Transit Agency	Escambia County TMC	Escambia/ Santa Rosa County Multimodal Transportation Operations Center	FHP Troop A	FHP Troop H	Leon County Emergency Management	Leon County TMC	Okaloosa County TMC	Panama City Traffic Center	Pensacola Satellite Traffic Operations Facility	Road Rangers Service Patrol	SEOC	Talahassee RTMC	TALTRAN Transit Control Center
City of Pensacola TMC					●												
City of Tallahassee Traffic Control Center									●							●	●
City/County Fire and Police																●	
Escambia County Area Transit Agency					●											●	
Escambia County TMC	●			●		●										●	
Escambia/ Santa Rosa County Multimodal Transportation Operations Center					●											●	
FHP Troop A																●	
FHP Troop H																●	
Leon County Emergency Management																	
Leon County TMC		●														●	
Okaloosa County TMC																●	
Panama City Traffic Center																●	
Pensacola Satellite Traffic Operations Facility																●	
Road Rangers Service Patrol																●	
SEOC																●	
Talahassee RTMC		●	●	●	●	●	●	●		●	●	●	●	●	●		
TALTRAN Transit Control Center		●															

Table 7 – District 4's Regional Transportation Management Center (RTMC) Communications Links

DISTRICT 4 REGIONAL TRAFFIC MANAGEMENT CENTERS	Broward County Emergency Management Center	Broward County ITS Operations Facility (RTMC)	Broward County Traffic Control Center	Broward County Transit Agency	City/County Police and Fire	County Emergency Management	FHP Troop K	FHP Troop L	Martin County Traffic Control Center	Palm Beach County Emergency Management Center	Palm Beach County ITS Operations Facility (RTMC)	Palm Beach County Traffic Control Center	Palm Beach County Transportation Authority	Pompano Beach Turnpike RTMC	Road Rangers Servive Patrol	St. Lucie County Traffic Control Center	SunGuide Smart Route TMC (For ATIS only)	SunPass Service Center	Tri-County Commuter Rail Authority
Broward County Emergency Management Center		●																	
Broward County ITS Operations Facility (RTMC)	●		●	●	●	●	●	●			●			●	●		●	●	
Broward County Traffic Control Center		●																	
Broward County Transit Agency		●																	
City/County Police and Fire		●																	
County Emergency Management		●																	
FHP Troop K		●																	
FHP Troop L		●																	
Martin County Traffic Control Center											●								
Palm Beach County Emergency Management Center																			
Palm Beach County ITS Operations Facility (RTMC)		●							●			●	●			●	●		●
Palm Beach County Traffic Control Center											●		●						
Palm Beach County Transportation Authority											●	●							
Pompano Beach Turnpike RTMC		●																	
Road Rangers Servive Patrol		●																	
St. Lucie County Traffic Control Center											●								
SunGuide Smart Route TMC (For ATIS only)		●									●								
SunPass Service Center		●																	
Tri-County Commuter Rail Authority											●								

Table 8 – District 5's Regional Transportation Management Center (RTMC) Communications Links

DISTRICT 5 REGIONAL TRAFFIC MANAGEMENT CENTERS	Brevard County Traffic Operations Center	Central Florida Regional Transportation Authority (LYNX) Transit Management Center	City of Datona Beach TMC (DASH)	City of Melbourne TMC	City of Ocala TMC	City of Orlando Traffic Operations Center	City/County Fire and Police	County Emergency Management	Disney/Reedy Creek TMC	District 1 Bartow VTMC	FDOT District 5 Headquarters STMC	FHP Troop C	FHP Troop D	FHP Troop G	FHP Troop K	OOCEA Tolls Office TMC	Orange County TMC	Orlando RTMC	Road Rangers Service Patrol	Seminole County Traffic Action Center	Space Coast Area Transit Agency	SunPass Service Center	Turkey Lake Turnpike RTMC	UCF Data Warehouse	Volusia County TMC	Volusia County Transit Agency (VOTRAN)	Volusia County EOC	Winter Park Traffic Operations Center
Brevard County Traffic Operations Center				●														●			●							
Transit Management Center																		●										
City of Datona Beach TMC (DASH)																		●										
City of Melbourne TMC	●																											
City of Ocala TMC																		●										
City of Orlando Traffic Operations Center											●						●	●										
City/County Fire and Police																		●										
County Emergency Management																		●										
Disney/Reedy Creek TMC																		●										
District 1 Bartow VTMC																		●										
FDOT District 5 Headquarters STMC						●											●	●		●				●	●		●	
FHP Troop C																		●										
FHP Troop D																		●										
FHP Troop G																		●										
FHP Troop K																		●										
OOCEA Tolls Office TMC																		●										
Orange County TMC						●					●							●										●
Orlando RTMC	●	●	●		●		●	●	●	●	●	●	●	●	●	●	●		●	●	●	●	●	●	●	●		
Road Rangers Service Patrol																		●										
Seminole County Traffic Action Center											●							●										
Space Coast Area Transit Agency	●																	●										
SunPass Service Center																		●										
Turkey Lake Turnpike RTMC																		●										
UCF Data Warehouse						●												●										
Volusia County TMC						●												●								●		
Volusia County Transit Agency (VOTRAN)						●												●							●			
Volusia County EOC						●																						
Winter Park Traffic Operations Center																	●											

Table 9 – District 6's Regional Transportation Management Center (RTMC) Communications Links

DISTRICT 6 REGIONAL TRAFFIC MANAGEMENT CENTERS	City/County Fire and Police	County Emergency Management	FHP Troop E	FHP Troop K	Miami RTMC	Miami-Dade County Traffic Control Center	Miami-Dade Expressway Authority (MDX) TMC	Miami-Dade Transit Authority (MDTA)	Pompano Beach RTMC	Road Rangers Service Patrol	SunGuide Smart Route TMC (For ATIS Only)	Sunpass Service Center	Tri-County Commuter Rail Authority (Tri-Rail)
City/County Fire and Police					●								
County Emergency Management					●		●						
FHP Troop E					●								
FHP Troop K					●								
Miami RTMC	●	●	●	●		●		●	●	●	●	●	●
Miami-Dade County Traffic Control Center					●		●	●					
Miami-Dade Expressway Authority (MDX) TMC		●			●	●		●			●		
Miami-Dade Transit Authority (MDTA)					●	●	●						
Pompano Beach RTMC					●								
Road Rangers Service Patrol					●								
SunGuide Smart Route TMC (For ATIS Only)					●		●						
Sunpass Service Center					●								
Tri-County Commuter Rail Authority (Tri-Rail)					●								

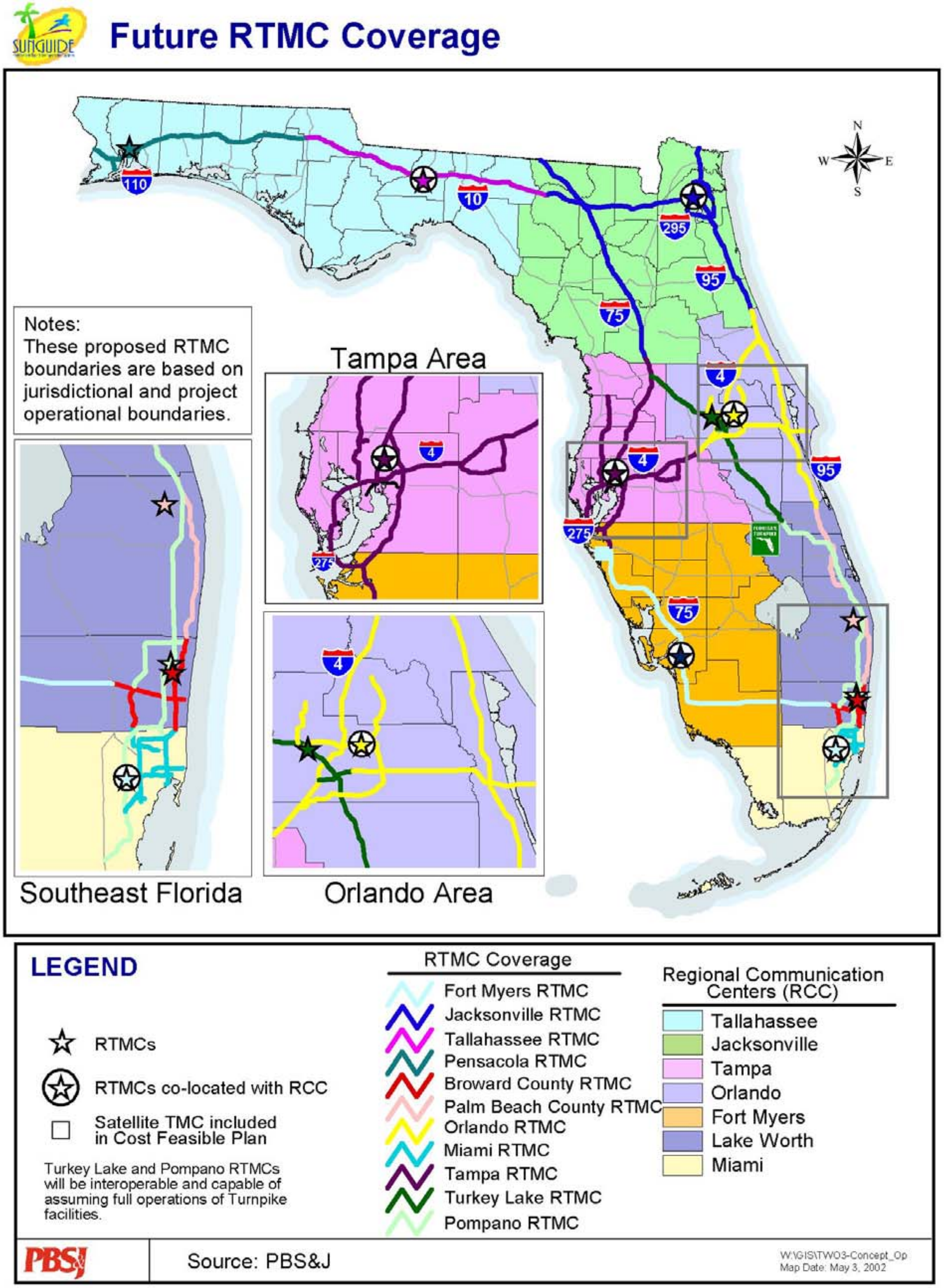
Table 10 – District 7's Regional Transportation Management Center (RTMC) Communications Links

