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Deliverable For:

Gateway Cities Traffic Signal Synchronization and Bus Speed Improvement Project

I-5/Telegraph Road Corridor

Deliverable 5.2.1

COMMUNICATION SYSTEMS ALTERNATIVES ANALYSIS REPORT

FINAL

Version 1

Submitted To:

Submitted By:

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Intelligent Transportation Systems Business Unit

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Draft Version 1	December 11, 2002	Initial submittal
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1 INTRODUCTION

1.1 Background

The County of Los Angeles Department of Public Works Traffic Signal Synchronization, Operation and Maintenance (SOM) Program has proven successful in creating an institutional infrastructure to coordinate the activities of the agencies responsible for traffic signal operations in the County. A key feature of this infrastructure is the Forums - groups of bordering agencies created to encourage and promote inter-agency cooperation. These Forums have enabled funding to be targeted at infrastructure improvements along arterial and arterial/freeway corridors in the County's sub-regions. Such projects are a critical part of what will eventually be a network of integrated ITS systems in Los Angeles County and in Southern California.

The I-5/Telegraph Road Corridor is one such project which will result in arterial infrastructure improvements along Telegraph Road in the South-East Los Angeles County (Gateway Cities) Forum. The Project area contains 277 intersections in 10 different jurisdictions, comprising 8 cities, the County and Caltrans.

The objective of this Project is to design, develop and deploy traffic control systems in the Corridor so that the signals along I-5/Telegraph Road and expanded area can be synchronized across the jurisdictional boundaries. This Project concentrates on the needs of the agencies in this Corridor with respect to signal synchronization along Telegraph Road and recommends improvements to field infrastructure to accommodate traffic signal controllers, changeable message signs (CMS) and closed circuit television (CCTV) and central traffic control systems to meet those needs.

When successfully completed, each of the agencies responsible for traffic signal operations in the I-5/Telegraph Road Corridor and expanded area will have full access to an Advanced Traffic Management System (ATMS) that monitors and controls the traffic signals under their jurisdiction. Agencies will be able to synchronize their signals with neighboring agencies, and exchange traffic information in real-time through an Information Exchange Network (IEN).

Agencies will also be able to exchange data with other agencies in the Gateway Cities region. This will allow the agencies to respond to recurrent and non-recurrent congestion in a coordinated fashion across the jurisdictional boundaries. The traffic control systems therefore form part of a larger, regional approach supporting multi-agency traffic signal operations.

Previous reports for this Project have addressed the user and functional requirements for the ATMS systems, interface systems, communication system, and local control centers (LCC) for the I-5/Telegraph Road Corridor.

This report presents the Communications Analysis and Recommendations for the I-5/Telegraph Road Corridor based upon previously define requirements.

1.2 Organization of Document

This document is organized into the following Sections:

<u>Section 1: Introduction</u>

Presents the Project background and introduces the document.

Section 2: Summary of Requirements

This section summarizes the relevant requirements derived in the "Gateway Cities Traffic Signal Synchronization and Bus Speed improvement Project – I-5/Telegraph Road Corridor, *Final Requirements Analysis*" Bandwidth requirements and communication requirements that were established in previous documents are discussed in this section.

At the end of this section a set of criteria for comparing the available communication technologies is established.

Section 3: Network Architecture

This section describes the overall Communication Network Architecture. It distinguishes between the field network that communicates with individual field devices like Controllers, CMS's, CCTV's, etc, and the IEN network that will be primarily responsible for the LCC-to-LCC data exchange. Further the IEN Network can be conceptualized in two ways, the Physical IEN Network layout; the equipment and the physical communication media between the different agencies, and the Logical IEN Network layout; how the high-level components such as the ATMS system and the IEN workstation exchange data.

This section also discusses options for the CCTV video image distribution architecture's as it is anticipated that the CCTV video image component will require substantially higher bandwidth compared to all the other communications needs including controller, CMS and CCTV control.

Section 4: Candidate Technologies

This section summarizes the currently available technologies that can be used for ITS communication. It concentrates on twisted wire pair, fiber-optic cable, wireless communication and leased line communication.

Section 5: Communications Technology Analysis

This section compares the currently available technologies that can be used for ITS communication based on the set of criteria established in section 3.

Section 6: Recommendations

Recommendations are presented for the communication network scenarios, depending on criteria such as distance between communication devices, bandwidth requirements, cost considerations and existing or planned communication infrastructure available. This section makes generalized recommendations for each of the different possible scenarios. The actual selection of the communication mode will take into consideration the recommendations made here.

Section 7: Acronyms

This section contains a list of the acronyms used in the report.

Section 8: Disposition of Comments

This section contains the disposition of comments received from the Draft version of the report.

1.3 Regional Area and Agencies Involved

The I-5/Telegraph Road Corridor Project encompasses several jurisdictions. Furthermore, it will be integrated, or have the ability to integrate, with other projects and existing systems in the region through the IEN architecture. The following cities and agencies are directly involved in the Project:

- Commerce
- Downey
- La Mirada
- Montebello
- Norwalk
- Pico Rivera
- Santa Fe Springs
- Whittier
- Los Angeles County Department of Public Works
- Caltrans District 7

1.4 Referenced Documents

The following documents have been used as reference material in the preparation of this report:

Gateway Cities Traffic Signal Synchronization and Bus Speed Improvement Project – I-5/Telegraph Road Corridor

Deliverable 3.5.1: Communication Systems Requirements - Draft

Deliverable 3.6: Final Requirements Analysis

2 COMMUNICATIONS REQUIREMENTS AND COMPARISON CRITERIA

2.1 Analysis Process

The process followed in this analysis is presented in Figure 2.1. The process covers three tasks within the project's scope of work. These are the Communications Analysis, Recommendations and Conceptual Design. The steps are as follows:

Communications Analysis (this report):

1. The communications requirements are derived from the previous requirement definition activities in this project
2. Categories are defined which represent the criteria which will be the basis for the analysis of the candidate technologies
3. The requirements are grouped together in these categories.
4. The candidate technologies are assessed against the requirements in the categories.

Recommendations

5. Identify recommended communications solutions

Conceptual Design

6. Apply the recommendations to the LCC's, ATMS's and devices in the project area

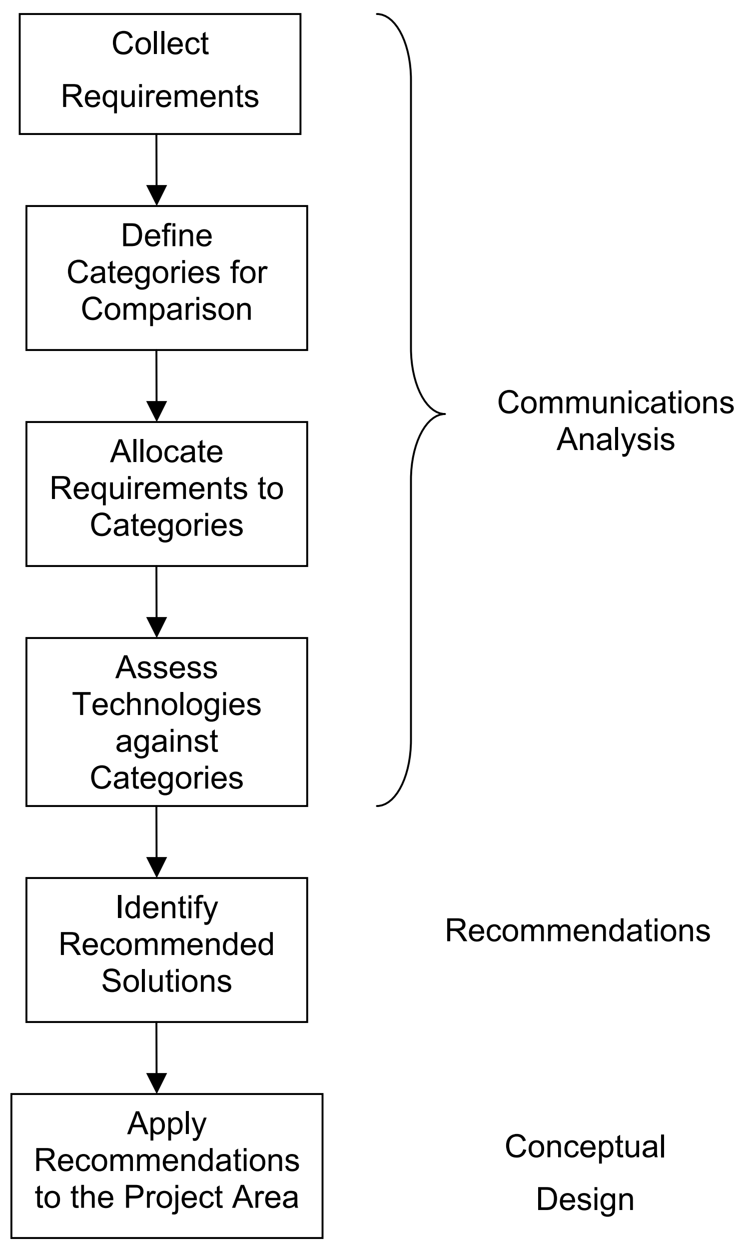
2.2 Relevant Requirements

2.2.1 <u>ATMS</u>

UR TS 3.3.5.1 The ATMS shall be consistent with the County's IEN Architecture

FR TS 1.13.3	The ATMS shall support controllers using the AB3418 protocol.
FR TS 1.13.4	The central signal system software shall include communications support for the NTCIP protocol (Level 1 conformance).
FR TS 1.13.5	The ATMS will communicate with each intersection once per second.
FR TS 2.1.6	The central signal system software shall support communication with the field controllers at rates from 1.2kbps to 38.4kbps.
FR TS 2.1.8	Upload/download commands shall be executed immediately upon command at a communication rate of 1.2kbps to 38.4kbps between the central signal system software and the field controllers.
FR 4.1.1	The central signal system software shall monitor the traffic signal controllers on a second-by-second basis.
FR TS 21.1.1	Using tools provided with the Windows operating system, the System Administrator or Network Administrator shall have the capability to monitor the network, including: which users are logged into the system, status of any system firewalls, and status of system servers.

Figure 2.1: Steps in the Communications Analysis Process



FR TS 25.1.9 The system shall support panning, tilting and zooming CCTV cameras.

2.2.2 LCC

None

2.2.3 Integration System

UR IS 11	The ATMS shall make available CCTV video images for viewing at other remote locations both in the Corridor and elsewhere.
UR IS 12	It shall be possible to view video images from CCTV cameras in other jurisdictions.
FR IS 27	The ATMS shall provide remote access via the IEN.
UR IS 30	At a minimum, the ATMS should have demonstrated the ability to support the relevant NTCIP protocol.
UR IS 31	Where there is a high degree of commitment or reasonable degree of use of the NTCIP protocol, then it should be specified for use.
FR IS 39	All system components of the I-5/Telegraph Road Project will communicate via the IEN.
FR IS 43	Access to the IEN shall be required on a 24 hours per day, 7 days per week basis (excluding an acceptable down time for system maintenance, backup, etc).

2.2.4 Other Forum Projects

From SGV Pilot:

Data must arrive at the destinations at the same rate it is introduced to the network.

A high percentage of data (99.95%) must reach the workstations (over the IEN).

- The system must work over a 384 Kbps LAN for up to 2000 detectors, 20 workstations with 50 requests each.

From I-105 Corridor Project:

2.2.4.1. Functional Requirements

FRD429: Existing communications infrastructure shall be used wherever feasible.

- FRD430: The communications system shall support the ability to monitor and download traffic signal timing plans to controller.

FRD431: The communications system shall support the ability to view and control CCTV cameras.

FRD432: The communications system shall support the ability to monitor and control CMS.

FRD433: The communications system shall support the ability to monitor and control HAR.

FRD434: If HAR are not deployed with this Project, bandwidth capacity for future HAR installations shall be provided.

FRD435: The communications system shall support the ability to monitor and control HAT.

FRD436: If HAT is not deployed with this Project, bandwidth capacity for future HAT installations shall be provided.

- FRD437: The communications system shall support communications to kiosks.

- FRD438: If kiosks are not deployed with this Project, bandwidth for future kiosk installations shall be provided.
- FRD439: The communications system shall support communications to Internet web pages.
- FRD440: If Internet web pages are not deployed with this Project, bandwidth for future Internet web page installations shall be provided.
- FRD441: The agency owned cable-based communications system shall be sized with a minimum of 50% spare capacity (as standard practice), if used.
- FRD442: The communications system between the Local LCCs, Sub-Regional LCC and County LCC shall be sized to accommodate 50 simultaneous intersections sending second by second status information.
- FRD443: The communications system shall have diverse routing options where feasible.
- FRD444: Communications rates utilized shall be telephony standards.

HLD Definitions and Recommendations

Camera control communications is considered low speed “bursty” and a 9600 bps asynchronous circuit is suggested.