DISTRICT 7 REGIONAL TRAFFIC MANAGEMENT CENTERS	City of Clearwater TMC	City of Lakeland TMC	City of Tampa Traffic Control Center	City/County Fire and Police	County Emergency Management	District 1 Bartow VTMC	FHP Troop C	FHP Troop F	Future SunGuide ISP Center	Future THCEA Management Center	HARTLine Transit Control Center	Hernando County Traffic Control Center	Hillsborough County Traffic Control Center	Manatee County Traffic Control Center	Pasco County Traffic Control Center	Pinellas County TMC	Pinellas Suncoast Transit Authority (PSTA)	Plant City Traffic Control Center	Road Rangers Service Patrol	St. Petersburg Traffic Control Center	SunPass Service Center	Sunshine Skyway North Toll Plaza Control Center	Tampa RTMC	Turkey Lake Turnpike RTMC
City of Clearwater TMC																●								
City of Lakeland TMC																							●	
City of Tampa Traffic Control Center													●											
City/County Fire and Police																							●	
County Emergency Management																							●	
District 1 Bartow VTMC																							●	
FHP Troop C																							●	
FHP Troop F																							●	
Future SunGuide ISP Center																							●	
Future THCEA Management Center																							●	
HARTLine Transit Control Center													●											
Hernando County Traffic Control Center																							●	
Hillsborough County Traffic Control Center			●								●							●					●	
Manatee County Traffic Control Center																							●	
Pasco County Traffic Control Center																							●	
Pinellas County TMC	●																●			●			●	
Pinellas Suncoast Transit Authority (PSTA)																●							●	
Plant City Traffic Control Center													●											
Road Rangers Service Patrol																							●	
St. Petersburg Traffic Control Center																●								
SunPass Service Center																							●	
Sunshine Skyway North Toll Plaza Control Center																							●	
Tampa RTMC		●		●	●	●	●	●	●	●		●	●	●	●	●	●		●		●	●		●
Turkey Lake Turnpike RTMC																							●	

Table 11 – Florida's Turnpike Enterprise Regional Transportation Management Center (RTMC) Communications Links

DISTRICT 8 REGIONAL TRAFFIC MANAGEMENT CENTERS	District 2 Jacksonville RTMC	District 4 Broward County RTMC	District 4 Palm Beach County RTMC	District 5 Orlando RTMC	District 6 Miami RTMC	District 7 RTMC	FHP Troop C	FHP Troop D	FHP Troop K	Pompano Beach ITS Operations Facility (RTMC)	Road Rangers Service Patrol	SunGuide Smart Route TMC (For ATIS Only)	SunPass Service Center	Turkey Lake ITS Operations Facility (RTMC)
District 2 Jacksonville RTMC														●
District 4 Broward County RTMC										●				
District 4 Palm Beach County RTMC										●				
District 5 Orlando RTMC														●
District 6 Miami RTMC										●				
District 7 RTMC														●
FHP Troop C										●				●
FHP Troop D										●				●
FHP Troop K										●				●
Pompano Beach ITS Operations Facility (RTMC)		●	●		●		●	●	●		●	●	●	
Road Rangers Service Patrol										●				●
SunGuide Smart Route TMC (For ATIS Only)										●				●
SunPass Service Center										●				●
Turkey Lake ITS Operations Facility (RTMC)	●			●		●	●	●	●	●	●	●	●	

Figure 4 –Future RTMC Coverage



Notes:
These proposed RTMC boundaries are based on jurisdictional and project operational boundaries.

Turkey Lake and Pompano RTMCs will be interoperable and capable of assuming full operations of Turnpike facilities.

Source: PBS&J

3.1.8 Bandwidth Requirements

Based on the general C2C requirements expressed here as found by a search of the literature it is safe to assume that the major factor in the bandwidth requirement for C2C ITS communications will be the sharing of video. Present planning for the Statewide C2C network can proceed based on the assumption of one T1 circuit per camera to be shared. To be safe an additional T1 could be added to handle all other shared data, but is probably not needed.

The assumption that will be used in this analysis is that no more than seven video transmissions, each requiring one T1 circuit per image be shared, and one additional T1 circuit for transmission of administrative, event and other device information is required. Therefore, the equivalent of a minimum of eight T1 circuits should be reserved for C2C communications between each RTMC. For communications between other traffic management centers and an RTMC, lower bandwidth requirements may be used as determined based on the specific requirements for information sharing and administrative requirements and availability of communications media (or their costs).

Using the communication link needs identified in Table 1, the total bandwidth required along each of the communication paths established can be determined.

3.2 Communications Plant

Because of the need for reliable, proven and cost effective communication network backbones for C2C communications, an initial screening of alternatives limited the review of these backbone communications to the following:

1. FDOT's existing microwave communication network that was implemented to support the motorist aid call box system covers approximately 1,350 miles of limited-access roadways.
2. Fiber optic communications networks that have been implemented by several districts to support ITS deployments on limited-access in some of the more advanced counties signal system deployments.
3. Leasing or acquisition of telecommunication services for ITS C2C communication purposes.
4. Use of the internet to provide the communication of information for C2C needs.

Other technologies such as other wireless communications and unshielded twisted pair wire communications networks are discussed in the center-to-field alternatives.

3.2.1 Microwave Communication Technology

Microwave signals radiated from an antenna propagate through the atmosphere along a line-of-sight path. The frequencies used must be unique to that area to prevent interference from other microwave transmissions. Because of this constraint, microwave frequencies are licensed by the FCC. Therefore, it can be very difficult to obtain a microwave frequency allocation in crowded urban areas. When frequencies are available, they are usually in the higher frequency bands (18 and 38 GHz) which have reduced transmission distances. Additionally, if two-way transmission links are required, two different transmit/receive frequencies are required.

Microwave frequencies are those frequencies in the range above 1 GHz (gigahertz). The frequencies currently allocated by the FCC for private and common carrier use are in the 4, 6, 10, 11, 12, 13 18, 23, 26 and 38 GHz bands, with the lower GHz channels (2-12) being used for long-haul transmissions.

Microwave communication provides an alternative to leased line and fiber optic point-to-point backbones, offering high data transmission capacity and the capability to transmit video. In areas where fiber is expensive or impossible to install and a connection to a leased line is not practical, microwave should be considered.

FDOT owns or has access to microwave towers, transmission systems and equipment shelters along most of the hard-to-reach limited access corridors. Rural RTMC's can utilize microwave communications as the core optical backbone or from RTMC to RTMC. Given the planned microwave deployment strategy, where FDOT plans to install digital microwave throughout the planned corridors (see concept of operations), this concept can be used as primary or secondary communications interconnectivity.

Microwave System Advantages

The advantages of utilizing the statewide microwave system are: First, taking advantage of existing tower and planned deployments. Secondly, allocated bandwidth is available for ITS and inter-district sharing. Lastly, lower cost to implement new technology within the existing infrastructure.

Microwave System Disadvantages

The disadvantages of utilizing the statewide microwave system as part of the communications backbone are the limitation of bandwidth with the planned microwave system deployment. Each microwave system will be limited to a DS-3 or a 28 T1 capacity to serve all the requirements of the planned system.

3.2.2 Fiber Optics[5]

Optical fibers are composed on concentric cylinders made of dielectric materials (i.e., nonmetallic materials that do not conduct electricity). At the center is a core comprising the glass or plastic strand or fiber in which light waves travel. In most ITS applications, optical fiber media requires that electrical signals be converted to light signals for transmission. Light emitting diodes (LED) and light amplification by stimulated emission or radiation (laser) devices are two examples of the technologies used with fiber optic cables to solid-state or semiconductor conversion/transmitter technologies used to with fiber optic cables. PIN diodes and avalanche photo diodes (APDs) convert electric signals to light signals.

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[5] The description of fiber optic systems was adapted from *The New McGraw Hill Telecom Fact Book*, Second Edition, McGraw Hill, New York, 2000.

Optical fibers are either single mode or multimode. Single mode fibers have sufficiently small core diameters that light waves are constrained to travel in only one transverse path from transmitter to receiver. This requires special considerations in the angular alignment of LEDs at points where light enters the fiber and increases costs. Multimode fiber systems have much wider fiber cores and allow light waves to enter various angles, and reflect off the core-cladding boundaries as light propagates from transmitter to receiver. As a result various paths of light traverse from end to end along a multimode fiber and arrive in a time delayed sequence as a result of the differences in speed of the light waves of different frequencies following different paths within the fiber. With these multiple paths and frequencies traveling within the optical cable, dispersion of the signal may occur as a result of mode dispersion (cancellations due to light wave overlaps due to different travel paths), material dispersion (caused by material effects on light waves of different frequencies) and structural dispersion (caused by imperfections in the transmission media). Various manufacturing techniques are used to manage and minimize these dispersion properties in multimode fiber.

Advantages of Fiber Optic Networks

The advantages of fiber optic networks for C2C or communication backbone applications in ITS include:

- Bandwidth is dramatically greater using optical fiber systems as compared to wireless or other metallic features, a factor of 10 or greater. With Dense Wave Division Multiplexing (DWDM), discussed in the next section, these advantages are even greater.
- Optical fiber is the telecommunications industry media of choice and in recent years has become widely available at affordable prices.
- Fiber optic networks can be installed within the existing rights-of-way along limited-access facilities with little disruption to existing lands and maintenance of traffic requirements.
- Fiber optic networks are less susceptible to natural or man-made disasters than microwave or other wireless communications.
- Fiber optic networks are more secure than microwave or other wireless communications.

Disadvantages of Fiber Optic Networks

The disadvantages of fiber optic networks include:

- The principal disadvantage of fiber optic networks for C2C communications is the cost of installation of regeneration hubs and electric signal to light signal converts at the centers. However, the costs of this equipment have greatly reduced in recent years.
- The costs of installing and burying fiber optic cable in rural areas where the number of access points in minimal is more costly than point to point microwave communications available through the FDOT's microwave backbone.

3.2.3 Leased Telecommunications Services

In addition to the installation of private communication networks for C2C communications, the alternative of purchasing or leasing telecommunication services should also be considered. Most C2C communication requirements identified in the *Ten-Year ITS Cost Feasible Plan* are intermittent, or event based, communication needs. For example the following requirements require only limited communication access.

- Coordination with all law enforcement, fire/rescue, and emergency management personnel
- Support operations and management during natural or manmade disasters or evacuations
- Provide secondary control of operations normally managed by other RTMCs during natural or man-made disasters
- Coordination with local traffic operation centers
- Coordination with county emergency management centers and the SEOC when appropriate
- Coordination with a freeway incident management team involving major stakeholders
- Reporting of data needed for performance monitoring and deployment evaluation including HPMS requirements through coordination with the TranStat Office
- Traffic data archiving and data warehousing including regional data sharing capabilities
- C2C communications to support major incidents that effect multiple jurisdictions including evacuation
- Support Advanced Public Transit Systems information needs such as transit, port and airport

Sharing video and secondary operations and management of ITS services during natural and man-made disasters will require significant bandwidth and high levels of reliability, but the needs are event based rather than continuous.

The following discussion was published in Public Roads Magazine in March/April 2001 by William Jones and contains an excellent summary of the potential for leased lines to be an effective procurement of ITS communications.

Exhibit 1 – "Telecommunications – Getting More For Money" Public Road, March/April 2001 by William S. Jones

There are three broad areas where transportation engineers can capitalize on new telecommunications developments: (1) new infrastructure from new competitors, (2) new technologies for wireline networks, and (3) new services from the wireless industry.

Most transportation engineers are well aware of the tremendous expansion in telecommunications infrastructure over the past few years. They have seen their streets and major roadways dug up to install cables and electronics. This new infrastructure, however, also presents an opportunity to transportation agencies planning new or expanded telecommunications.

The opportunity arises from the competition among multiple communications companies, including traditional telephone companies that are branching into other areas of communications. Consider the myriad of services offered the consumer: Internet access, cable television, satellite television, long-distance telephone, digital telephone, etc.

New competitors typically need large customers, such as government agencies, to provide a solid base for offering their services to customers. Two obvious consequences of this new competition are the reduction in the cost of services and the creation of incentives to improve the quality of service.