The result (for CMS) is low speed “bursty” communications (and) a 9600 bps asynchronous circuit is suggested.

The Highway advisory radios use dial-up telephone facilities to interface with the control center. The typical controller uses dual-tone, multi-frequency (DTMF) signals for control. The messages are sent from the LCC/Control Center to the transmitter over the analog voice channel.

(For kiosks) a data rate of 56kps is expected to be more than adequate

2.3 Communication System Requirements

2.3.1 Categorizing Requirements

The Communications System Requirements are mainly derived from the requirements listed previously. In this section, they are grouped into the following categories:

City work stations/control sites
Integration System Requirements
Non-transportation related issues
Public relations issues
O&M issues
Expandability
Bandwidth requirements
Reliability
Redundancy
Diversity
Performance requirements
Communications system access points

Potential bottlenecks and weak links

These categories are relevant for both the IEN and the center–to-field communications links and are the basis for the criteria which are used in the later comparative analysis of candidates.

2.3.2 IEN Communications Requirements

2.3.2.1. City Work Stations/Control Sites

None

2.3.2.2. Integration System Requirements

UR TS 3.3.5.1 The ATMS shall be consistent with the County's CAMS and IEN Architecture

FR IS 27 The ATMS shall provide remote access via the IEN.

FR IS 39 All system components of the I5/Telegraph Road Project will communicate via the IEN.

2.3.2.3. Non-Transportation Related Issues

FR CS 1. Evaluation of the cost of the communications network shall consider a 10-Year Life Cycle cost analysis.

2.3.2.4. Public Relations Issues

None

2.3.2.5. O&M Issues

FR TS 21.1.1 Using tools provided with the Windows operating system, the System Administrator or Network Administrator shall have the capability to monitor the network, including:

The status of any system firewalls

FR TS 21.1.2 The communications technology should be easy to operate and maintain.

FR TS 21.1.3 If new technology (to the Agency) is deployed, the agency staff should be provided training in maintenance and trouble shooting of the equipment.

FR TS 21.1.4 Tools should be provided to the agencies for automatic checking of the communication equipment and media.

2.3.2.6. Expandability

FR CS 2. (FRD441): The agency owned cable-based communications system shall be sized with a minimum of 50% spare capacity (as standard practice), if used.

FR CS 3. (FRD435): The communications system shall support the ability to monitor and control HAT.

FR CS 4. (FRD436): If HAT is not deployed with this Project, bandwidth capacity for future HAT installations shall be provided.

FR CS 5. (FRD439): The communications system shall support communications to Internet web pages.

FR CS 6. (FRD440): If Internet web pages are not deployed with this Project, bandwidth for future Internet web page installations shall be provided.

2.3.2.7. Bandwidth Requirements

FR CS 7. (FRD444): Communications rates utilized shall be telephony standards.

UR IS 11 The ATMS shall make available CCTV video images for viewing at other remote locations both in the Corridor and elsewhere.

UR IS 12 It shall be possible to view video images from CCTV cameras in other jurisdictions.

FR CS 8. The system must work over a 384 Kbps LAN for up to 2000 detectors, 20 workstations with 50 requests each (excluding CCTV video transfer).

FR CS 9. (FRD429) Existing communications infrastructure shall be used wherever feasible.

2.3.2.8. Reliability

FR IS 43 Access to the IEN shall be required on a 24 hours per day, 7 days per week basis (excluding an acceptable down time for system maintenance, backup, etc).

2.3.2.9. Redundancy

FR CS 10. (FRD443): The communications system shall have diverse routing options where feasible.

2.3.2.10. Diversity

FR CS 11. (FRD429): Existing communications infrastructure shall be used wherever feasible.

2.3.2.11. Performance Requirements

FR CS 12. The IEN shall be continuously available and not require an application to request connection.

FR CS 13. Data must arrive at the destinations at the same rate it is introduced to the network.

FR CS 14. A high percentage of data (99.95%) must reach the workstations (over the IEN).

FR CS 15. (FRD442): The communications system between the Local LCCs, Sub-Regional LCC and County LCC shall be sized to accommodate 50 simultaneous intersections sending second by second status information.

2.3.2.12. Communications System Access Points

FR IS 27 The ATMS shall provide remote access via the IEN.

2.3.2.13. Potential Bottlenecks and Weak Links

See redundancy.

2.3.3 Center-to-Field Communications

2.3.3.1. City Work Stations/Control Sites

Not applicable

2.3.3.2. Integration System Requirements

Not Applicable

2.3.3.3. Non-Transportation Related Issues

FR CS 16. Evaluation of the cost of the communications network shall consider a 10-Year Life Cycle cost analysis.

2.3.3.4. Public Relations Issues

Not applicable

2.3.3.5. O&M Issues

FR TS 21.1.2 The communications technology should be easy to operate and maintain.

FR TS 21.1.3 If new technology (to the Agency) is deployed, the agency staff should be provided training in maintenance and trouble shooting of the equipment.

FR TS 21.1.4 Tools should be provided to the agencies for automatic checking of the communication equipment and media.

2.3.3.6. Expandability

FR CS 17. (FRD441): The agency owned cable-based communications system shall be sized with a minimum of 50% spare capacity (as standard practice), if used.

FR CS 18. (FRD433): The communications system shall support the ability to monitor and control HAR.

FR CS 19. (FRD434): If HAR are not deployed with this Project, bandwidth capacity for future HAR installations shall be provided.

FR CS 20. The Highway advisory radios shall support the use of dial-up telephone facilities to interface with the control center. (The typical controller uses dual-tone, multi-frequency (DTMF) signals for control. The messages are sent from the LCC/Control Center to the transmitter over the analog voice channel.)

FR CS 21. (FRD437): The communications system shall support communications to kiosks.

FR CS 22. (FRD438): If kiosks are not deployed with this Project, bandwidth for future kiosk installations shall be provided.

FR CS 23. (For kiosks) a data rate of 56kps is expected to be more than adequate.

2.3.3.7. Bandwidth Requirements

UR IS 30	At a minimum, the ATMS should have demonstrated the ability to support the relevant NTCIP protocol.
UR IS 31	If there is a high degree of commitment or reasonable degree of use of the NTCIP protocol, then it should be specified for use.
FR TS 1.13.4	The central signal system software shall include communications support for the NTCIP protocol (Level 1 conformance).

Traffic Signals

FR TS 1.13.3	The ATMS shall support controllers using the AB3418 protocol.
FR TS 1.13.5	The ATMS will communicate with each intersection once per second.
FR TS 2.1.6	The central signal system software shall support communication with the field controllers at rates from 1.2kbps to 38.4kbps.
FR CS 24.	(FRD430): The communications system shall support the ability to monitor and download traffic signal timing plans to controller.
FR TS 2.1.8	Upload/download commands shall be executed immediately upon command at a communication rate of 1.2kbps to 38.4kbps between the central signal system software and the field controllers.
FR 4.1.1	The central signal system software shall monitor the traffic signal controllers on a second-by-second basis.

Appendix A contains an analysis of the NTCIP and AB3418 protocols. The resultant bandwidth requirements are as follows:

FR CS 25. At 9600bd per channel the following shall be the minimum number of traffic signal controllers per 9600 bd circuit:

- AB3418 (no overlap) 5 controllers per circuit
- AB3418 (with overlaps) 6 controllers per circuit
- NTCIP (no overlap) 5 controllers per circuit
- NTCIP (with overlaps) 6 controllers per circuit

CCTV

FR TS 25.1.9	The system shall support panning, tilting and zooming CCTV cameras.
FR CS 26.	(FRD431): The communications system shall support the ability to view and control CCTV cameras.

Analog

FR CS 27. The communications system shall accommodate the standard NTSC bandwidth for video of 4.2 MHz based on a 6 MHz channel spacing for video signals.

Digital

FR CS 28. Either motion JPEG or MPEG formats should be used.

Control

FR CS 29. Each camera will also require a camera control signal to control camera functions such as pan, tilt, zoom, etc.

FR CS 30. This control signal, ranging from 300 bps to 9600 bps will be accommodated over a common channel in a multi-dropped environment.

FR CS 31. In a twisted pair network, one pair can be used to address multiple cameras.

CMS

FR CS 32. FRD432: The communications system shall support the ability to monitor and control CMS.

FR CS 33. The result (for CMS) is low speed "bursty" communications (and) a 9600 bps asynchronous circuit is suggested.

2.3.3.8. Reliability

FR CS 34. The field-to-center communications shall have 99.5% availability.

2.3.3.9. Redundancy

FR CS 35. (FRD443): The communications system shall have diverse routing options where feasible.

2.3.3.10. Diversity

FR CS 36. FRD429: Existing communications infrastructure shall be used wherever feasible.

2.3.3.11. Performance Requirements

FR CS 37. The field-to-center communications shall be continuously available and not require an application to request connection.

FR CS 38. Data must arrive at the destinations at the same rate it is introduced to the network.

2.3.3.12. Communications System Access Points

Not Applicable

2.3.3.13. Potential Bottlenecks and Weak Links

See Redundancy.

2.4 Criteria for Comparison Derived from Requirements

The communications requirements as presented earlier in this section need to be used as a basis for deriving a set of criteria for comparison purposes. The criteria's are divided into two sections, the IEN and the Center-To-Field communications requirements.

2.4.1 IEN Communications Requirements

- Life Cycle Cost
  - Evaluation of the cost of the communications network shall consider a 10-Year Life Cycle cost analysis

- Operations and Management (O&M)
    - Monitor the network, including status of any system firewalls
    - Communications technology should be easy to operate and maintain
    - Automatic checking of the communication equipment and media
- Expandability
    - Monitor and control HAT
    - bandwidth capacity for future HAT installations
    - Support communications to Internet web pages
    - Bandwidth for future Internet web page installations
- Bandwidth
    - ATMS shall make available CCTV video images for viewing at other remote locations both in the Corridor and elsewhere
    - View video images from CCTV cameras in other jurisdictions
    - System must work over a 384 Kbps LAN for up to 2000 detectors, 20 workstations with 50 requests each (excluding CCTV video transfer)
- Reliability
    - Access to the IEN shall be required on a 24 hours per day, 7 days per week basis
- Redundancy
    - Communications system shall have diverse routing options where feasible
- Performance
    - Existing communications infrastructure shall be used wherever feasible
    - IEN shall be continuously available and not require an application to request connection
    - Data must arrive at the destinations at the same rate it is introduced to the network
    - A high percentage of data (99.95%) must reach the workstations (over the IEN)
    - Communications system between the Local LCC's, Sub-Regional LCC and County LCC shall be sized to accommodate 50 simultaneous intersections sending second by second status information
    - ATMS shall be consistent with the County's IEN Architecture
    - ATMS shall provide remote access via the IEN
    - All system components will communicate via the IEN
    - ATMS shall provide remote access via the IEN

2.4.2 Center-to-Field Communications

- Life Cycle Cost
  - Evaluation of the cost of the communications network shall consider a 10-Year Life Cycle cost analysis
- Operations and Management (O&M)
  - Communications technology should be easy to operate and maintain
  - Automatic checking of the communication equipment and media
- Expandability
  - Monitor and control HAR
  - Bandwidth capacity for future HAR installations
  - Highway advisory radios use dial-up telephone facilities (DTMF signals for control) to interface with the control center
  - Support communications to kiosks
  - Bandwidth for future kiosk installations (data rate of 56kps is expected to be more than adequate.)
- Bandwidth
  - At a minimum, the ATMS should have demonstrated the ability to support the relevant NTCIP protocol
  - If there is a high degree of commitment or reasonable degree of use of the NTCIP protocol, then it should be specified for use
  - Central signal system software shall include communications support for the NTCIP protocol (Level 1 conformance)
  - Traffic Signals
    - ATMS shall support controllers using the AB3418 protocol
    - ATMS will communicate with each intersection once per second
    - Monitor the traffic signal controllers on a second-by-second basis
    - Support communication with the field controllers at rates from 1.2kbps to 38.4kbps
    - Support the ability to monitor and download traffic signal timing plans to controller
    - Upload/download commands shall be executed immediately upon command at a communication rate of 1.2kbps to 38.4kbps between the central signal system software and the field controllers
  - CCTV
    - Support panning, tilting and zooming CCTV cameras
    - Support the ability to view and control CCTV cameras
      - Analog

- Accommodate the standard NTSC bandwidth for video of 4.2 MHz based on a 6 MHz channel spacing for video signals
- Digital
  - Either motion JPEG or MPEG formats should be used
- Control
  - Each camera will also require a camera control signal to control camera functions such as pan, tilt, zoom, etc
  - Control signal, ranging from 300 bps to 9600 bps will be accommodated over a common channel in a multi-dropped environment
  - In a twisted pair network, one pair can be used to address multiple cameras

- CMS
  - Support the ability to monitor and control CMS
  - The result (for CMS) is low speed “bursty” communications (and) a 9600 bps asynchronous circuit is suggested

- Reliability
  - Field-to-center communications shall have 99.5% availability
- Redundancy
  - The communications system shall have diverse routing options where feasible
- Performance
  - Field-to-center communications shall be continuously available and not require an application to request connection
  - Data must arrive at the destinations at the same rate it is introduced to the network
  - Existing communications infrastructure shall be used wherever feasible

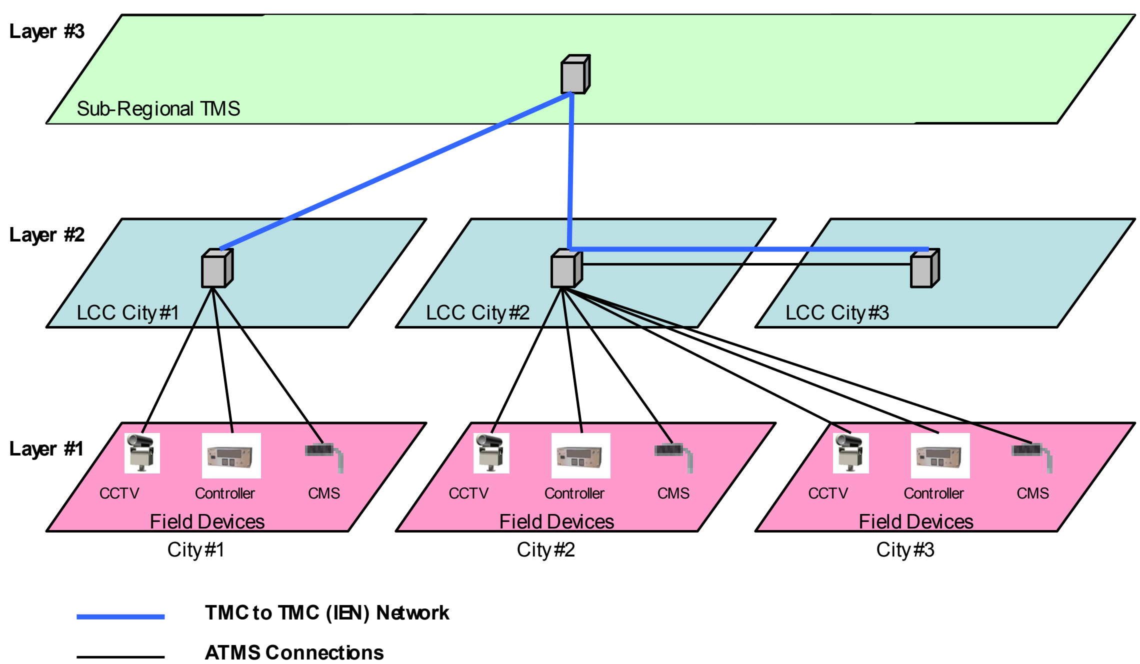
3 NETWORK ARCHITECTURE

3.1 Description of Networks

3.1.1 Overall Network

Figure 3-1 shows a representation of the communication network supporting the countywide architecture to be deployed through the I-5 Telegraph Road project. At a high level the communication infrastructure can be viewed at three different layers with interconnections between the layers. The lowest layer is the field devices layer which contains all the field elements such as controllers, CCTV and CMS devices. Each element in layer #1 would potentially be connected to a central ATMS system located within the city or to an ATMS of a different city. Figure 3-1 shows devices of City #3 directly connected to the ATMS located in City #2. The different LCC locations are then connected to the Sub-Regional Traffic Management Center (SRTMC) using the IEN network. A city like city #3 that already has a connection to city #2 for its ATMS workstation, could possibly use that same physical connection to link up to the IEN network. This is represented by the two lines between the LCC for City #2 and City #3.

Figure 3-1 Communication Network



3.1.2 Logical and Physical Architectures

Referring to Figure 3.1, the IEN links ATMS's on layer 2 and also provides layer 2 to layer 3 connectivity. The IEN network can be represented as a logical IEN Network and a Physical

IEN Network. The Logical IEN Network is represented by Figure 3.2. This shows the logical connections between the different components of the IEN network. Logically the configuration of the IEN network can be different from the way the components are connected physically. Figure 3.3 further expands the IEN network to show the remote ATMS and IEN workstations.

In practice, the various logical communication links are implemented as physical connections (e.g. a twisted wire pair, fiber optic cable, or wireless channel). Communications links which are logically separate can be physically combined. Figure 3.4 shows two examples. Physical (1) illustrates a case where the link between City 1, hosting the TCS for City 2, does dual service as supporting the remote ATMS workstation and also the field connection between the ATMS and the controllers. Physical (2), is an example of the link from a City to the County where the County is acting as a TCS host for that City. In this case, the link carries ATMS, IEN and field data.

This is relevant for the communications analysis because a critical consideration in selecting the communications method or technique or mode, is the bandwidth that needs to be supported. These examples show that, in some cases, the bandwidth needs are dependent upon the possibility of combining the logical connections into physical links. The viability of this will be dependent upon the geographic location of the devices being supported. This will not be known until later in the project when all device locations are able to be identified.

3.2 Bandwidth Considerations

3.2.1 Field Network

Field network devices are those devices that will be communicating to the different ATMS systems. The field network devices will be connected to the ATMS via different communication media as discussed later on in the report. It is possible that field devices belonging to a certain city may be connected to an ATMS system that is residing at a different city LCC location.

Table 3.1 summarizes the bandwidth needs for each of the field device to LCC communication. It is apparent from this table that the application that uses the highest bandwidth is retrieving the CCTV video images from the field cameras to the LCC location.

Table 3.1 Summary of Bandwidth needs for Field Device to LCC communication

Field Device	Type of Communication	Bandwidth
Controller Monitoring	Once-per-second	1.2kbps to 38.4Kbps
Controller Upload/download	Short infrequent	1.2Kbps to 38.4Kbps
CCTV Camera Images (Analog)	Standard NTSC	4.2MHz based on a 6MHz channel
CCTV Camera Images (Digital)	Streaming video	0.5MBps to 3MBps
CCTV Camera Control (PTZ)	Short infrequent	0.3Kbps to 9.6Kbps
CMS	Short infrequent	1.2Kbps to 19.2Kbps

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Figure 3.2 Logical IEN Architecture

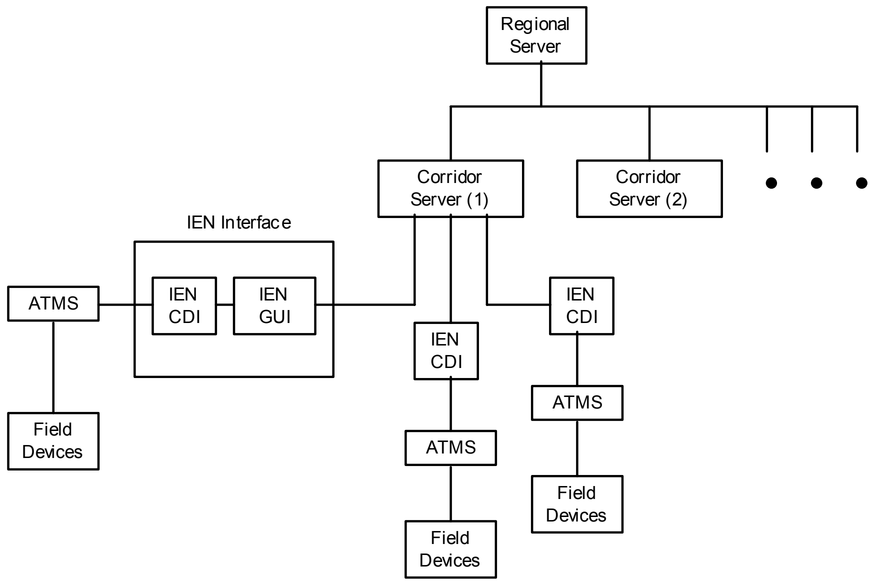


Figure 3.3 Expanded Logical IEN network

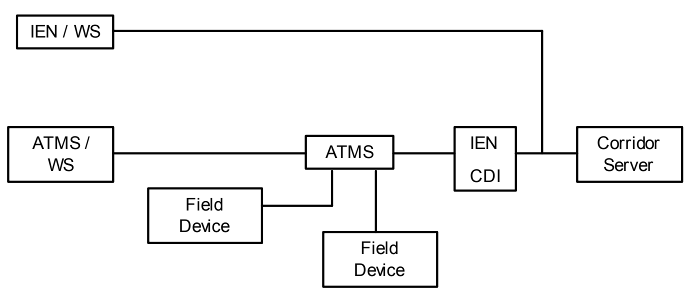
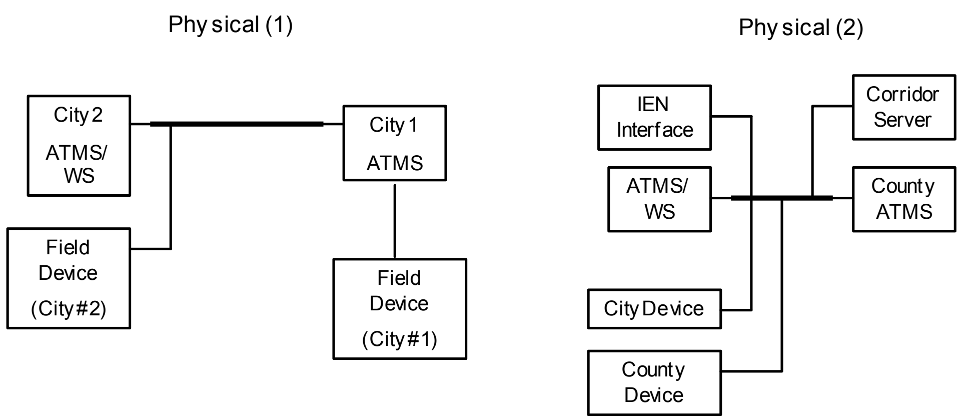


Figure 3.4 Physical Combination of Links



3.2.2 LCC to LCC Communications

To assess the physical IEN network, we have to consider all the bandwidth requirements that will be needed to transfer data between the LCC locations. Table 3.2 summarizes the bandwidth needs for the LCC to LCC communication. The IEN requirement is based upon the requirement for supporting 2000 detectors and 20 workstations. It also accounts for transferring the controller status for 50 intersections at any one time on a once-per-second basis as a minimum for supporting a remote ATMS workstation, although other functions of the workstation (i.e. database access) will require what could be considered a fractional LAN connection; therefore up to 500kb is noted in this case. It also shows the CCTV aspects of the LCC-to-LCC communications. As can be seen the dominant requirement is again for carrying video.

Table 3.2 Summary of Bandwidth needs for LCC to LCC communication

Type	Type of Communication	Bandwidth
IEN Workstation	Continuous	384Kb
Remote ATMS Workstation	Once-per-second	(1.2Kbps * 50) minimum to 500Kb
CCTV Camera Images(Analog)	Standard NTSC	4.2MHz based on a 6MHz channel
CCTV Camera Images(Digital)	Streaming	0.5MBps to 3MBps
CCTV Camera Control	Short bursty communication	0.3Kbps to 9.6Kbps

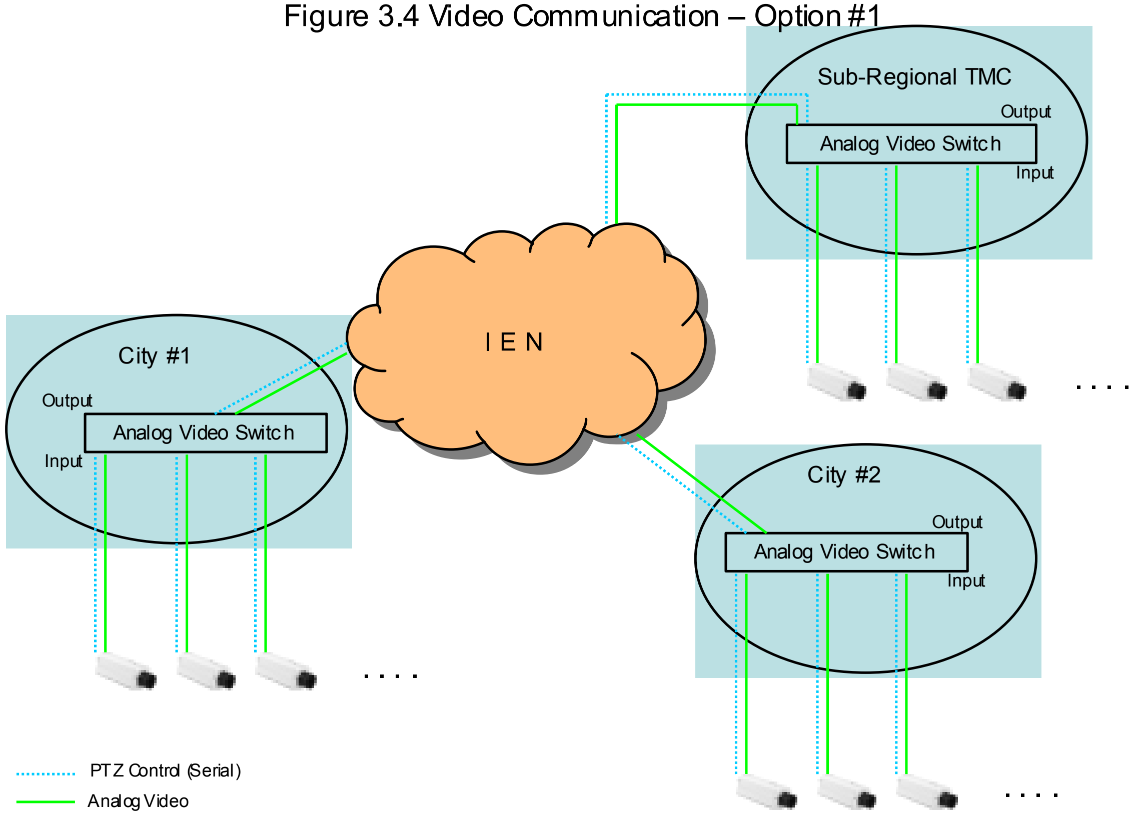
3.3 Discussion of Video Architecture

We have established in the previous two sections that bringing back the CCTV video images from the field and sharing of CCTV video images between the different agencies via the IEN network is the predominant requirement for the communications when establishing bandwidth requirements. This section discusses three options for a video architecture.