Regardless of the telecommunications architecture chosen by a transportation agency, there generally will need to be some form of "backbone" or "wide area network" technology that can collect - and subsequently disseminate - information from widely dispersed field equipment, such as signal controllers, cameras, other sensors, etc.

Increased competition in the telecommunications industry allows transportation agencies to lease rather than purchase communications infrastructure. Owning the telecommunications infrastructure has been standard practice in the transportation community. However, in the few serious evaluations of leasing, the life cycle cost of leasing was half that of owning infrastructure. The cost savings from leasing could be tens of millions of dollars for a statewide or metropolitan network.

Leasing obviously brings its own set of problems; it is no panacea. There are pros and cons. The rapid pace of technological change and the competitive market compel communications companies to keep their networks up-to-date and competitive. By leasing, a transportation agency can keep up with the technology without the heavy burden of new purchases or the unavailability of parts for maintenance.

The rapid change in technology has also reduced the cost of services. In most instances, agencies have overestimated the cost of leased services over time. This dramatically contrasts with a few years ago, when agencies suffered from escalating prices for leased lines from monopolistic providers.

Advantages of Leased Telecommunications Services
The advantages of leased telecommunication services include the following:

- The FDOT will only purchase the bandwidth needed when needed and no costs for the installation, maintenance and operations of a large communications network will be incurred by the taxpayers.
- The reduction of costs for the installation, operations and management of communications networks that can be leased increases the coverage of the ITS that can be deployed.
- The risk for changes in technologies and operations of the communications network is transferred to the private sector.
- The ability of the State to purchase low cost bandwidth and require dedicated bandwidth to support public good enhances the cost effectiveness of leased telecommunication services for C2C communications.
- Telecommunication providers maintain larger systems that have greater redundancy and multiple points of failure as opposed to a single system installed and operated by the FDOT.

Disadvantages of Leased Telecommunications
The following are the disadvantages of leased telecommunications:

- The costs of leasing bandwidth are a transfer of costs from deployment to operations where resources are traditionally constrained.
- Once the ITS system is installed and telecommunications are being purchased by the State we are dependent on private sector telecommunication providers and their rate change with little flexibility

3.2.4 Internet/Virtual Private Network Communications

Some transportation agencies, such as the Maryland State Highway Administration (MDSHA), are implementing and testing the use of the internet as a communications media for C2C communications. This alternative eliminates the need for the construction of dedication communications infrastructure between centers by using the internet to create secured virtual provide networks. The internet offer ubiquitous coverage and near infinite points of failure. Virtual private networks (VPN) provide an encrypted connection between a user's distributed sites over a public network (e.g., the Internet). By contrast, a private communication network uses dedicated networks/circuits and possibly encryption. The basic idea is to provide an encrypted IP tunnel through the Internet that permits distributed sites to communicate securely. The encrypted tunnel provides a secure path for network applications and requires no changes to the application. VPNs may provide excellent opportunities for C2C communications to share information in a media independent environment.

Advantages of a Virtual Private Network

The advantages of using a VPN for C2C communications include:

- VPNs are supported by all common platforms and are seamless
- VPNs are easy to use are accessible to any user with internet access, encryption software and access permissions.
- The bandwidth of transmissions is limited to the users' bandwidth access.
- The costs of maintaining internet server can be outsourced and are considerably cheaper than installation of dedicated communication networks.

Disadvantages of a Virtual Private Network

- Full motion video and command and control of cameras in the ITS environment may be less than desirable due to latency; however, feasible.
- Security to ITS related information may be of a concern, particular as related to privacy issues during an incident or other sensitive information.
- No NTCIP standards have been developed for XML or other internet standards or protocols needed for C2C communications. TCI/IP configuration of the VPN should allow use of existing standards, although in a less efficient manner.

3.2.5 Summary

There are number of communication media that are available for C2C communications to support the deployments identified in the *Ten-Year ITS Cost Feasible Plan*. Each of these media has their own advantages, disadvantages and appropriate use in the overall communications plan. The following summarizes the recommended use of the various media at the plant level to support the C2C communications in the *Ten-Year ITS Cost Feasible Plan*. Figure 5 illustrates the proposed communications plant identified in the *Ten-Year ITS Cost Feasible Plan.*

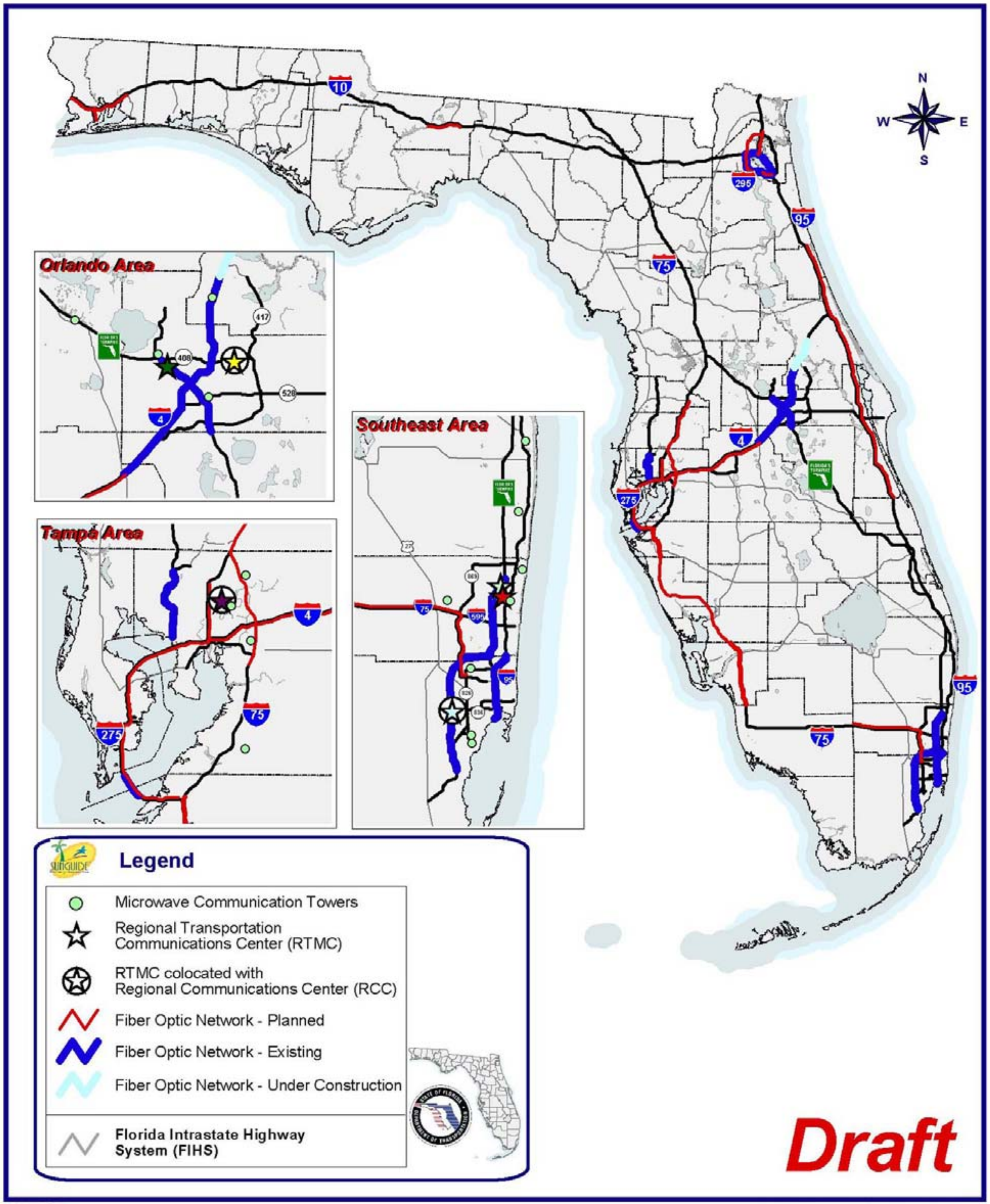
Microwave Plant

- Communications between centers in rural areas where no center-to-field communication infrastructure will be deployed and the FDOT's microwave communication backbone already exists. Examples of where microwave will be most appropriate include connections between the Pensacola, Tallahassee and Jacksonville RTMCs along I-10.

Fiber Optic Plant

- Communications between centers where fiber optic cable is needed to support center-to-field communications and connections between centers can be made easily. Examples of where fiber optic plant is the most appropriate include connections between the Broward RTMC and District Six RTMC that are located near limited-access facilities where fiber optic networks will be installed for center-to-field communications.

Figure 5 - ITS Communications Plant to Support the *Ten-Year ITS Cost Feasible Plan*



PBSJ Source: PBS&J / FDOT

GIS/TWO3-Communications/CommDevices
Map Date: October 2002

Leased Telecommunication Services

- Leased telecommunication services should be purchased where no fiber optic center-to-field communications are needed and the microwave backbone does not exist, or connection can not be easily achieved. Examples of where leased telecommunication services are most appropriate include connections between RTMCs and other local traffic management centers where dial-up access is most appropriate.

Virtual Private Networks

- The FDOT should consider adopting a VPN approach for the sharing of information with information service providers (ISPs) for advanced traveler information systems (ATIS) and statewide data warehousing/archived data service functions. The VPN approach will ensure a single synchronous set of information is provided to multiple users who disseminate traveler information or use data for performance monitoring. Once, this concept proves feasible for ATIS in Florida and is proven in other states, a statewide VPN could used to support all C2C communications between as a reliable and feasible communication network for state and local agencies that will provide a single set of synchronous traveler information that supports security, safety and ATIS applications.

- In the short-term, the FDOT should also consider the use of a VPN to provide the State Emergency Operations Center (SEOC) access to video (images only) and traffic information for emergency management and evacuation support.

3.3 Subnetwork Level

Following the NTCIP framework, once a communications plant is selected, the next step is to select a standard for physical management of the media, or the subnetwork level.

3.3.1 Synchronous Optical Network Technologies (SONET)

Synchronous Optical Network (SONET) is a set of standards for a fiber optic communications network. Originally developed in the U.S. and finalized in 1988, SONET shortly thereafter was internationalized by the CCITT (now ITU-T) as SDH (Synchronous Digital Hierarchy).

SONET employs TDM (Time Division Multiplexing), which allows multiple communications channels to be carved out of a single, digital transmission facility. Each channel supports a single transmission in the form of a bit stream, with each channel providing the level of bandwidth demanded by the application.

A SONET system will support any native application type, whether it's voice, video, fax, or some form of computer data. Specifically, SONET (and SDH) are based on T3, which has a total signaling rate of 44.736 Mbps and which accommodates a payload rate (i.e., actual data content) of 43.008 Mbps. In a voice application, the T3 typically comprises 28 T1s, each of which runs at a total signaling rate of 1.544 Mbps and which supports a payload of 1.536 Mbps, which comprises 24 byte-interleaved voice transmissions.

Alternatively, the T3 payload may comprise a single high-bandwidth data stream, such as that associated with a full motion videoconference or medical image transfer. At the extreme, 24 voice transmissions are interleaved to form a T1, and 28 T1s are interleaved to form a T3. As the T3 is presented to the edge of the SONET network, overhead is added to the T3 frame to form an STS-1 (Synchronous Transport Signal level 1), which then is converted from electrical to optical to form an OC-1 [6](Optical Carrier level 1) signal.

Each OC-1 frame runs at a signaling rate of 51.84 Mbps, supporting a payload of 44.736 Mbps, with the difference being the additional overhead of signaling and control data. Within this SONET payload is a T3 and, perhaps 28 T1s, each of which includes its own overhead. So, the overhead can be as much as 8.832 Mbps, which is considerable in terms of bandwidth consumption, but which yields considerable network management advantages.

As the technology works up the hierarchy from OC-1 to OC-768, the speed of the lasers and detectors increases from 51.84 Mbps to nearly 40 Gbps -- and their cost increases considerably.

SONET/SDH Advantages

The main advantages of SONET/SDH are:. First, a standardized approach allows the construction of a multi-vendor network comprising a variety of equipment built by multiple manufacturers.

Second, SONET/SDH standards include extremely robust network management functionality.

SONET/SDH Disadvantages

The main disadvantages of SONET/SDH are: First, the equipment is very costly.

Second, the amount of overhead is considerable. As overhead consumes bandwidth, less bandwidth is available for payload.

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[6] Optical Carrier (OC) the transmission speeds defined in the SONET specification. OC defines transmission by optical devices, and STS is the electrical equivalent.

Service	**Speed (Mbps)**
OC-1 STS-1	51.84 (28 DS1s or 1 DS3)
OC-3 STS-3	155.52 (3 STS-1s)
OC-3c STS-3c	155.52 (concatenated)
OC-12 STS-12	622.08 (12 STS-1, 4 STS-3)
OC-12c STS-12c	622.08 (12 STS-1, 4 STS-3c)
OC-48 STS-48	2488.32 (48 STS-1, 16 STS-3)
OC-192 STS-192	9953.28 (192 STS-1, 64 STS-3)
OC-768 STS-768	38813,12 (768 STS-1, 256 STS-3)

Third each OC-1 in an OC-n (e.g., OC-768) system fires across the network every 125us, whether it is full of data, partially full, or totally empty. To use an OC-1 frame efficiently, therefore, the carrier must groom, shape and aggregate data quickly and often based on traffic type, destination and QoS (Quality of Service) requirements. This process of grooming, shaping and aggregating involves placing SONET gear at strategic physical locations in order to avoid stranding bandwidth. This adds to the cost and complexity of a SONET/SDH network.

3.3.2 Dense Wave Division Multiplexing

Dense Wavelength Division Multiplexing (DWDM) is defined as a transmission technique involving eight or more wavelengths of light.

As each wavelength functions at a different frequency each, in effect, is a totally separate carrier. (*Note:* Wavelength is the inverse of, and therefore is directly related to, frequency.) In other words, DWDM is Frequency Division Multiplexing (FDM) at the optical level. Given this fact, each wavelength, or lambda, can run at a given rate, or they each can run at a different rate. For example, each of 32 wavelengths can run at OC-12 speeds of 622 Mbps, or some can run at OC-12 and others at OC-3. All run through the same fiber, at the same time, and without any issues of mutual interference.

This minor miracle is achieved by tunable lasers which emit light signals at different wavelengths, with each wavelength being introduced through a separate window into a common optical fiber. Matching light detectors at the receiving end of the system each sense a given wavelength, ignoring the others.

Now, each wavelength, or lambda, is a world of bandwidth unto itself. The violet lambda might carry native TCP/IP data at 622 Mbps, and the ruby red lambda might carry digitally encoded voice in the traditional PCM (Pulse Code Modulation) format at 155 Mbps. Each wavelength is switched, and otherwise treated, individually by means of photonic (i.e., optical) switching devices. The following figure illustrates how DWDM systems can be used as a transport technique.

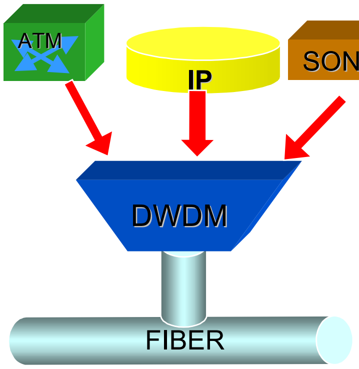

Figure 6- DWDM Transport Technique.

DWDM Advantages

From both technical and economic perspectives, the ability to provide potentially unlimited transmission capacity is the most obvious advantage of DWDM technology. The current investment in fiber plant can not only be preserved, but optimized by a factor of at least 32. As demands change, more capacity can be added, either by simple equipment upgrades or by increasing the number of lambdas on the fiber, without expensive upgrades. Capacity can be obtained for the cost of the equipment, and existing fiber plant investment is retained. Bandwidth aside, DWDM's most compelling technical advantages can be summarized as follows:

Transparency
Because DWDM is physical layer architecture, it can transparently support both TDM and data formats such as ATM, Gigabit Ethernet, and Fiber Channel with open interfaces over a common physical layer.

Scalability
DWDM can leverage the abundance of dark fiber in many metropolitan area and enterprise networks to quickly meet demand for capacity on point-to-point links and on spans of existing SONET/SDH rings.

Migration from SONET and Reliability
By using DWDM as a transport for TDM, existing SONET equipment investments can be preserved. Often new implementations can eliminate layers of equipment. For example, SONET multiplexing equipment can be avoided altogether by interfacing directly to DWDM equipment from ATM and packet switches, where OC-48 interfaces are common. Additionally, upgrades do not have to conform to specific bit rate interfaces, as with SONET, where aggregation of tributaries is locked into specific values.

Longer Distance: Up To Thousands Of Kilometers Without Regeneration
Optical signals become attenuated as they travel through fiber and must be periodically regenerated in core networks. In SONET/SDH optical networks prior to the introduction of DWDM, each separate fiber carrying a single optical signal, typically at 2.5 Gbps, required a separate electrical regenerator every 60 to 100 km (37 to 62 mi). As additional fibers were "turned up" in a core network, the total cost of regenerators could become very large, because not only the cost of the regenerators themselves, but also the facilities to house and power them, had to be considered. The need to add regenerators also increased the time required to light new fibers. Figure 5 illustrates the concept of how DWDM technology eliminates conventional TDM transmission regeneration.

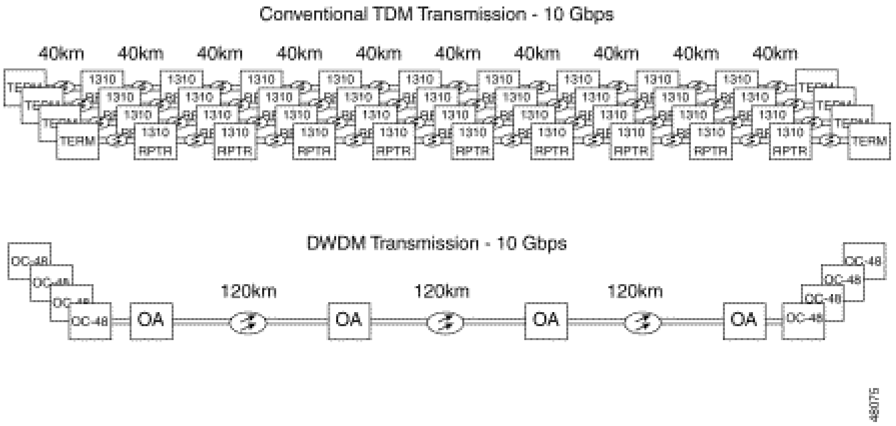

Figure 7 - DWDM Eliminates Regenerators

The upper part of Figure 7 shows the infrastructure required to transmit at 10 Gbps (4 x OC-48 SR interfaces) across a span of 360 km (223 mi) using SONET equipment; the lower part of the figure shows the infrastructure required for the same capacity using DWDM. While optical amplifiers[7] could be used in the SONET case to extend the distance of spans before having to boost signal power, there would still need to be an amplifier for each fiber. Because with DWDM all four signals can be transported on a single fiber pair (versus four), fewer pieces of equipment are required. Eliminating the expense of regenerators (RPTR) required for each fiber results in considerable savings.

The optical amplifier merely amplifies the signals; it does not reshape, retime or retransmit them as a regenerator does, so the signals may still need to be regenerated periodically. But depending on system design, signals can now be transmitted anywhere from 600 to thousands of kilometers without regeneration. In addition to dramatically reducing the cost of regenerators, DWDM systems greatly simplify the expansion of network capacity. The only requirement is to install additional or higher bit-rate interfaces in the DWDM systems at either end of the fiber.

Although amplifiers are of great benefit in long-haul transport, they are often unnecessary in metropolitan networks. Where distances between RTMC network elements are relatively short, signal strength and integrity can be adequate without amplification.

Mean Time Between Failures (MTBF) Factor

While optical amplifiers are major factors in the ability to extend the effective range of DWDM, other factors also come into play. For example, DWDM is subject to dispersion and nonlinear effects. Many components, such as the optical add/drop multiplexer (OADM), are passive and therefore continue to work in the event of a power failure, provided there is a battery back-up system to power the shelf electronics at the OADM site. In addition, these components tend to have a very high mean time between failures (MTBF). Protection schemes implemented on DWDM equipment and in the network designs are at least as robust as those built into SONET. All these factors contribute to better performance and lower maintenance in the optical network.

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[7] Optical amplifier (OA) - A single optical amplifier can re-amplify all the channels on a DWDM fiber without de-multiplexing and processing them individually, with a cost approaching that of a single regenerator.

Network Management Capability
One of the primary advantages offered by SONET technology is the capability of the data communication channel (DCC). Used for operations functions, DCCs ship such things as alarms, administration data, signal control information, and maintenance messages. When SONET is transported over DWDM, DCCs continue to perform these functions between SONET network elements. In addition, a DWDM system can have its own management channel for the optical layer. For out-of-band management, an additional wavelength (for example, a 33rd wavelength in a 32-wavelength system) can be used as an optical supervisory channel.

Economic Benefits
-Lowest cost per service and highest service density
-Quick deployment and turn up

DWDM Disadvantages

DWDM has at least one clear disadvantage. Each lambda must be treated individually. For example, if 32 lambdas share one optical fiber and a repeater must be placed at some point to clean up and boost the signal, the 32 must be separated, repeated individually, then recombined and sent on their way.

There's no mixing of TCP/IP data and PCM voice traffic in the same lambda. It's all or nothing, and it's all headed to the same destination. Therefore, DWDM assumes that the carrier can pack a lambda full of data of the same type, headed for the same destination, and with the same QoS (Quality of Service) requirements; or that the carrier has access to so many lambdas that their efficient use is of little or no concern.

3.3.3 SONET vs. DWDM

DWDM is the clear winner in the backbone. The advantages of pure DWDM are several. First, DWDM provides the ability to increase the bandwidth of a single fiber to incredible proportions. Consider even 32 lambdas, each operating at an OC-192 rate of 10 Gbps, for a total of 320 Gbps. Second, DWDM equipment is relatively inexpensive in comparison to SONET gear. DWDM provide more bandwidth at much lower cost. Thirdly, faced with the challenge of dramatically increasing capacity while constraining costs, agencies have two options: Install new fiber or increase the effective bandwidth of existing fiber.

Deploying new fiber is a costly proposition. It is estimated at about $120,000 per mile, most of which is the cost of permits and construction rather than the fiber itself. Laying new fiber may make sense only when it is desirable to expand the embedded base.