3.3.1 Option#1:

This is purely an analog solution. Analog video is brought back to the LCC locations via Fiber or twisted pair into analog video switches at local LCC. This allows for baseband video (Baseband video is raw, unprocessed, un-modulated analog video) at the local LCC locations. From the video switch, analog video can be made available to the other jurisdiction LCC’s via the IEN Network. This would mean that all the LCC’s would have to adopt common switching and control protocols to accommodate each other’s video switches. This option would greatly increase the switching logic involved in selecting and controlling a camera by a particular user, especially a user from a different jurisdiction. This option is also not very scalable since adding a new video switch would mean adding a new communication channel between all the LCC’s. Also adding a new camera requires an available communication channel between the LCC and the field. This option also does not lend itself well to the IEN network architecture. Figure 3.4 shows this option.

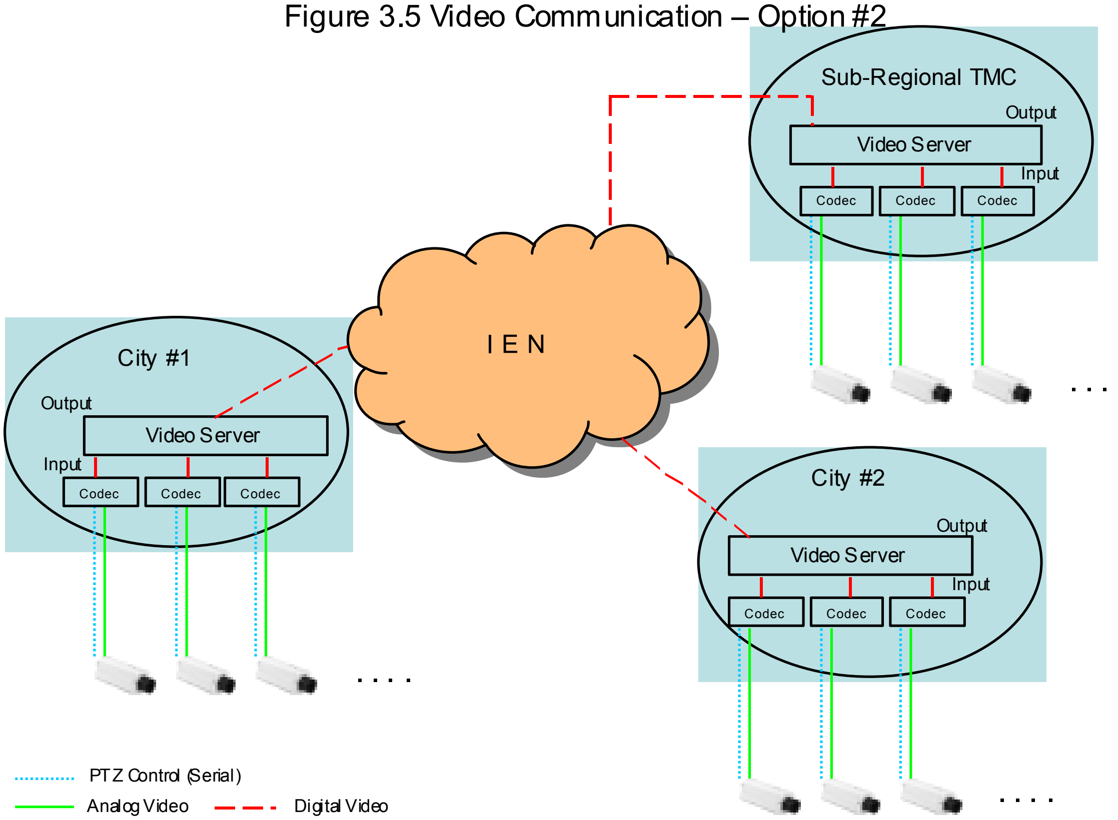
Figure 3.4 Video Communication – Option #1



3.3.2 <u>Option#2:</u>

This is a combination of an analog solution and partly a digital solution (see Figure 3.5). Analog video is brought back to the LCC location via Fiber or Twisted Pair as in Option 1. The video is then digitized utilizing a video codec device that converts Baseband video into digital streaming video. The digital video is then made available to the IEN network for the other jurisdictions. The advantage of this option is that high quality, analog video is available at the local LCC for each city. Also the PTZ control option for the local agency would be over a serial channel and very responsive. There may be some delays for PTZ control over the IEN network for the other agencies. This option has improved scalability over option #1 since adding additional video servers can be easily accomplished. Adding additional cameras still requires separate communication channel between the LCC and the camera.

Figure 3.5 Video Communication – Option #2



3.3.3 Option#3:

This is a completely digital solution. Figure 3.6 shows this option. The video image is encoded in the field. The encoder could be built in to the field camera or the encoder could be located in a cabinet out in the field. Digitized video is then made available directly from the camera onto the IEN network. This solution gives the most flexibility to the cameras network and fits within the IEN architecture. If designed appropriately, this architecture will allow the video network data to be routed via multiple pathways giving the system a lot of redundancy. The PTZ control would also have to be digitized and hence may result in increased latency. The increased latency would be caused by the need for the PTZ data to be encoded and transported with the video. The Field-to-LCC and LCC-to-LCC communication network design would be simplified with this approach and scalability is improved since adding a video camera essentially requires available bandwidth on the network. With this design there is a potential for overloading the network if it is not appropriately designed to accommodate scalability, since there is only one network for both data and video. Added attention must be given to security and user access rights (PTZ control) issues in this configuration since everything is digital. With a completely digital solution, control and viewing capabilities are available anywhere on the network and the PTZ control is all software based. This configuration is the general direction in which the industry is heading where the cameras are directly Ethernet/IP addressable. Whereas traditional camera systems support separate analog video and serial data control channels, Ethernet/IP based systems provide a single integrated channel over which encoded digital video and camera control/status may be accessed. This allows camera video and control to be supported over the same "converged" network supporting other ITS elements and centers. This design lends itself well to having a large number of cameras with video servers monitoring and controlling all these cameras. This means that there is no necessity for each city to purchase and host a video server. Agencies could combine their resources and access the video directly over the IEN network.

Figure 3.6 Video Communication – Option #3

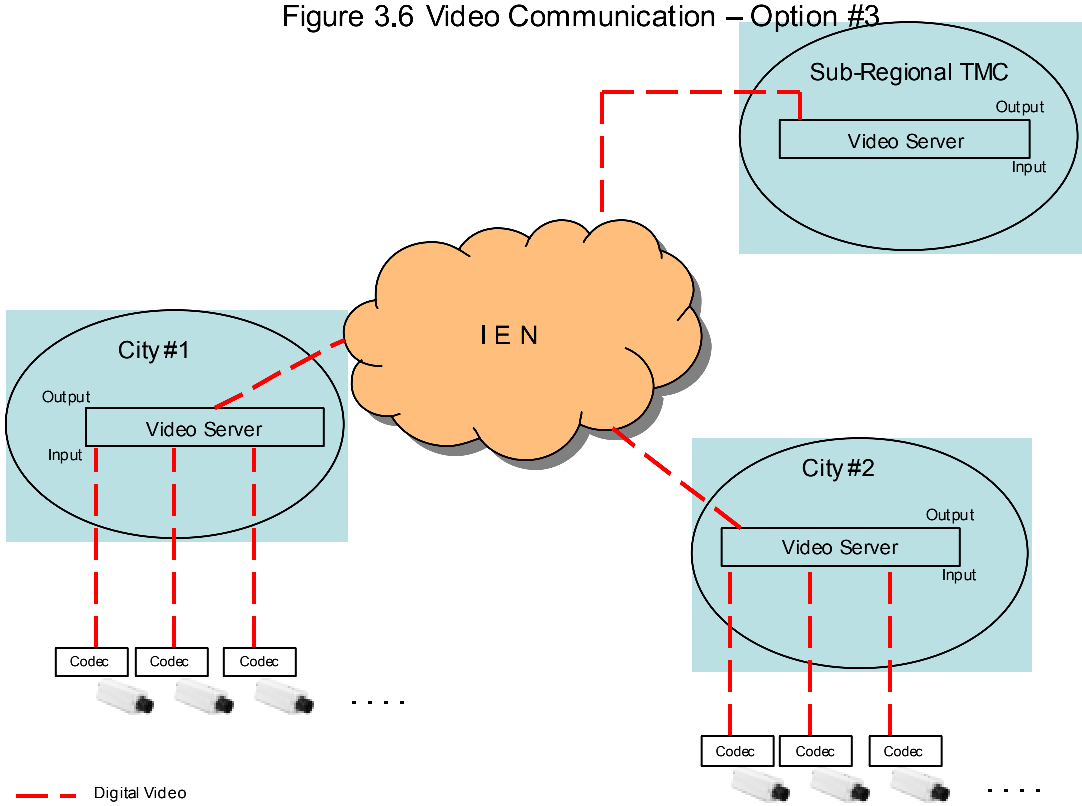


Table 3.3 Characteristics of the Video Options

	Option # 1	Option # 2	Option # 3
Type of video available	• Baseband video	• Baseband at LCC • Digital compressed over IEN	• Digital compressed
Switching Logic	• Very Complex	• Camera switching logic is built into the network and hence is as complex as the network is.	• Not applicable, video directly over the network.
Scalability	• Not easily scalable	• Moderately scalable	• Very easily scalable

	Option # 1	Option # 2	Option # 3
PTZ Control	• Very responsive, low latency	• Very responsive at local LCC • Added latency via the IEN for other agencies	• Performance impact may depend on number of users and available bandwidth
User Access / Security	• Dependant on the video switch	• Controlled at the LCC Video server level	• Very flexible, but needs careful planning

Table 3.4 Advantages and Disadvantages of the Video Options

	Option # 1	Option # 2	Option # 3
Advantages	• Baseband video gives best video quality. • No degradation. • Camera control most responsive.	• Reduced switching logic and hence reduced control complexity. • Baseband video available at LCC.	• Field to LCC architecture simplified because IP based video goes directly on the network. • Architecture very suitable for large number of cameras. • In case of single communication channel failure, the IP routing can be reconfigured via the Ethernet network (network redundancy) • Digital signal made available immediately on the IEN network. • This architecture is becoming the industry standard and as more manufacturers get on board, the prices of the equipment are being driven down by competition. • Network of video servers can be set up to accommodate redundancy. The server functionality is similar to those in option #2; however, because option #3 is all digital, these servers can provide redundancy to one another.
Disadvantages	• Not easily scalable • Switching logic is very complex. • Need to standardize on switching protocols and equipment being used by all the cities. • High cost of laying analog communication between all the jurisdictional LCC's.	• Encoding the signal at the LCC for IEN distribution to other agencies may degrade the quality of the signal. • PTZ access via the IEN network may introduce latency in the control channel and hence impact performance (1-5 seconds depending on number of users and available bandwidth). Operator usability may be addressed by using preset controls.	• Encoding the signal at the camera may degrade the quality of the video images. The degradation is dependent on size, quality and frame rate selected. • PTZ access via the network introduces latency in the control channel and hence impacts performance.(1-5 seconds depending on number of users and available bandwidth)

	Option # 1	Option # 2	Option # 3
		• Need to consider proper network design to avoid congestion that may impact throughput and performance. • Network will need to be designed appropriately to accommodate scalability. • Need individual channel for each camera back to the LCC. • Need for PTZ communication channel between the camera and the LCC. • Need for individual video servers at LCC for video encoding, user and control prioritization.	• Encoding/decoding process introduces overall latency making it difficult to synchronize field images with status from other real-time telemetry sources, such as traffic controller status. • Potential for overloading the network exists if the number of simultaneous users and cameras viewing sessions exceeds the throughput capability of the network.