Increasing the effective capacity of backbone fiber can be accomplished in two ways:

1. Increase the bit rate of existing systems.
2. Increase the number of wavelengths on a fiber.

The demand placed on the transport infrastructure by bandwidth-hungry applications has exceeded the limits of traditional TDM. Fiber on SONET infrastructure, which once promised seemingly unlimited bandwidth, is being exhausted, and the expense, complexity, and scalability limitations of the SONET infrastructure are becoming increasingly problematic.

DWDM can relieve the fiber bandwidth problem in a statewide deployment. Although alternatives for capacity enhancement exist, such as pulling new cable and SONET overlays, DWDM can do more. Additional benefits of DWDM are its fast and flexible provisioning of protocol- and bit rate-transparent, data-centric, protected services, along with the ability to offer new and higher-speed services at less cost.

3.3.4 Gigabit Ethernet

Gigabit Ethernet is fully compatible with FDOT's huge installed base of Ethernet and Fast Ethernet nodes. The original Ethernet specification was defined by the frame format and support for CSMA/CD (Carrier Sense Multiple Access with Collision Detection) protocol, full duplex, flow control, and management objects as defined by the IEEE 802.3 standard. Gigabit Ethernet does support all of these specifications.

Gigabit Ethernet offers the following benefits

- Enable routing between multiple IP subnets and network traffic control
- Preserve 10/100 Mbps connections while migrating to Gigabit Ethernet
- RTMC's can share resources to maximize the existing network infrastructure
- Deliver high-quality video and preserve network performance
- Use the existing wiring infrastructure (Internal LAN)
- Preserve 10/100 Mbps connections while migrating to Gigabit
- Fiber optic connections up to 70 km
- IP routing
- Wire-speed switching at Layer 2 and Layer 3
- 10/100/1000 Mbps connections throughout the network
- Gigabit-over-copper for short connections (Internal LAN)
- Gigabit-over-fiber for long hauls

3.3.5 Ten Gigabit Ethernet

10 Gigabit Ethernet is the natural evolution of the well-established IEEE 802.3 standard in speed and distance. It extends Ethernet's proven value set and economics to metropolitan and wide area networks by providing:

- Potentially lowest total cost of ownership (infrastructure/operational/human capital)
- Straightforward migration to higher performance levels
- Proven multi-vendor and installed base interoperability (Plug and Play)
- Familiar network management feature set
- Metro-based campus interconnection over dark fiber targeting distances of 40km and greater

- End to end optical networks with common management systems

Table 12- Comparison of 1 GbE to 10 GbE

1 GbE to 10GbE Comparison	
1 Gigabit Ethernet	**10 Gigabit Ethernet**
CSMA/CD + Full Duplex Carrier Extension Optical/Copper Media Support LAN/MAN distances to 5 km-70km	Optical Media ONLY Leverage OC-192 PMDs and create new PMDs New Coding Schemes (64B/66B) Support LAN/MAN/WAN distances to 40 km-160km on dark fiber

3.3.6 Gigabit Ethernet vs. DWDM

Usually in statewide area networks the largest cost is not equipment, but leasing or deploying fiber between sites.

Support of Service Types
The major advantage DWDM has over 10GigE is its ability to support a variety of service types on different wavelengths. However, if only TCP/IP applications at each RTMC are necessary (as is planned), 10G Ethernet represents a far more cost-effective solution than DWDM. Using DWDM requires an extra switch at each endpoint, on top of whatever a gigabit switch or router feeds into it. That's another set of boxes to manage and another potential point of failure, as well as a source of latency.

Cost of Ownership
Another key advantage of 10G Ethernet over SONET and over newer technologies such as DWDM is that it's an old friend to most IT managers. There is no need to learn a new set of operational parameters or commands, or a new set of management tools. Indeed, management and administration is one of the key areas where 10G Ethernet can bring major savings in terms of total cost of ownership.

Quality of Service
A single 10 Gbit/sec connection generally provides enough extra bandwidth capacity (at least for two or three years) to satisfy the need for Quality of Service (QoS) management.

3.3.7 Summary

Based on the analysis of various subnetwork alternatives available, a 10 Gigabit Ethernet is the recommended standard for deployment for C2C communications.

3. 4 Transport-Level Network Protocols

3.4.1 TCP/IP Protocol

The Internet protocols are the best-proven approach to networking diverse ranges of LAN and WAN technologies. The Internet protocol suite includes not only lower-level specifications (such as TCP and IP), but specifications for such common applications as electronic mail, terminal emulation, and file transfer. The Internet protocols are the most widely implemented multi-vendor protocol suite in use today. Support for at least part of the Internet protocol suite is available from virtually every computer vendor.

The Transmission Control Protocol/Internet Protocol (TCP/IP) is a connection-oriented transport protocol that sends data as an unstructured stream of bytes. By using sequence numbers and acknowledgment messages, TCP can provide a sending node with delivery information about packets transmitted to a destination node. Where data has been lost in transit from source to destination, TCP can retransmit the data until either a timeout condition is reached or until successful delivery has been achieved. If the sending device is transmitting too fast for the receiving computer, TCP can employ flow control mechanisms to slow data transfer. TCP can also communicate delivery information to the upper-layer protocols and applications it supports the 10 Gigabit subnetwork layer selected the most efficiently.

Figure 8 summarizes ITS transport alternatives for IP based networks.

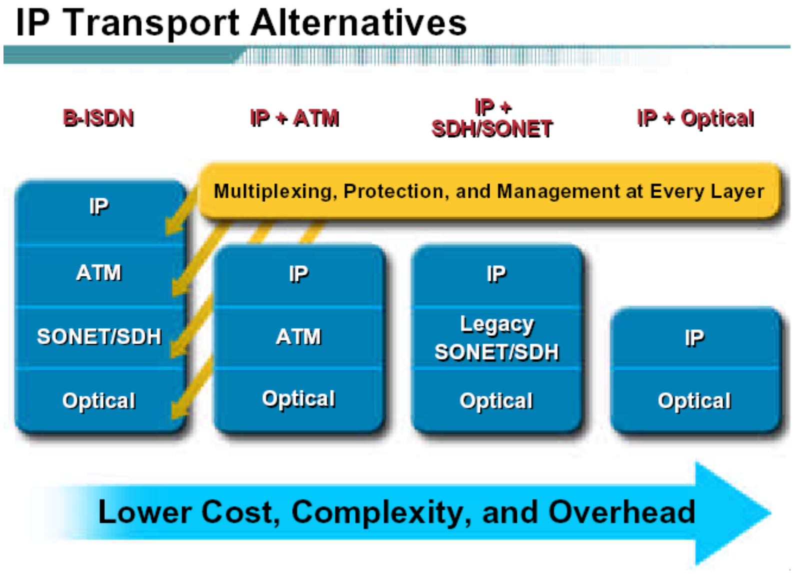

Figure 8- IP Transport Atlernatives

3.5 Application Level Protocol[8]

A separate study is underway to address the application level protocols needed for C2C communications. NTCIP provides two alternative protocol choices for C2C 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.

3.5.1 Data Exchange Between Systems (DATEX)

DATEX provides a general purpose C2C 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.

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

3.5.2 Common Object Request Broker Architecture (CORBA)

CORBA is a general purpose C2C communications protocol based on the computing industry standard of the same name. For object-oriented systems, CORBA 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.

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.

3.5.3 Comparison of DATEX and CORBA

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

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[8] This section was adapted from the NCTIP Guide

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.

C2C 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.

C2C 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. 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).

The *TMC Software Study* conducted by Southwest Research Institute and the analysis of DATEX and CORBA performed to support the development of scope of work and functional requirements for the development of a statewide TMC software library both recommended DATEX because of its maturity and effective use for ITS.

3.6 Information Level

With the recommendation of DATEX as the application level standard for C2C communications, a statewide ITS data dictionary and standard message is needed. The Traffic Management Data Dictionary and Message Sets for External Traffic Management Center Communications Standards developed as part of the NTCIP work together to provide a high level of interoperability among regional and local systems/centers. These Standards will:

- Help traffic agencies and emergency management agencies to more easily and clearly communicate during incident conditions, working to improve safety,
- Improve the potential of having effective traveler information systems with data and information that travelers want to know, and

- Enable public agencies and private companies to reduce system deployment costs and project delays while providing more effective public service and customer benefits.

The Traffic Management Data Dictionary Standard provides consistent names, definitions, and concepts similar to spelling and parts of speech to the word-like “data elements” in the Standard. The Traffic Management Data Dictionary enables concepts from traffic management to be defined and used in the same way by different systems and centers. However, the Standard also anticipates and provides for the use of locally unique data elements to recognize the individuality of each system or center. The Message Sets for External Traffic Management Center Communications Standard uses these data elements by combining them together in a sentence-like way in the sharing of data or pre-defined typical messages between systems or centers. That Standard also anticipates that every center will have their own unique messages they want to send and receive.

These two Standards provide a framework for interoperability that is consistent with the National ITS Architecture and work in conjunction with other standards, such as the Standard for Data Dictionaries. There are also complementary standards for other functional areas associated with Intelligent Transportation Systems, such as a similar data dictionary for Traveler Information Systems. There is a need to have a clear plan for migrating from current systems to those that are being planned, designed, and implemented to be in conformance with these two Standards.

As part of the C2C standards project or the Statewide TMC Software Library project a TMDD should be designed and implemented to meet Florida’s needs for C2C communications. The requirements identified in Section 3.1 should be used to prioritize the customization and implementation of the TMDD.

3.7 Summary of NTCIP Stack for Center-to-Center Communications

This section of the communications plan documented the requirements for C2C communications and made recommendations for the specific plant, subnetwork standards, transport protocols, application protocols and information needed using the NTCIP standards framework as a guideline as follows:

3.7.1 Physical Plant

Microwave Plant

- Communications between centers in rural areas where no center-to-field communication infrastructure will be deployed and the FDOT’s microwave communication backbone already exists. Examples of where microwave will be most appropriate include connections between the Pensacola, Tallahassee and Jacksonville RTMCs along I-10.

Fiber Optic Plant

- Communications between centers where fiber optic cable is needed to support center-to-field communications and connections between centers can be made easily. An example of where fiber optic plant is the most appropriate includes connections between the Broward RTMC and District Six RTMC that are located near limited-access facilities where fiber optic networks will be installed for center-to-field communications.

Leased Telecommunication Services

- Leased telecommunication services should be purchased where no fiber optic center-to-field communications are needed and the microwave backbone does not exist, or the connection cannot be easily achieved. An example of where leased telecommunication service is most appropriate includes connections between RTMCs and other local traffic management centers where dial-up access is most appropriate.

Virtual Private Networks

- The FDOT should consider adopting a VPN approach for the sharing of information with information service providers (ISPs) for advanced traveler information systems (ATIS) and statewide data warehousing/archived data service functions. The VPN approach will ensure a single synchronous set of information is provided to multiple users who disseminate traveler information or use data for performance monitoring. Once, this concept proves feasible for ATIS in Florida and is proven in other states, a statewide VPN could used to support all C2C communications between as a reliable and feasible communication network for state and local agencies that will provide a single set of synchronous traveler information that supports security, safety and ATIS applications.

- In the short-term, the FDOT should also consider the use of a VPN to provide the State Emergency Operations Center (SEOC) access to video (images only) and traffic information for emergency management and evacuation support.

3.7.2 Subnetwork Level

A Gigabit (where maximum transfer rate available) or 10-Gigabit Ethernet (preferred) standard is recommended for the standard protocols on the subnetwork level for C2C communications.