3.4 Summary

The fully analog option (1) is considered to be impractical due to the difficulty associated with the distribution of the video and provision for the requirement to support camera control.

Video distribution should be accomplished using digital techniques of either option 2 or 3. Option 2 should be considered if:

- Baseband (full motion analog) video images are desired at the LCC. Uncompressed video provides the highest quality images and most responsive camera control.
- Desire to support existing analog video (camera, switchers, controllers, communications) equipment.
- LCC backup operations of video control/monitoring is not required. Since camera field communications and related equipment terminate at the LCC, redundancy is not possible.

Option 3 should be considered if:

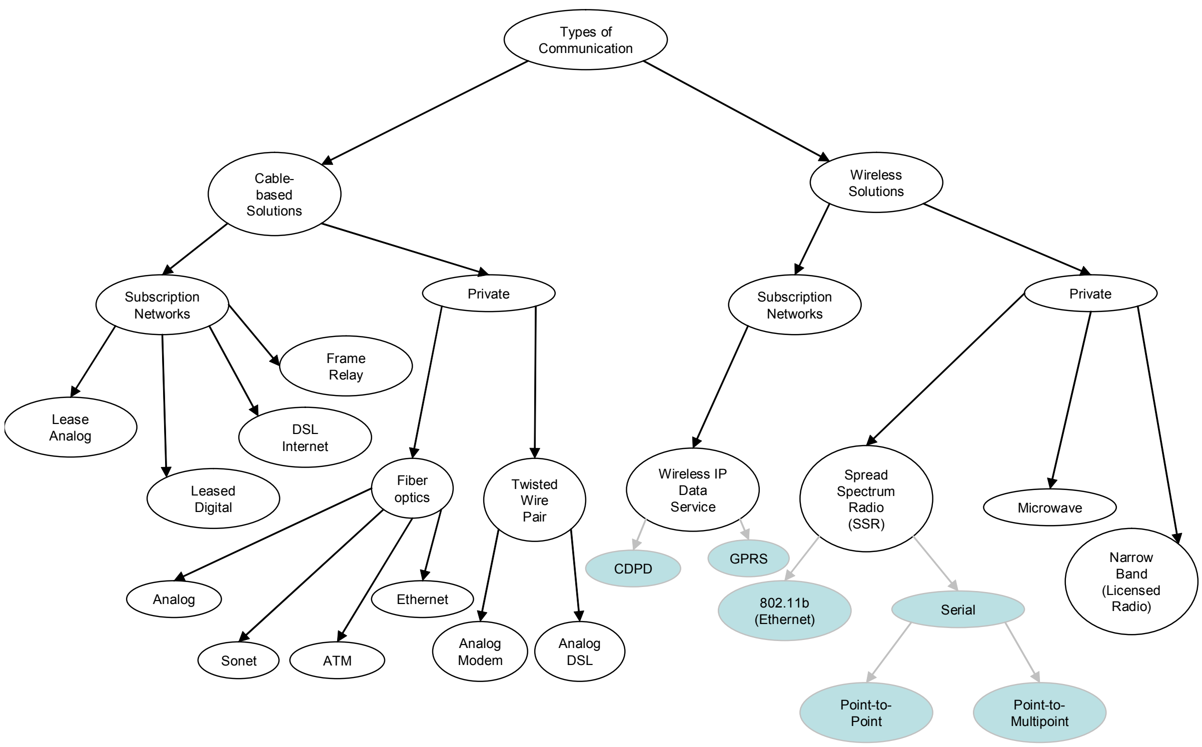
- Digitally encoded video (compressed) is acceptable at the LCC. Depending upon bandwidth, encoded video can result in image artifacts that include blocking, pixelization, and less than 30 frame per second motion resolution; produce latency of the video image making it difficult to synchronize with other real-time data sources such as controller status; and can reduce control responsiveness.
- Existence of or planned deployment of advanced communications infrastructure to support access of digitally encoded video from the field by multiple LCCs.
- LCC backup operations of video control/monitoring is desired. Cameras can continue to be used even if the primary LCC fails

It is important to note that the distribution of digital video (either option 2 or 3) would permit the viewing of images using a standard browser via the Internet. This may well be an acceptable method for smaller agencies to get access to the video made available either via the IEN through a County link to the Internet, or by Internet video servers at the local agencies.

4 CANDIDATE TECHNOLOGIES

Several options exist for communications media to support traffic signal operations and CCTV video systems. New solutions are being added to the list at a continuous rate as wireless technologies improve, leased networks become increasingly available and the ability to carry ever-increasing amounts of data over fiber optic cables continues to advance. This Section presents technologies, which are considered to be relevant to I-5/Telegraph Road Corridor's needs. It is by no means exhaustive as there are solutions which are simply not appropriate, or would be prohibitively expensive to implement (e.g. satellite communications). Figure 4-0a shows a high-level diagram of the candidate technologies described later in this section.

Figure 4.0a: Candidate Technologies

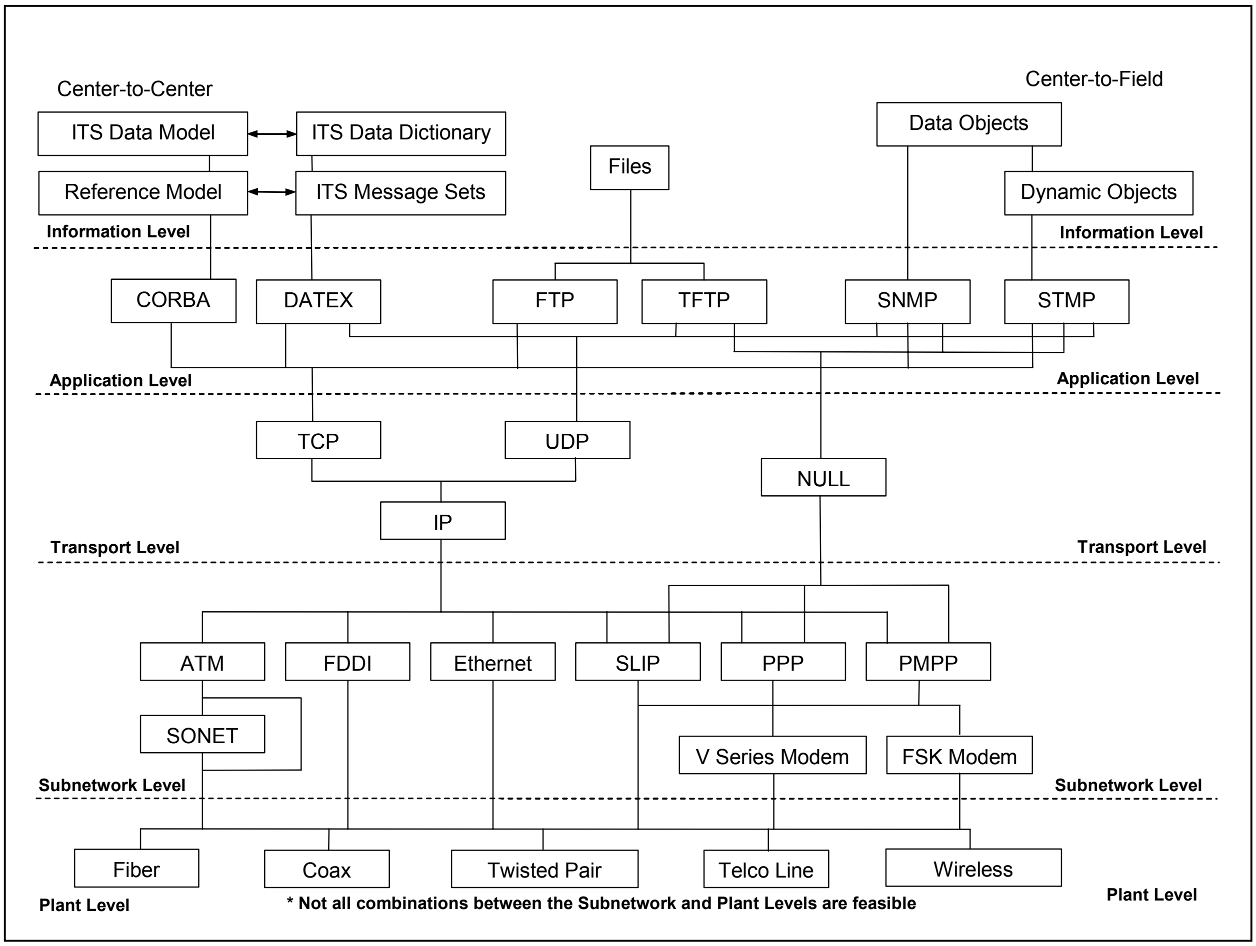


The candidate solutions offer the agencies within the corridor a consistent and coherent approach for their communications infrastructure and so allow them to establish a sustainable system. While combinations are possible, the eventual solution should limit the number of different media used in order to avoid technically complex solutions which would require the support of multiple technologies resulting in high maintenance costs.

In addition to traditional buried cable technologies, non-cable based technologies are also assessed. Both wireless and leased-line options are considered.

Figure 4-0b shows the NTCIP Standards Framework as a reference for the various candidate technologies. This diagram shows which standards at each level can be used (within each dotted box), and which standards are compatible with other standards in the other levels (connecting lines). Together, a series of standards that traverse all levels from the physical plant to the information level constitutes a protocol stack. This document addresses only the physical plant and some of the subnetwork level standards. The transport, application, and information level standards are dependent upon the particular systems used and are beyond the scope of this document. See the NTCIP Guide (www.ntcip.org) for a more detailed description of this framework.

Figure 4.0b: NTCIP Standards Framework



The following technologies are considered as candidates:

- Twisted Wire Pair (Copper)
  - Analog modems
  - Private DSL
- Coaxial Cable – although coax has been successfully used to support field communications, specifically analog video, there are other more suitable technologies, such a fiber optic, that offer greater benefit for similar installation cost

(see discussion on fiber optic). Since coaxial cable is not already installed within the project area its use is not recommended. No further discussion is provided.

- Fiber Optic
  - Analog
  - Sonet
  - ATM
  - Ethernet
  - FDDI – Fiber Distributed Data Interface is an older local area networking technology that was popular due to its high bandwidth (100 Mbps) and low deterministic latency characteristics. Its popularity has decreased significantly due to improvements made with lower cost Ethernet in its ability to support higher bandwidth and low latency real-time control applications. Suitable equipment is also limited and expensive. Its use is not recommended. No further discussion is provided.
- Wireless
  - Microwave
  - Licensed Radio
  - SSR
  - Wireless IP Data
- Leased (Telco)
  - Leased Analog
  - Leased Digital
  - DSL (via Internet)
  - Frame Relay

4.1 Twisted Wire Pair Copper

4.1.1 Analog Modem (TWP)

Twisted Wire Pair (TWP) copper is the most common media for many communications systems, from telephone applications to traffic management systems. As shown in Figure 4-1 and Figure 4-2, TWP analog modems support point-to-point (PP) and point-to-multipoint (PMP) communication connections. This is a very mature technology used by many agencies around the country to communicate with field controllers and other low-speed devices. Typical data rates for analog modems range from 1200 to 19200 bps; with typical distances about 8 miles for 9600 bps and 5 miles for 19200 bps. Newer 38400 bps modems are also coming available with distances of about 2 miles. There is an inverse relationship between frequency and distance using TWP. Higher data rates require the use of higher frequencies, which are in turn distance limited. The further the distance between modems the slower the speed. TWP analog modems can also be used to transmit PP baseband video signal over short distances, typically 3500 feet. Repeaters may be used to extend this distance up to several miles before signal degradation occurs.

Although these devices are easy to install and maintain, they typically do not include remote monitoring and management capabilities. These modems cannot be queried or monitored remotely from the LCC to indicate status, failures, or performance. Generally, troubleshooting is limited to visual inspection of simple front panel status LED indicators typically providing power, link, and transmit/receive status. Operations and management costs can be complicated due to the lack of fault management support.

TWP signals are susceptible to radio, electro magnetic interference (EMI), and power surges that can impair communications and possibly damage equipment. It should also be noted that TWP does not have the range of data rate and bandwidth available compared with fiber optics.