3.7.3 Transport Level

The Transmission Control Protocol/Internet Protocol (TCP/IP) is recommended for use at the transport level.

3.7.4 Application Level

DATEX is recommended as the application level standard because of its maturity and effective use for ITS.

3.7.5 Information Level

Implementation of the Traffic Management Data Dictionary (TMDD) and Message Sets for External Traffic Management Center Communications standard is recommended for C2C communications.

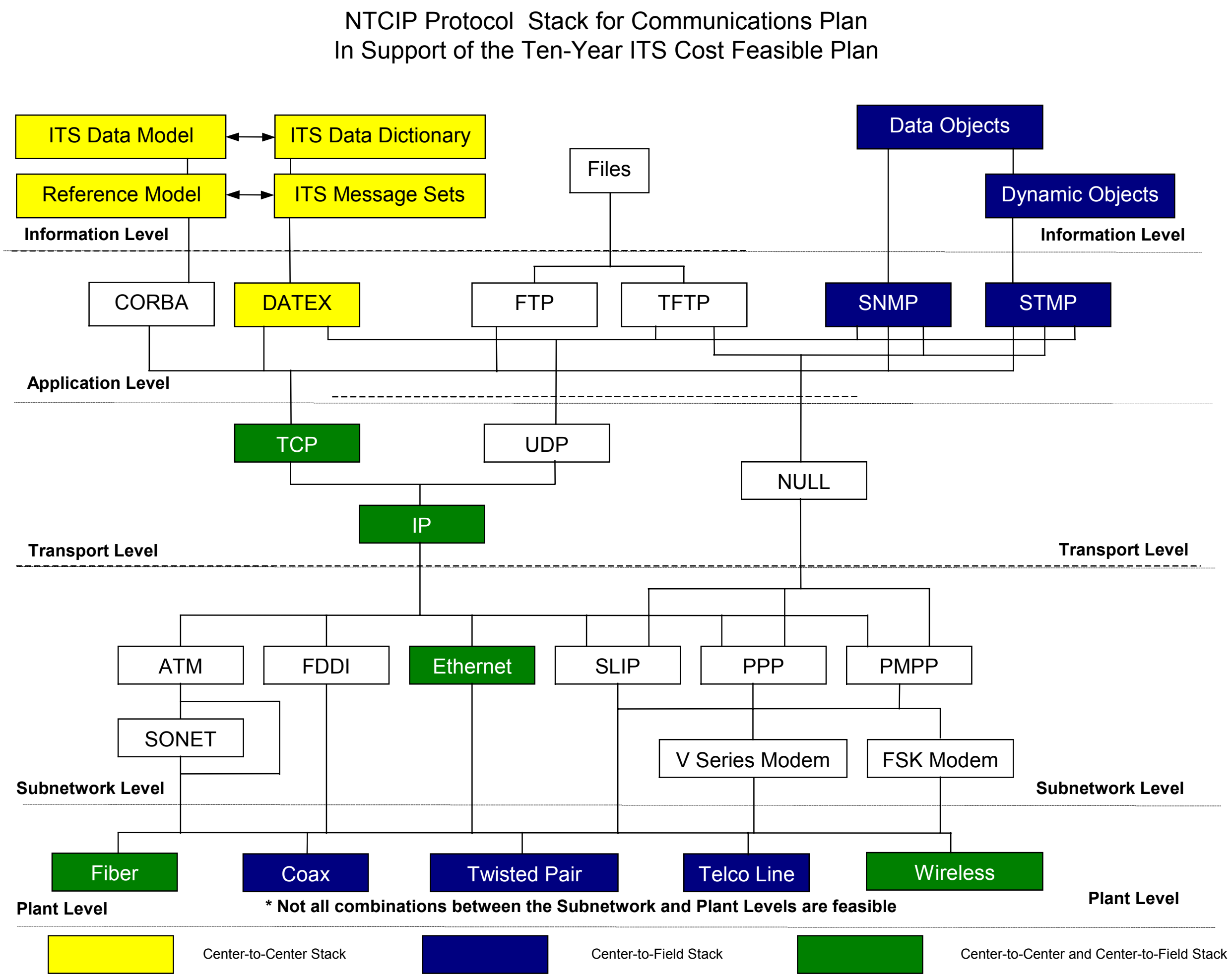
3.7.6 Bandwidth Requirements for Center-to-Center Communications

A minimum of the equivalent to eight T1 lines of bandwidth should be reserved for center-to-center communications between each RTMC to allow for the simultaneous transmission of video, traffic and other administrative or control information. These requirements are only concurrent paths in several locations.

3.7.7 NTCIP Stack

The collection of NTCIP standards recommended for use in the C2C communications to support the *Ten-Year ITS Cost Feasible Plan* are identified in Figure 9.

Figure 9 – NTCIP Stack For ITS Communications in the *Ten-Year ITS Cost Feasible Plan*



3.8. ITS Center-to-Center Communications Architecture

Following the establishment of a basic set of requirements and concepts for the C2C communications, an overall framework for the application of ITS communications can be established. For this analysis the framework was defined in the following layers:

- ITS Communications Backbone Architecture
- ITS Communications Backbone Topology

3.8.1 ITS Communications Backbone Architecture

Several alternative architecture concepts have been used nationally and in Florida to support ITS communications.

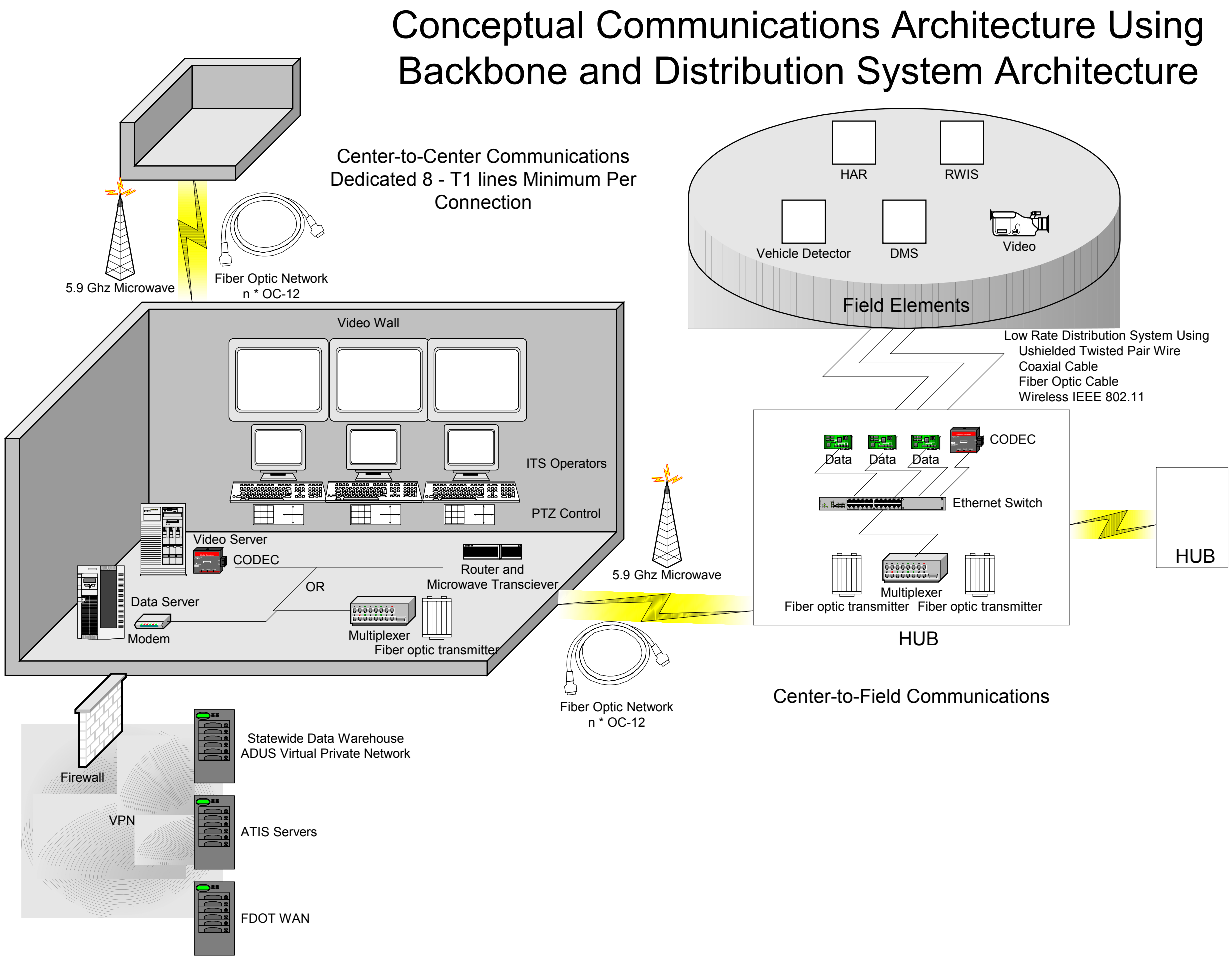
Centralized Architecture
A centralized architecture is often utilized in urban and densely populated suburban environments. In such instances, xDSL solutions provide direct access between the remote camera locations and the TMC.

Distributed Architecture: High-Speed backbone
One form of distributed architecture utilizes a high-speed backbone. Frequently used along major freeways, architectures allow for xDSL tail circuits. For example, sDSL can provide the link between a camera along an arterial roadway and a communications hub along the backbone. This arterial location may be several miles away.

Distributed Architecture: Closed Loop (Dial-up)
A "closed loop" — another form of distributed architecture — is often used in rural environments where field devices are connected via dial-up circuits. Within this architecture, xDSL tail circuits between the remote location and a central office would be linked to the TMC using high-speed switched services. Unless switching facilities are owned by DOT or the local municipality, this implementation requires the availability of xDSL services from local network access providers.

Based on the analysis of C2C requirements and recommendations in Section 3, a Backbone-Distribution architecture is recommended for limited-access facility ITS deployments. The concept is illustrated in Figure 10.

Figure 10 – Backbone and Distribute Communications Architecture



3.8.2 ITS Communications Backbone Topology

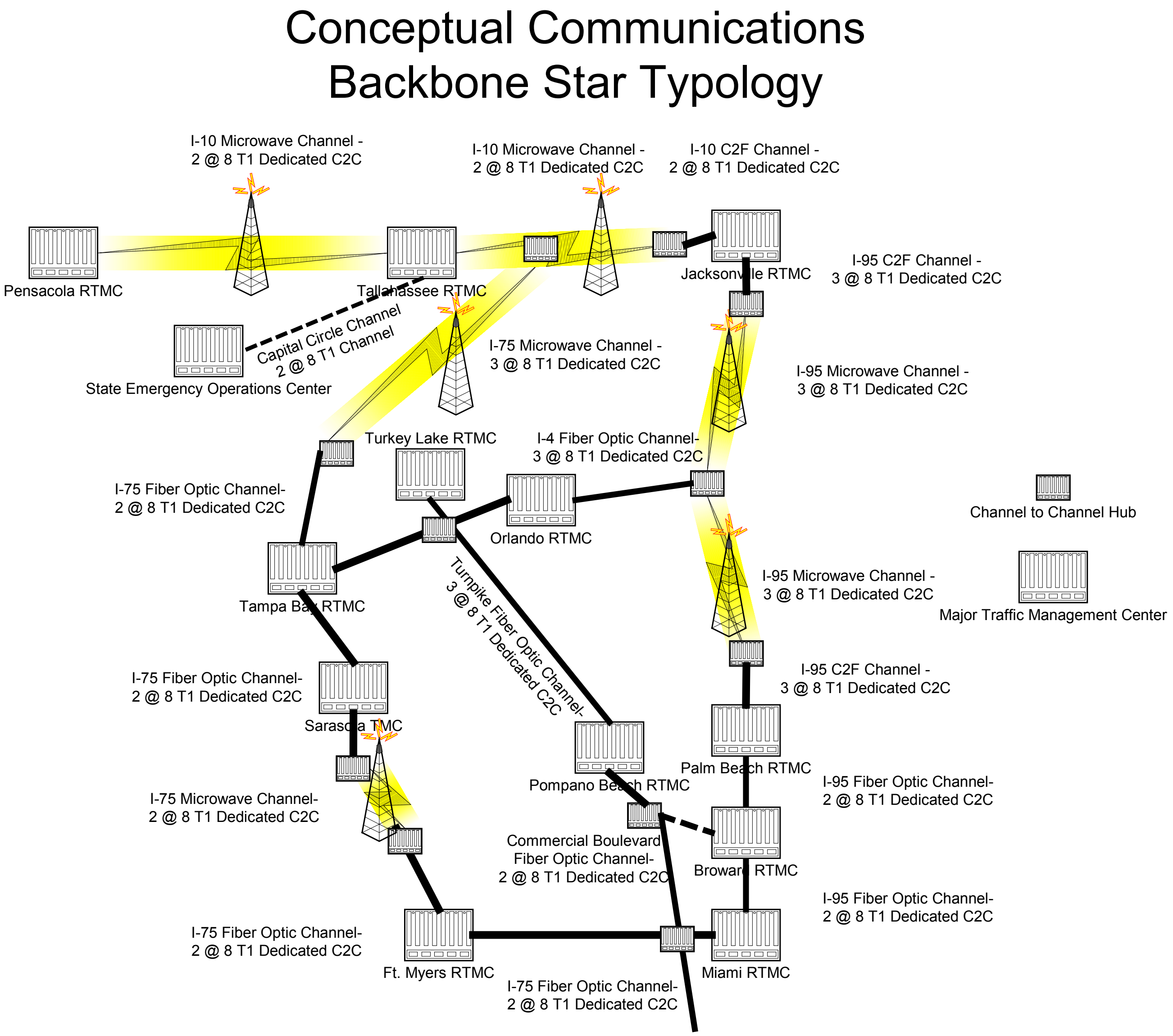
In addition to establishing a basic communications backbone-distributed architecture and topology or configuration of the ITS backbone for C2C communications is also needed. The topology uses a star configuration. The typology alternatives that are available include:

- **Unprotected Ring** - Each node (i.e., communications hub or TCS equipment) connected to two others by a uni-directional transmission link, creating a "closed" loop.
- **Protected Ring** - Two rings used instead of one, thereby providing two unidirectional transmission paths that may run in opposite directions. Redundant opposite-direction paths allow each node to communicate with every other node even if a cable is cut.
- **Linear Drop** - Nodes connected in a string or chain, with transmission data being "dropped" at a designated node.
- **Star** - Communication links emanated from a source node (e.g., traffic control center) to multiple secondary nodes (e.g., communication hub or TCS equipment).

Figure 10 summarizes the proposed star typology for the communications backbone proposed in the *Ten-Year ITS Cost Feasible Plan*. Within this star, each RTMC is considered a hub in the system. Additional hubs are considered between communication channels for the microwave backbone or where connections between microwave channels and fiber optic network channels are needed. The diagram also includes recommendations for the reservation of bandwidth for C2C communications based on the requirements for C2C secondary command and control and information sharing at an equivalent of 8-T1 lines per connection. The star topology depends on the communication of information from one-to-many points within the network. Considering the Gigabit Ethernet subnetwork selected, this star topology will provide redundancy for backbone “cuts” through providing multiple paths for most C2C communications.

However, the remote location of the Pensacola RTMC, Tallahassee RTMC and State Emergency Operations Center (SEOC) make redundancy in C2C communications problematic. Because the need for reliable C2C communications between the SEOC and the risk associated with relying on the microwave backbone exclusively through a single channel (Interstate 10), access to traffic and traveler information and video images through a virtual private network (VPN) or an internet-based application should be considered. The level of information needed to support decision making in the SEOC is similar to the needs for advanced traveler information services (ATIS) for which a VPN or internet-based information sharing strategy is proposed to ensure a single source of synchronous traveler information statewide.

Figure 10 – ITS Communications Proposed Star Typology



4. Center-to-Field Communications

This section focuses on the connections between field devices such as DMS, CCTV, highway advisory radio and vehicle detection devices, and a traffic management center via a communications backbone. The communications backbone to support ITS is defined in Section 3 for C2C communications. Center-to-field communications links generally consists of connections to hundreds of field devices that commonly use 56 kbps modems or 1200 bps in a proprietary communications protocol. However, this is changing. The NTCIP standards and protocols will make uniform application of communication technologies and standards feasible in the near future. A management information base (MIB) for DMS was recently published by the FDOT and is being put into place. MIB and other NTCIP compliance supporting mechanisms and standards are emerging for most types of devices except for video. Video surveillance for transportation represents a very small percentage of the market place and NTCIP standards are not likely to direct market decisions. However, common standards are available for managing most video, such as National Television Systems Committee (NTSC), and have been effectively applied in Florida.

Because of the scale, complexity and multiple potential combinations of field devices that are available, this element of plan is not as detailed as Section 3 on C2C communication standards. Once the basic architecture, topology and NTCIP stack are established, the development of a detailed communications plan for the center-to-field application occurs in the design phase for each project. However, this chapter provides an overview of planning and design issues for center-to-field communications.

4.1 Functional Requirements

To design an effective ITS communications system, the following functional requirements for center-to-field communications must also be addressed:

Center-to-field communications are need to the following types of devices:

- Traffic operations center controllers and field master controllers
- Local controllers
- Dynamic message signs (DMS)
- Highway advisory radio (HAR)
- Vehicle detection devices
- Closed-circuit television cameras (CCTV)
- Road weather information systems/environmental sensors (RWIS)
- Connections to the C2C communications backbone (microwave or fiber optic)

Center-to-field communication requirements associated with the management and operations of limited-access facilities during peak demand periods include:

- Traffic data collection to support incident detection
- Incident detection along the limited-access facilities
- Video surveillance along the limited-access facilities
- Video surveillance of the interchange areas (along the mainline and crossroads);
- Real-time video display
- Real-time video control
- Video verification of messages posted on DMS
- Incident data archiving
- Dissemination of traveler information using DMS, HAR, and ATIS services (511 telephone services, Internet, commercial radio, television, text messaging, etc.) for freeway operations and where available along other arterial routes independently or through an ISP contractor for ATIS.
- Management, dispatch, and coordination of RR Service Patrols
- Support of lane or road closures during natural or manmade disasters or evacuations
- Management and operations of limited-access facilities during incident management
- Management and operations of one-way operations during evacuations
- Detection of road weather conditions that may impact operations
- Identification of construction work zones and activities to support operations and management of these work zones and, where smart work zone management is provided, integration of the smart work zone management into FMS and IMS

The two greatest issues associated with management of center-to-field communications include:

- Configurations and standards associated with managing multiple devices
- Latency and timing issues associate with managing CCTV (latency and timing issues are much less sensitive for other types of devices)

4.1.1 Configurations and Standards Associated With Managing Multiple Devices

The *Ten-Year ITS Cost Feasible Plan* includes more than 6,000 ITS devices that will need to be deployed in an interoperable and effective manner. There are currently three major legacy systems in Miami, Orlando and Jacksonville and more limited deployments of permanent ITS devices in the Tampa Bay area. These existing systems should be fully integrated with emerging systems that are constructed and deployed to newer standards. This is technically attainable, but careful design is required.

4.1.2 Latency and Timing Issues for Video

When managing video for use in incident detection, verification or general surveillance latency and timing are important. Latency (or delay) in the system affects the ability to control the pan-tilt-zoom controls for most modern surveillance cameras effectively. Real-time or near real-time video is also desired with frequency of images appropriate to an operator to understand the traffic flow conditions through visual inspection.

4.2 Architecture Alternatives

Building on the backbone-distributed architecture recommended for implementation in the Section 3, the center-to-field communications architecture address the analysis of bandwidth required along the backbone communications media needed for distribution of transmissions to communications hubs distributed appropriately within the field. In the *Ten-Year ITS Cost Feasible Plan* a communications hub was planned at each interchange area to support this architecture.

4.3 Topology Alternatives

From the field hub to the field devices associated with center-to-field communications the typologies that were identified at the C2C can also be used. These network topologies include:

- **Unprotected Ring** - Each node (i.e., communications hub or TCS equipment) connected to two others by a unidirectional transmission link, creating a "closed" loop.
- **Protected Ring** - Two rings used instead of one, thereby providing two unidirectional transmission paths that may run in opposite directions. Redundant opposite-direction paths allow each node to communicate with every other node even if a cable is cut.
- **Linear Drop** - Nodes connected in a string or chain, with transmission data being "dropped" at a designated node.
- **Star** - Communication links emanated from a source node (e.g., traffic control center) to multiple secondary nodes (e.g., communication hub or TCS equipment).

Depending on the physical configuration for the field device installation, any of the network topologies could be considered. For example, in a rural scenario, significant distance between field hubs may exist and a linear drop topology may be the most appropriate. The risk of cuts in the communications and costs associated with each topology should be analyzed by the project designer to assess the best field device to field hub configuration for each project.

4.4 Bandwidth Requirements by Typical Device Type

The NTCIP Guide provides specific guidance on the computation of bandwidth requirements for center-to-field devices and addresses the overhead requirements for systems management and maintenance based on the type of device and standards implemented.

4.5 Communications Plant Alternatives

Center-to-field communications have typically been performed using UTWP operating with 1200 bps FSK (frequency shift keying) modems for wireline communications. There modems come in different applications, such as half or full duplex. When analyzing bandwidth requirements for copper communications plant and attempting to increase bit rate, it is important to remember that not all modems and bit rates may be practical. 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.

4.6 Communications for Video[9]

4.6.1 Functional Requirements

CCTV is vital to freeway and incident management systems that are the foundation of the *Ten-Year ITS Cost Feasible Plan*. The functions provided by CCTV are addressed in Section 4.1 and include:

- Incident detection
- Incident verification
- Roadway and traffic monitoring
- Security
- Video surveillance along the limited-access facilities
- Video surveillance of the interchange areas (along the mainline and crossroads);
- Real-time video display
- Real-time video control
- Video verification of messages posted on DMS

These functions are different than video used for vehicle detection. With these systems, the vehicle presence and other information provided through the systems can be transmitted to the traffic management center as traffic characteristic data rather than images that are needed to support the functions above.