Figure 4-1 Analog Modem TWP (PP)

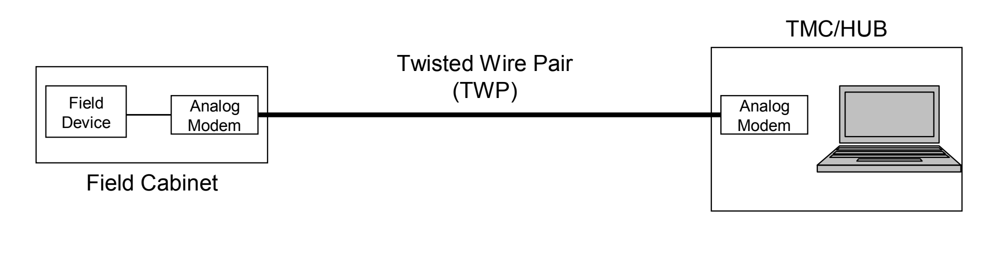
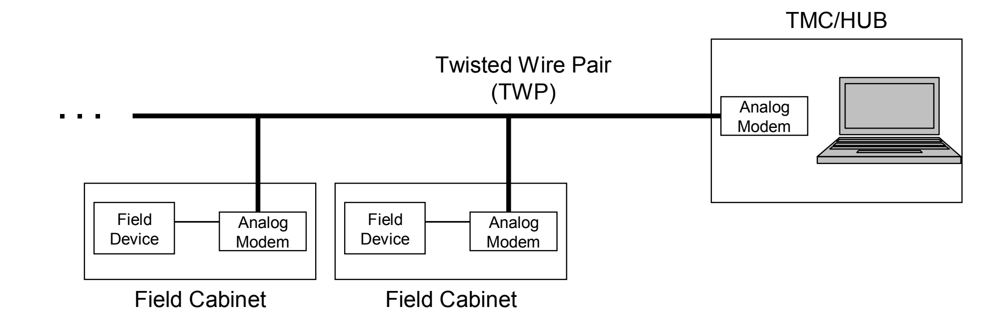


Figure 4-2 Analog Modem TWP (PMP)



4.1.1.1. ITS Applications

TWP analog modems are most effective for field-to-hub communications supporting PP or PMP low-speed devices over distances up to about 8 miles. This technology can also be used to support PP baseband analog video over short distances for “last-mile” connections. However, because of the inverse bandwidth and distance relationship, TWP solutions are not suitable for long distance field-to-hub circuits or for IEN (hub-to-hub) transmissions.

TWP analog solutions are most effective where existing copper infrastructure exists. However, because of the limitations of this technology it is not typically recommended for new installations.

4.1.2 DSL (private via Agency-Owned TWP)

Digital Subscriber Line (DSL) is a high speed solution that supports from 128kbps to several megabits of bandwidth over existing copper cable. DSL encompasses a number of different technologies that offer significant increases in connection speed and data transfers for access to information.

DSL supports point-to-point (PP) connections up to about 4 miles dependant upon data rates between the DSL modems. A DSL modem at each end of the circuit accepts the digital data and converts it to analog signals for transmission over the copper cable. In this respect it is very similar to TWP analog modem technology, as shown in Figure 4-1. The same inverse frequency (bandwidth) and distance relationship also applies. Even though DSL modems are capable of achieving much higher speeds than regular analog modems they are more expensive and more sensitive to the quality of the TWP cable. To use DSL the TWP cable needs to be in good condition and configured as a continuous circuit (without branch circuits) without load coils or other impairments.

DSL modems come in various configurations to support different equipment interfaces. The most common is support for Ethernet. As a result most DSL modems support IP (Internet Protocol) communications and therefore also include SNMP (Simple Network Management Protocol) support. SNMP provides remote monitoring and management capabilities which can simplify operations and management tasks.

4.1.2.1. ITS Applications

DSL modems over agency-owned TWP are suitable for field-to-hub high-bandwidth PP communication. Their ability to support IP-based terminal equipment makes them a candidate solution to support Ethernet capable devices such as the Model 2070 controller and IP ready CCTV cameras.

However, because of the inverse bandwidth and distance relationship, TWP solutions are not suitable for long distance field-to-hub circuits or for IEN (hub-to-hub) transmissions.

Private DSL solutions are most effective where existing copper infrastructure exists. Due to distance limitations of this technology it is not typically recommended for new installations where more capable media such as fiber would be more appropriate.

4.2 Fiber-Optic Cable

Fiber optic cable has become the standard for most ITS deployments around the world. The characteristics of fiber include nearly unlimited bandwidth capability, and protection from electromagnetic and radio frequency interference, lightening, and other power surges on the communications line.

In a fiber optic link a coherent light source feeds into one end of a fiber, and a light-sensing device is attached to the other end of the fiber. This provides unidirectional operation. Two fibers are typically employed for a bi-directional communications link, although advanced multiplexing techniques are available to achieve two-way communications on a single fiber.

In the past, the cost of installing fiber-optic cable was much higher than twisted copper wire. Over the years, as the demand for fiber-optic cable has increased, the cost differential between the fiber-optic cable and twisted pair copper has become small. For systems where new communications media need to be installed, the cost of deploying fiber optic or copper wire can therefore be considered to be comparable.

The chief characteristics of fiber optic communications are the wavelength of the source (the mode) and the diameter of the core which carries the light signal. The propagation of the signal results from internal refraction caused by the difference in refractive indices of the core glass and the surrounding glass. So there exists a relationship between the size of the core and the mode transported.

There are two types of optical fiber: multi-mode and single-mode. Multimode fiber has standard core diameters of 50 μm and 62.5 μm, as opposed to a core diameter of 8 μm for single-mode fiber. The relatively larger core of the multi-mode fiber allows many modes or different wavelengths of light to propagate down the core. The multiple wavelengths effectively “spread out” the signal at the receiving end. If the spread is too much, information at the receiving end will be lost. Because of this, multimode fiber is used for short communications runs (typically less than 2 miles).

Single-mode fiber, on the other hand, has a relatively tiny core for light transmission, so only one mode is supported. This results in more bandwidth and higher data rates being possible for longer distances. It is not uncommon to be able to send a single-mode signal over 40 miles without the need for repeaters.

Since most of the agencies in the corridor have no or very little existing infrastructure and will most likely be installing new conduit, installation of single-mode fiber-optic is recommended whenever the agencies have adequate funds to install or lease conduit.

A major advantage of single mode fiber installation is that without damaging the fibers, higher data rates are available by simply changing the end equipment. Thus the fiber-optic plant investment is not lost due to changes in communication technologies but actually allows the owner to benefit from such advances. Single mode fiber is recommended if fiber is the media of choice to install.

For fiber optic networks there are four main fiber transmission techniques relevant to this project: Analog, Sonet, ATM and Ethernet

4.2.1 Fiber Analog Modems

Fiber based analog modems have long been a popular solution to transporting various ITS data along backbone and distribution fiber trunks. Ever since fiber became the medium of choice in ITS applications analog fiber modems have been used. They are still often the preferred technology for small systems due to cost and simplicity, and even on larger systems are used as a “last mile” solution. It has only been recently that more capable technologies such as SONET/ATM/Ethernet are becoming more affordable and are often preferred for medium to large systems.

Analog modems, and more recently digital equivalent modems, are designed as simple point-to-point (PP) or point-to-multipoint (PMP) transceivers to support low speed serial data and video over fiber. More advanced modems also support self-healing ring topologies to protect against fiber or equipment failures. These modems accept one or multiple serial ports, or video, and output a single light wave signal. At the receiving end the light wave signal is converted back to the original serial and video channels. Multi-drop modems operate similar to copper-based multi-drop modems in that each device on the line receives all the data, but only the addressed device should respond. The encoding of data onto a lightwave signal is proprietary to each vendor so equipment is not interoperable. However, interoperability is only necessary between two transceiver end points. Hardware from multiple vendors may be used as long each link transceiver pair is from a common source. Modems typically support serial data rates up to 38.4 kbps and analog baseband color video. A separate pair of fibers is needed for each link although some modems support a single fiber interface and use different light waves to transport bi-directional data.

Analog modems are available with various transmitter power and receiver sensitivity configurations that support operations up to about 40 miles. Analog modems are strictly a physical layer transport solution without higher layer network intelligence. They provide simple point-to-point transport over dedicated fibers. Most modems do not provide any type of remote network management capability. These modems cannot be queried or monitored remotely to indicate status, failures, or performance. Generally no trouble-shooting can be done unless the technician is right in front of the modem. Most only support simple front panel status LED indicators and only a limited amount of knowledge can be gained from these LED indicators. Limited network topology options also limit the level of system reliability available through these modems. Since most are point-to-point solutions, a simple fiber cut or equipment failure disables the entire link. Modems that support a self-healing ring topology are able to withstand a single fiber or equipment failure on the ring. Most modems do not support remote monitoring or management capabilities.

Analog modems have limited scalability and are therefore only typically used on small to medium sized systems or "last mile" connections. Since each modem link requires a dedicated fiber pair, using analog modems can lead to higher fiber utilization when compared with other solutions, such as SONET/ATM/Ethernet. Figure 4-3 shows how a single field device is connected using fiber modems to a hub or LCC location. Figure 4-4 shows how multiple fiber modems can be daisy-chained together.

Figure 4-3 Fiber Analog Modem (PP)

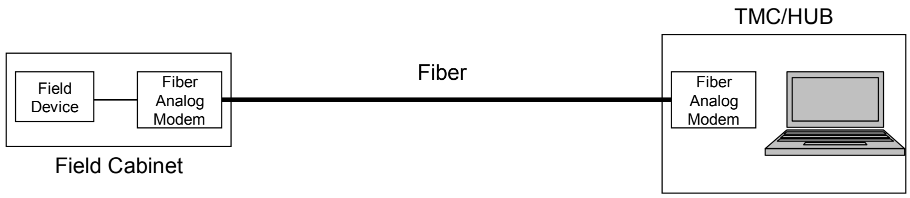
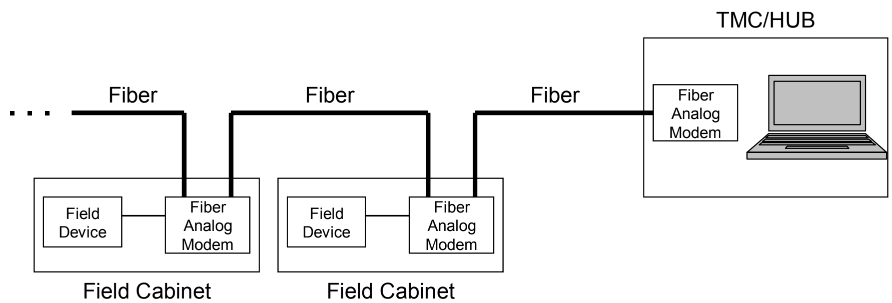


Figure 4-4 Fiber Analog Modem (PMP)



4.2.1.1. ITS Applications

Analog fiber modems have been used extensively in ITS and traffic management applications providing connectivity between central processing systems and field devices such as traffic signal controllers, signs, and CCTV. These have mainly been deployed as serial interface extensions for traffic controller communications and CCTV control. One-way CCTV video transport between camera and the LCC is also used.

This technology is suitable for field-to-hub PP or PMP communication of both serial data and video. Analog fiber solutions are most effective for small to medium sized systems. Since analog fiber modems require a pair of fibers for each separate channel, larger sized systems will require many pairs of fiber. The resulting high fiber count makes this technology less desirable for larger sized systems.

4.2.2 Fiber SONET

SONET (Synchronous Optical Network) was developed in the 1980's as a standard fiber optic transport for high-capacity telephone trunk lines. Before SONET, long-haul transmission systems were based on the T-carrier standard developed by Bell Communications Research (Bellcore) during the 1960's.

The T-carrier system is based on a hierarchy of time division multiplexed digital signals (DS), whereby the DS-0 channel is the basic building block for the system. Bellcore determined that the human voice, for the purpose of bandwidth efficiency, requires only 4 kHz of bandwidth for acceptable voice transmission over telephones. To accurately convert the analog 4 kHz voice signal to digital required a sampling rate of twice the bandwidth, or 8 kHz (8 kHz x 8 bits, or 64 kbps).

To combine these DS-0 voice channels into a higher speed system, Bellcore developed the DS-1 (T-1) standard. A DS-1 channel multiplexes 24 individual DS-0 voice channels into a single high-speed 1.544 Mbps channel. This channel includes 1.536 Mbps of data (24 x 64 Kbps DS-0 channels) and 8 kbps for network management. Higher order multiplexing was also created to develop the DS-2 (6 Mbps) and the DS-3 (45 Mbps). However, several problems developed from this technique. The fact that these signals were not entirely synchronous meant that it was impossible to extract a DS-0 channel directly from a DS-2 or DS-3 channel without first de-multiplexing each DS channel to its next level in the hierarchy. Thus, several levels of de-multiplexing are required to extract that single DS-0 channel: DS-3 to DS-2, DS-2 to DS-1, and DS-1 to DS-0. In addition, the hierarchy was not linear. While there are 24 DS-0's within a DS-1, there are 4 DS-1's in a DS-2, and 7 DS-2's in a DS-3 (28 DS-1's in a DS-3). This results in substantial end equipment in terms of numbers and complexity to extract a single lower order signal or channel.