4.6.2 Elements of Video Systems

The devices involved with providing video usually include:

- Cameras mounted on poles or existing structures
- Camera accessories, including pan, tilt and zoom control
- A video server or switch located in the traffic management center
- Controllers for pan, tilt and zoom on operator workstations or through software
- Monitors in the traffic management center
- Peripheral devices such as recorders

Since video requires much more bandwidth than the other voice and data functions typically provided by traffic control systems, CCTV frequently becomes the dominant factor in the communications network design.

In freeway traffic management systems, operators verify incidents increasingly via CCTV. Other recent trends show replacement of conventional vidicon tubes with solid state cameras to reduce

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[9] Adapted from *Communications Handbook for Traffic Control Systems,* FHWA Publication No. FHWA-SA-93-052.

maintenance needs and specification of compressed video techniques (CODEC for compressions and decompression) to reduce bandwidth requirements.

4.6.3 Full Motion Video

Video cameras used for most traffic control applications conform to standards defined by the National Television Standards Committee (NTSC), which has defined the color television standard used in most of North America and Japan. NTSC video cameras generate an analog signal with the characteristics shown in Table 13.

Table 13 NTSC Standards

Characteristic	Value
Bandwidth	4.2 MHz
Transmission Channel	6.0 MHz
Video Resolution	700 pixels (picture elements x 525 lines
Aspect Ratio	4 : 3
Frame Update	30/second

A variety of privately owned media (e.g., coaxial cable, fiber, microwave radio) or leased facilities can transmit full-bandwidth analog video and control (i.e., pan, tilt, zoom) signals (see Chapters 6 and 7 for further discussion). Often, a dedicated coaxial cable or fiber between the camera and the nearest communications hub transmits one baseband video signal. The same video channel or a separate communications channel may transmit control signals. Once a communications hub concentrates multiple analog video signals, a technique such as frequency division multiplexing can transmit them on a backbone to the traffic operations center. The coded TV options described below may prove more appropriate for a given traffic control application for a variety of reasons. For example, with leased communications facilities it may prove cost effective to code video to use less bandwidth. Similarly, applications which use a digital communications backbone for voice and data, may benefit from using the same digital backbone for video rather than a separate analog video backbone. Finally, to provide a high quality video signal for some applications (e.g., video transmitted over a long distance) may require digital transmission since the latter regenerates signals to filter out noise rather than amplifying both the signal and noise as with analog transmission.

4.6.4 Freeze Frame Video Transmission

A wide variety of applications including traffic control have used freeze frame or slow scan video image transmission. In general, freeze frame techniques capture a black and white or color image and code it for transmission over standard voice grade telephone circuits or other narrowband communications media. After transmission, equipment reconverts the coded signal to a still image displayed on a television monitor.

Freeze frame transmission times range from a few seconds to several minutes depending on factors such as:

- Modem data rate,

- Image resolution,
- Black & white or color image, and
- Shades of gray.

Table 15 presents scan times reported by one product vendor for color and black and white images when transmitted on a voice grade channel. For example, an NTSC monochrome image with a resolution of 512 x 480 and 64 gray scale levels (6 bit) would take 35 seconds to transmit.

Table 15 Representative Freeze Frame Scan Times (on a voice grade channel)

Monochrome	
Resolution and Gray Level	**Transmission Time 525 Line**
256 X 240X 6	35 Seconds
256 X 480 X 6 cr 8	76 Seconds
512 X 480 X 6 cr 8	152 Seconds
Color	
Resolution and Color Level	**Transmission Time**
512 X 240 X 6	72 Seconds
512 X 480 X 8	152 Seconds

4.6.5 Coded TV Transmission

NTSC Standard

Video compression techniques take advantage of data redundancy and human visual limitations to reduce the transmission bandwidth required to transport video signals. Interframe coding techniques eliminate redundancy between successive frames by transmitting only the differences between frames, while intraframe coding eliminates redundancy within a video field. For example, video compression may result in transmission of 12 frames per second rather than the 30 frames per second specified by the NTSC.

Currently, no standard metric exists to judge the quality of coded video output. Two factors that influence a viewer's perception of video quality are resolution and frame rate. Many CODEC (compression and decompression) which transmit video at rates of 384 Kbits per second or below provide a video resolution of 256 pixels by 240 lines, in comparison to the 700 by 525 NTSC resolution. The H.261 standard specifies a resolution of 352 pixels by 288 lines.

Frame rate refers to the number of times a display updates each second, with extremely low frame rates producing "jerky" motion sequences. While CODEC manufacturers include maximum frame rates as part of equipment specifications, the frame rate actually used for a particular video sequence changes adaptively based on the amount of bandwidth available and the amount of video processing performed by the video coding algorithms. For example, in a video sequence with much motion the CODEC might transmit fewer frames each second to compensate for the additional video processing required.

Based on a study conducted by the Connecticut Department of Transportation in the 1990s, CODECs operating at 384 Kbits per second, the video quality for freeway surveillance and camera movement operations rate as either "good" or "excellent" for traffic management applications..

CODEC can transmit video at even lower data rates, i.e., 64 and 128 Kbits per second. The picture quality at a given transmission rate varies with the manufacturer. Prior to preparing a specification, the user should attend demonstrations provided by the manufacturers to identify an acceptable transmission rate.

MPEG
In addition to the NTSC CODEC standard, the Motion Picture Experts Group (MPEG), an organization of the International Standards Organization, has develop standard video compression formats that achieve high compression by storing only the changes that occur from one frame to the next, instead of the entire frame. Established in 1988, the group has produced MPEG-1, the standard on which such products as Video CD and MP3 are based, MPEG-2, the standard on which such products as Digital Television set top boxes and DVD are based, MPEG-4, the standard for multimedia for the fixed and mobile web and MPEG-7, the standard for description and search of audio and visual content. Work on the new standard MPEG-21 "Multimedia Framework" has started in June 2000. So far a Technical Report and two standards have been produced and three more parts of the standard are at different stages of development. Several Calls for Proposals have already been issued. MPEG-2 is becoming a popular software-based compression technique for CCTVs used in traffic monitoring.

4.6.6 Managing Video

Three basic approaches to video are emerging in Florida's ITS applications.

1. Managing video through a central server using NTSC standards in the traffic management center.
2. Managing video through a distributed approach with servers located in the field for better bandwidth management
3. Internet Protocol (IP) video applications over Gigabit Ethernet.

Central Video Servers
Traditional management of video for ITS involves locating a central video server and switch in the traffic management center where real-time full-motion video continuously streamed to the traffic management center. The NTSC standard and server is used primarily for controlling how the video is displayed on a wall for center-wide use or on an operators desktop. This technique requires significant bandwidth since video images are transmitted to the traffic management center continuously from each camera and significant hardware to manage the flow of information and need for control.

Distributed Video Approach
Recently, distributed architectures have been explored and deployed for managing video. In District 5, the I-4 SMIS is being converted to this approach through the implementation of a Gigabit Ethernet with five field video switches. These switches transmit only the video signals

from the cameras that are needed from each of the switches. This approach is a more effective utilization of bandwidth, but limits the number of cameras that can be viewed simultaneously.

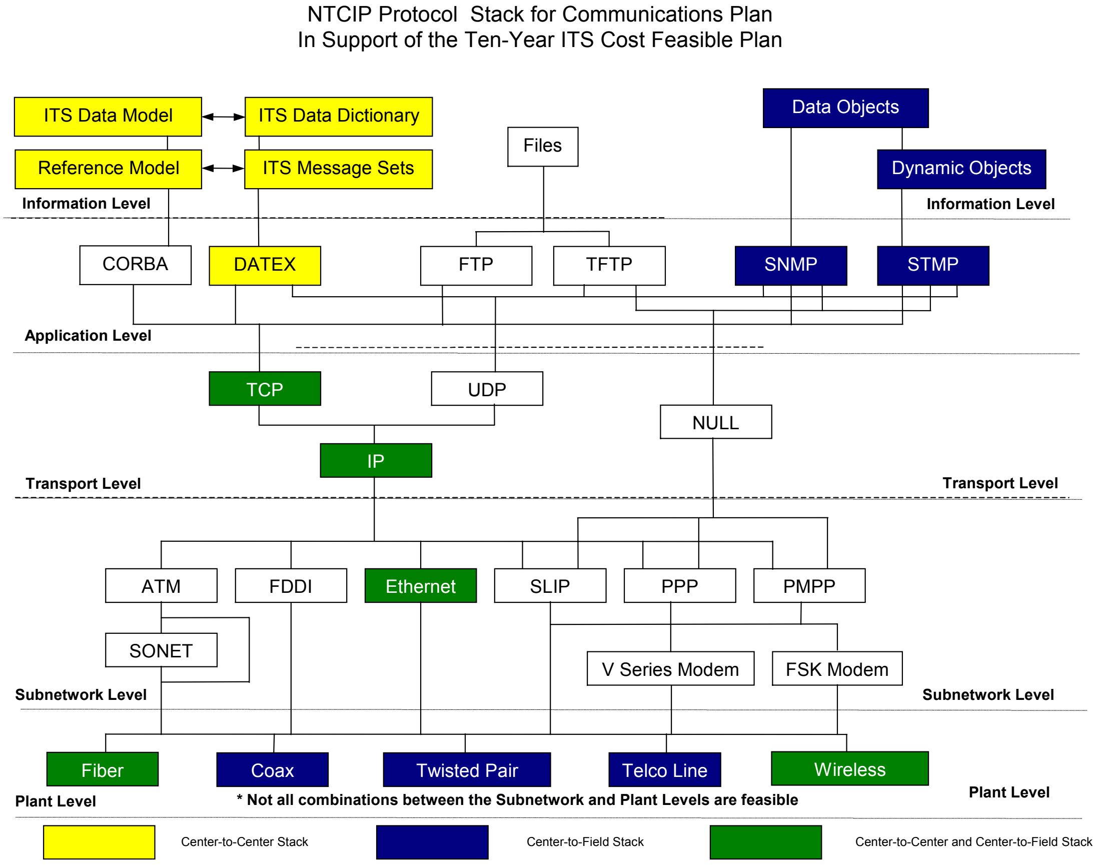
Internet Protocol Video

An emerging trend is the use of fully IP addressable video network applications. The FDOT demonstrated this concept over their microwave wireless communications backbone at ITS America 2001 and several recent papers have been published demonstrating the potential for this management technique to provide a cost-effective approach to managing video and bandwidth for ITS applications since bandwidth is only required for each CCTV called based on the IP address. This technique also provides opportunities for enhanced sharing of video between multiple stakeholders in a software, rather than hardware, dependent scenario.

4.7 NTCIP Stack

Figure 11 summarizes the NTCIP Stack recommended for use for center-to-field communications to support the *Ten-Year ITS Cost Feasible Plan*. Significant additional work is required by the designer to select the appropriate standards and specifications within the NTCIP framework for the design of interoperable and integrated system.

Figure 11 – NTCIP Stack For ITS Communications in the *Ten-Year ITS Cost Feasible Plan*


NTCIP Protocol Stack for Communications Plan
In Support of the Ten-Year ITS Cost Feasible Plan

4.8 Summary

Center-to-field communications are a complex communications problem that involves a variety of field devices with several alternatives that must be addressed to achieve a cost effective design that meets the functional requirements of the users. This section outlined some of the basic issues associated center-to-field standards. However, significant work is required at the system level and in the design of individual projects to ensure an integrated and interoperable system is achieved. An NTCIP Stack is recommended, however, the emergence of these standards will undoubtedly undergo some refinement as systems are implemented and maturity is achieved.