SONET was developed to standardize higher data transmission rates, standardize network management, improve system reliability, and simplify the means by which signals are multiplexed. The synchronous nature of SONET makes it possible to theoretically know where each bit of information is in the payload relative to time. This allows for direct access to individual low order signals without first de-multiplexing through various intermediate stages. Signal "grooming", multiplexing, and de-multiplexing are all simplified.

SONET is an international standard, defined by the ITU, and globally known as the Synchronous Digital Hierarchy (SDH). SONET is a transport technology, occupying the physical layer (layer 1) of the 7-layer OSI model. The basic building block for the SONET standard of OC-1 (51.84 Mbps) was chosen to accommodate the T-carrier DS-3 (45 Mbps) with additional capacity for channel management overhead. Higher order channels are merely a multiple of the OC-1 signal. The most common SONET rates are OC-1, OC-3 (155.52 Mbps), OC-12 (622.08 Mbps), OC-48 (2.4 Gbps), and OC-192 (9.6 Gbps). To accommodate the lower order DS-1 and DS-3 channels, the SONET standard defined Virtual Tributaries (VT) to map the DS signals into the standard SONET payload. VT circuits have a pointer to identify the starting bit of the payload to allow for a single DS-1 to be retrieved without back-to-back multiplexing.

SONET systems are designed to operate in a ring topology using a primary active ring and backup protection ring. The protection ring is only activated in the event of a fiber or node failure. The dual-redundant self-healing ring architecture or topology protects against cable cuts or equipment failures. The network management monitors the transmission path and switches the optical signal onto the protection ring in the opposite direction to reroute around a failure. The response time is typically less that 50ms.

With SONET, circuits are provisioned in a point-to-point manner over a specified path at a fixed allocated channel bandwidth. SONET does not support dynamic bandwidth allocation. Once a circuit is provisioned between two points, it is considered somewhat permanent. If a change in bandwidth is desired, the user must use the network manager to allocate additional channels. If the channel is not in use at a particular time, the bandwidth allocated to the application is unusable to other applications. Some manufacturers are attempting to provide a variation of dynamic bandwidth functionality; however, these are proprietary extensions.

SONET is a WAN only protocol that can support very long link distances. The laser transmitters and receivers in the SONET hardware determine the distance.

Because SONET is a transport technology it does not support higher layer network intelligence or services typically found in other networking protocols. It is a pure wide area network (WAN) and the only transparent transport technology that relies on higher layer protocols to provide quality of service (QOS) and traffic management needs. To support other data or video applications typically requires additional protocols on top of the SONET infrastructure. Common higher layer protocols include ATM and Internet Protocol (IP).

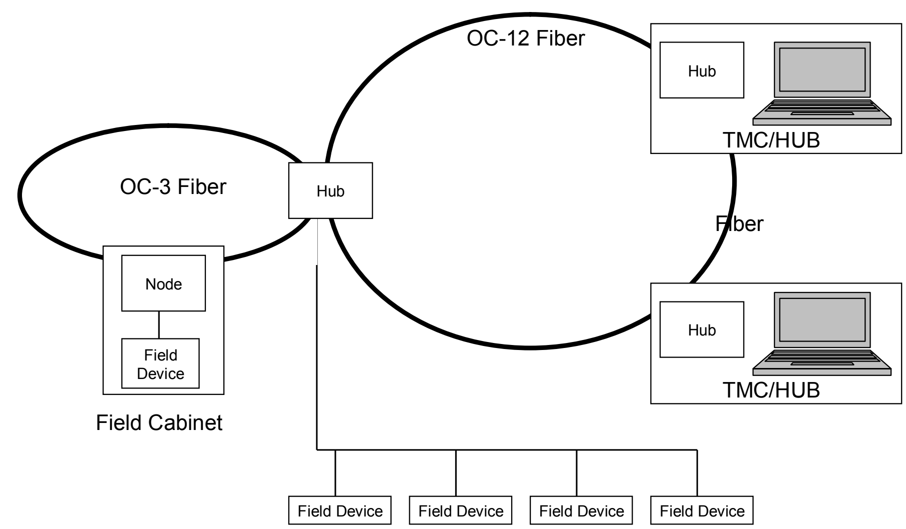
Network management is standardized under SONET allowing interoperability of common network management functions across vendor hardware.

SONET is designed to be very fault tolerant and reliable through the use of its self-healing ring architecture. However, the ring architecture allows only one backup path and is only effective if the fiber is also physically routed along different paths. In a collapsed ring design (where SONET links run over fiber within the same cable), the benefits of the self-healing ring architecture are limited. Reliability is further improved by using multiple interconnected rings with switching nodes that can reroute traffic along more than one path. The switchover to the redundant path occurs in less than 50ms.

SONET supports a defined hierarchy of ever increasing channel data rates from T-1 rate virtual tributaries up to OC-192 (9.6 Gbps). Most multiplexing equipment support interface cards that will accept low rate serial channels that are then multiplexed to higher rates. Channels are statically provisioned whereby bandwidth is permanently allocated whether it is used or not by the end application. As such, SONET is a highly scalable transport technology that easily supports any ITS application needs.

Figure 4-5 shows a typical fiber SONET ring topology with a number of LCC/hub locations and some field devices connected directly and via a hub to the SONET ring.

Figure 4-5 Fiber Sonet / ATM Ring Network



4.2.2.1. ITS Applications

SONET has been used quite extensively in large scale ITS and traffic management applications. SONET node switches are typically deployed along backbone fiber routes. A hierarchy of cascaded fiber rings is typically used to scale bandwidth from smaller data collection/distribution feeder rings to larger backbone rings. The interconnected ring structure provides a high degree of system reliability. The small data feeder rings typically support OC-3 speeds while the backbone typically supports OC-12/48 speeds. Field equipment (i.e., traffic controllers) are then connected to feeder ring node points using point-to-point (PP) or point-to-multipoint (PMP) low-speed analog fiber modems (see Analog Fiber description above). This is typically referred to as the "last mile" connection. The benefits of SONET are therefore only realized on the backbone and feeder rings. A node switch on the backbone ring typically supports the LCC. A backup LCC or alternate operations centers can easily be supported as secondary nodes anywhere on the backbone ring.

SONET equipment is available from multiple manufacturers and is typically designed to operate in an environmentally conditioned facility. Equipment designed to operate in a telephone central office may offer some extended temperature range, but not to the extent necessary to operate in a typical traffic control cabinet. As such, SONET equipment is typically installed in special conditioned node cabinets or facilities.

4.2.3 <u>Fiber ATM</u>

Asynchronous Transfer Mode (ATM) is a relatively new communications standard allowing all video, data, and voice information to be integrated into a single network. ATM takes all information and splits it up into fixed length 53-byte data packets, called cells, which allows for very fast switching over a common network. By using fixed length cells, voice, data, and video can be intermingled into a common "single pipe" network while still supporting the unique needs of each application. Virtual path and connection information allows each cell to be associated with a separate logical connection, each with its own unique transport characteristics.

ATM is a physical and data link layer protocol (layers 1 and 2) of the 7-layer OSI model providing both multiplexing and switching support. ATM is media independent which defines SONET as one of its standard transport interfaces. It can also operate over other fiber transport, Cat5/6 copper, wireless, and satellite. The ATM Forum has defined 13 different physical interfaces so far, including SONET. The term asynchronous refers to the non-periodic nature of the information exchange with higher layers. The underlying physical layer transport is synchronous.

ATM systems can operate with virtually any physical topology including, point-to-point, ring, star, mesh or hybrid. This provides a high degree of flexibility in designing fault-tolerant networks.

With ATM, links are defined as permanent virtual circuits (PVC) or switched virtual circuits (SVC) each with defined link characteristics. PVC's are statically provisioned through the network management interface. SVC's are dynamically assigned, based on application needs and only if the contracted link characteristics can be guaranteed. Typically, a user only needs to define the end points of each PVC or SVC and the system automatically configures the link. Users do not need to be concerned about intermediate switch or node configurations.

ATMS offers bandwidth on demand. ATM uses a "common data pipe" philosophy, allowing applications to use necessary bandwidth as needed. Bandwidth is dynamically allocated, meaning that applications may use greater bandwidth if necessary at times. However, if not needed, this bandwidth is available for other applications.

ATM was designed to integrate all information into a single common network operating across both the LAN and WAN. A computer with an ATM network interface card connected to the ATM network can access, for example, video directly to the PC. ATM includes standards to emulate existing LAN standards, such as Ethernet, and to service internetworking protocols such as IP.

ATM is designed to operate in both the LAN and WAN environment with different physical interfaces to support various distances. ATM typically relies on a SONET physical layer when used in the WAN, thereby supporting very long distances.

ATM provides quality of service (QOS) controls over individual application-to-application data flows. The ATM standard defines service categories for the different needs of each application. Data transmission, such as file transfers, is typically bursty in nature and can easily adapt to changes in network delay (latency), variance in delay (jitter), and bandwidth availability. Voice and video require continuous transmission at a fixed data rate, with little or no latency and jitter. The service categories include: constant bit rate (CBR), variable bit rate (VBR), available bit rate (ABR), and unspecified bit rate (UBR). ATM is the only technology that was originally designed to provide QOS support.

ATM defines a standard network management layer allowing for interoperability across vendor hardware. Additionally, higher layer network protocols, such as the Simple Network Management Protocol (SNMP), are often used to support this function.

ATM, through the use of virtual circuits, fast packet switching, and underlying SONET physical layer is designed to be fault tolerant. An ATM network can be set up as a comparable ring, with line cards available to provide the 50 ms switchover defined by SONET. Implementing a mesh network with multiple backup paths can further strengthen an ATM network. The ATM network determines how to route information around a failure, with the capability of prioritizing mission critical data.

ATM is highly scalable and with its ability to dynamically assign bandwidth as needed its utilization of available bandwidth is very efficient. ATM equipment has been designed to operate with direct SONET rate optical interface cards therefore eliminating the need for separate SONET equipment. Typical ATM equipment is available with OC-3, OC-12, and OC-48 line cards. If additional bandwidth is desired, equipment can be swapped out or an additional line card added, maintaining the original investment of the hardware.

Figure 4-5 shows a typical fiber ATM topology with a couple of LCC/hub locations and some field devices connected directly and via a hub to the ATM ring.

4.2.3.1. ITS Applications

ATM has been used in some medium to large scale ITS and traffic management applications. In these applications ATM was selected over SONET primarily due to the increased flexibility in bandwidth management, and adaptability to multimedia and streaming video content needs. Both interconnected ring and mesh architectures have been used to provide the level of desired system reliability. In some of these installations, ATM has been utilized directly out to the traffic signal controller cabinet, thereby eliminating the last mile connections commonly used with SONET solution. With these installations, an OC-3 ring is used to interconnect a series of traffic controller cabinets or hubs to one or more OC-12 backbone rings. The LCC and other operations centers are nodes on the backbone. ATM is used in the entire network from the traffic signal cabinet to the LCC. Temperature hardened OC-3 multiplexers accept surveillance video, Ethernet, and serial interfaces at the cabinet and output a single OC-3 payload. Each interface is configured as separate PVC in the ATM fabric and is accessible from anywhere on the network. This provides a great deal of flexibility to support various normal and backup operation modes.

ATM equipment is available from multiple manufacturers and is typically designed to operate in an environmentally conditioned facility. Most equipment designed to operate in a telephone central office may offer some extended temperature range, but not to the extent necessary to operate in a typical traffic control cabinet. Some specialized ATM access multiplexers are becoming available that offer extended temperature operation to support ATM operation out to the traffic signal cabinet.

4.2.4 <u>Fiber Ethernet</u>

Ethernet has quickly become the *de facto* local area network (LAN) standard for computer-to-computer communications. More than 86 percent of all installed network connections were Ethernet by the end of 1998 according to IDC. This represents over 118 million interconnected PCs, workstations and servers. As Ethernet speeds have increased over the years, older LAN protocols such as 10/16 Mbps Token Ring, and 100 Mbps Fiber Distributed Data Interface (FDDI) have virtually disappeared. Ethernet is a media access control (MAC) data link layer (layer 2) protocol of the 7-layer OSI model. It is commonly used as the underlying support layer to other upper layer protocols such as Transmission Control Protocol/Internet Protocol (TCP/IP), IPX, NetBEUI and DECnet. All popular operating systems and applications are Ethernet-compatible.

Ethernet is actually synonymous with several different but related technologies. The original 10 Mbps 10BaseT (twisted wire pair) Ethernet based on IEEE 802.3 standard employed a Carrier Sense Multiple Access with Collision Detection *(CSMA/CD)* protocol. The protocol allows multiple devices to share a common transport media. Devices that need to communicate first sense the line (carrier sense) and then transmit if no activity is detected. If collisions result (collision detection) the device backs off for an arbitrary amount of time before retrying. Ethernet was designed as a non-deterministic “best effort” service without guaranteed delivery. It relies upon higher layer protocols to guarantee data ordering and delivery. Communications are half duplex (data in either direction but not both directions at once) since all devices share a common interface. As such the effective throughput is quite a bit less than the 10 Mbps line rate. In fact, throughput quickly deteriorates above about 35% (3.5 Mbps) utilization. To address these limitations other enhancements to the standard were developed including full-duplex capability, and the use of switches instead of shared media hubs. Full-duplex support is possible when using a single device per switch port. Separate transmit and receive channels allow both simultaneous transmission and reception of data, effectively doubling the bandwidth to 20 Mbps. Switches offer a single collision domain (a local area network comprising of a single segment, or multiple segments connected by repeaters will function as a single collision domain) per switch port effectively eliminating contention for shared media. With a single device connected per port the collision detection and random retry capability and resulting inefficiencies were eliminated.

The Fast Ethernet standard, approved in 1995, established Ethernet as a scalable technology and was developed in response to the volume of network traffic increase and the resulting inadequacy of the original Ethernet LAN standard. Fast Ethernet provides a 100 Mbps Ethernet capability over both category 5 twisted wire pair (100 Base TX) and both multimode and single mode fiber (100 Base FX) physical interface. Fast Ethernet is commonly deployed using networking switches thereby providing full 100 Mbps support to the attached device. Among the high-speed LAN technologies available today, Fast Ethernet, or I00BASE-T, has become the leading choice. Building on the near-universal acceptance of 10BASE-T Ethernet, Fast Ethernet technology provides a smooth, non-disruptive evolution to 100 Mbps performance. The growing use of 100BASE-T connections to servers and desktops, however, has created a clear need for an even higher-speed network technology at the campus backbone and server level.

The Gigabit Ethernet (GigE) standard (IEEE 802.3z), approved in 1998, extends the scalability of Ethernet even further to 1000 Mbps. GigE provides 1 Gbps bandwidth with the simplicity of Ethernet at lower cost than other technologies of comparable speed. It offers a natural upgrade path for current Ethernet installations, leveraging existing end stations, management tools and training. Gigabit Ethernet employs the same Carrier Sense Multiple Access with Collision Detection *(CSMA/CD)* protocol, same frame format and same frame size as its predecessors, providing a natural migration path for increased network capacity.

A 10 Gbps Ethernet standard (IEEE 802.3ae) was approved in June 2002. This has effectively extended the Ethernet capability to compete with comparable OC-192 SONET and ATM solutions. While previous Ethernet version supported half- or full-duplex operation, point-to-point or multiple access bus topologies, over various media (category 3/5 TWP, coax, fiber), 10 GigE is strictly a point-to-point, full duplex over fiber standard. As a result of Ethernet’s steady increase in speeds and continued universal popularity along with a large base of installed fiber, Ethernet is now being considered for use outside the traditional LAN environment. Various equipment vendors and service providers are heavily promoting Ethernet use as a competing Metropolitan Area Network (MAN) standard to the more traditional SONET and ATM solutions.

Through the use of cascaded and interconnected switches Ethernet can be deployed using various star, mesh, and hybrid topologies. Switching architectures are typically designed with higher speed Ethernet at the backbone core to connect high-performance servers and aggregated data streams. 10/100Base-T switches are often used at the network edge to connect end users and low duty devices. These switches then connect to 100/1000Base-T switches to aggregate traffic and connect high performance devices. Finally, 10 GigE may be used as a high-performance switch-to-switch backbone link. Multiple links can be aggregated to create a single virtual link for increased bandwidth using the IEEE 802.3ad Link Aggregation standard.

Ethernet is now used as both a LAN and WAN networking standard over fiber. The result is a single integrated networking standard from end device to end device. Dealing with a single protocol has the potential for simplifying operations and maintenance. A single standard also avoids protocol translation issues that can lead to performance impacts and troubleshooting complexity.

Ethernet, Fast Ethernet, and Gigabit Ethernet were originally conceived and specified as a LAN technology. Because of this, all Ethernet topologies have required segment length limitations to support the collision detection capabilities. In a switched full-duplex environment using fiber media these distance limitations are more a factor of the media and fiber transceivers themselves and not the CSMA/CD algorithm.

Gigabit Ethernet solutions for single-mode and multimode dedicated fiber have been defined by IEEE 802.3 including SX up to 550 meters, LX up to 5 Km and ZX up to 70 Km. The 10-GigE standard includes support for 10 and 40 Km.

Ethernet is a non-deterministic protocol that provides a “best effort” level of service. It was never designed to support traffic or congestion management capability. To address this shortcoming, most networks are over designed with extra bandwidth so as not to encounter an over subscription situation. The IEEE 802.1pq standards for priority and queuing were recently developed to address traffic management and end-to-end QOS (Quality of Service). Even if bandwidth utilization is low, QOS ensures that delay sensitive streams such as video are transported without being affected by other data transfers.

IP multicasting (IP Multicasting is a bandwidth-conserving technology that reduces traffic by simultaneously delivering a single stream of information to multiple users) standards allow video and other streaming media content to be efficiently transported over a switched Ethernet network. Multicasting manages streaming content from source to destination, and only replicates the content as needed at a point closest to the final destination.

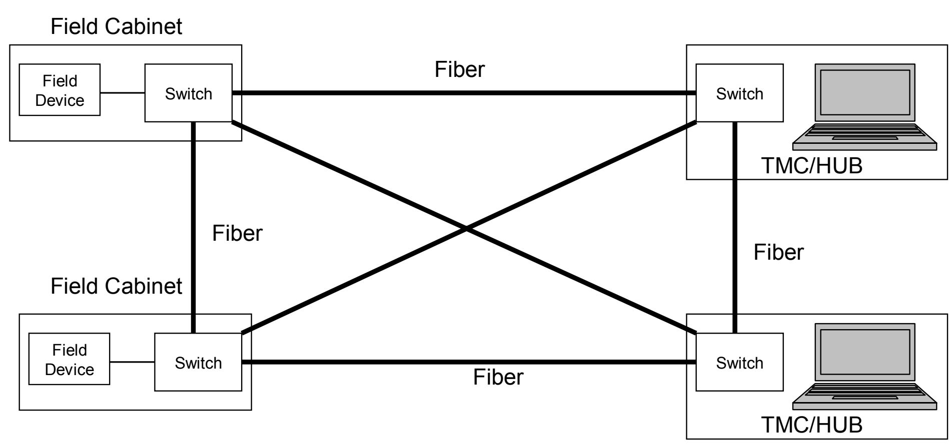
Network management in an Ethernet/IP based network is supported through the Simple Network Management Protocol (SNMP). SNMP defines a standard method to collect device-level Ethernet information based on management information base (MIB) structures to record key statistics such as collision count, packets transmitted or received, error rates and other device-level information. Standard MIBs are defined for all types of devices that ensure interoperability among management applications and managed devices. The remote monitoring (RMON) agents aggregate the statistics for presentation via a network management application. Both SNMP and RMON allow an administrator to view the status of all IP-capable desktops and network elements, including redundant elements, from a central station.

Since the introduction in 1986 of star-wired 10BASE-T hubs, structured wiring systems have continued to evolve and hubs and switches have become increasingly reliable. Architectures designed with redundant paths between switches have also added to overall system reliability. Although Ethernet along with the Internet protocol (IP) is particularly resilient, it does not yet approach the reliability and restoration capability of more traditional WAN solutions such as SONET/ATM. Ethernet and IP were designed primarily to support data applications. The Spanning Tree (IEEE 802.1Q) and Rapid Spanning Tree (IEEE 802.1W) standards provide for 30 second and one second restoration times in the event of link failure, and even longer convergence times depending upon network complexity. Although this is not as fast as ATM and SONET restoration times it is probably adequate for ITS applications. The Resilient Packet Ring (IEEE 802.17) standard is being developed to provide SONET-like ring performance to Ethernet.

Through the Fast Ethernet, GigE, and 10 GigE standards, Ethernet has proven itself to be a scalable technology. Each follows the same form, fit and function as its predecessor, allowing a straightforward, incremental migration to higher-speed networking. This compatibility also allows for seamless integration with minimal disruption to the existing network.

Figure 4-6 shows a typical fiber Ethernet mesh topology with a couple of LCC/hub locations and directly connected field devices.

Figure 4-6 Fiber Ethernet Network



4.2.4.1. ITS Applications

Ethernet, as a WAN solution in ITS and traffic management applications, has only recently been explored with only limited practical experience. A few agencies are currently exploring its use or are in initial design/deployment stages. Siemens GTS has performed some initial limited tests using switched Ethernet to support both traffic controller and video surveillance data. The test architecture included small 8-port 10/100 Mbps Ethernet switches at the cabinet level, and medium port density 100/1000 Mbps switches as backbone aggregation devices. The cabinet level Ethernet switch integrates field equipment onto a single common uplink connection to a mid-level switch. Redundant links to more than one mid-level switch were used to demonstrate link fail over and system reliability. Mid-level switches were interconnected to provide a completely meshed architecture. Standards-based Ethernet QOS features were used to manage data flow priorities and characteristics between streaming video, CCTV control, and traffic controller status and commands. The tests successfully proved out the use of Ethernet as a viable backbone technology.

Additionally, when used with the Internet Protocol, the Ethernet solution becomes a completely seamless solution from field device to operator workstation. The National Transportation Communications for ITS Protocol (NTCIP) standard framework provides direct support for IP and related TCP/UDP transport layers. Additionally, most field equipment including the new Model 2070 traffic controller is being equipped with a direct Ethernet interface making possible Ethernet/IP communications out to the field equipment. Other field devices, such as CCTV cameras, are also being made Ethernet/IP capable. Non-IP capable devices would require additional equipment, such as a terminal server, to convert serial to Ethernet. The ability to support this configuration is dependent upon the capabilities of the central system and controller application.

The type of high-end Ethernet equipment needed to support ITS backbone applications is available from several manufactures. These are layer 2/3 switches that support the various IEEE protocol extensions for bandwidth management, link aggregation, prioritization, and QOS. This equipment is designed to operate in an environmentally conditioned facility, and is not suitable for direct installation in a traffic control cabinet. As with the SONET and ATM solutions, specialized field node cabinets or facilities would be required. There are also a number of manufactures that produce small temperature hardened switches suitable for installation in the traffic control cabinet. These are typically simple Ethernet switches that do not provide the layer 2/3 functionalities of more capable mid-level switches, but are sufficient as field connection devices.

4.3 Wireless Communication

This Section discusses the wireless based communication options for monitoring and controlling field devices. This option mainly discusses the available wireless modes of communication available in the general Los Angeles area.

Four wireless technologies are discussed below; Microwave, Spread Spectrum Radio (SSR), Wireless IP Data and Licensed Radio. Microwave, Licensed Radio, and SSR represent private agency-owned networks requiring capabilities for maintenance and support. Wireless IP is a service and does not require support infrastructure but does result in recurring monthly operational costs. Microwave is expensive to deploy as indicated, but SSR can be very inexpensive and would be suitable for video and data. Although current wireless IP (CDPD) is practically limited to video, next gen (3G) wireless will have bandwidth (115 to 384k) and TOS/QOS capabilities to make limited highly compressed video an option.

4.3.1 Microwave

The use of microwave radio to provide communications links in a system is useful where a hard-wired link is not possible, not cost-effective, or desirable. Microwave systems provide high bandwidth and as such can transport voice, data, and video information to remote sites over large distances.

Microwave radio links with the corresponding support infrastructure can be expensive. In a system with literally hundreds of ITS devices, this means a substantial up-front cost.

Microwave systems can support both digital and analog signals. Digital microwave requires the use of video coders and decoders (collectively known as CODEC). Video is encoded prior to transport and decoded for viewing. The additional CODEC equipment, along with the greater expense of digital systems, makes this solution more expensive. The advantage is that the signal quality is typically of higher quality across a digital microwave link than analog links. Analog microwave systems can modulate and transport video in base-band format (uncompressed). These systems typically lead to lower cost solutions although degradation and interference is more noticeable.

Each microwave radio link must be licensed with the Federal Communications Commission (FCC) before putting it into operation. Each license petition requires: a site survey, a detailed path analysis, frequency coordination with other local area users, and the petition must be certified by a licensed radio engineer. This is time consuming and costly, and not always successful. Some types of low-power microwave systems do not require an FCC license. Due to limited power output and typically higher frequencies these systems are limited to very short distances. The risk in this is that there is no protection from the FCC if another user interferes with your signal. Also, at least twice recently the FCC has taken away previously unlicensed frequency bands from various transportation systems for use by other groups or industries.

In metropolitan areas, such as Los Angeles, radio microwave activity is very common and active. Radio frequency coordination for microwave might prove a very difficult task. The microwave signal is attenuated not only by distance, but also is susceptible to heavy rain, or fog; the very conditions during which the system is needed most.

4.3.1.1. ITS Applications

Microwave links are capable of communication at speeds between 1.5 to 45 Mbps and are setup in a point to point configuration. This makes them suitable as a last-mile solution for some field devices that may not be along a main communication route. In such installations, an FCC license would not be needed. Microwave is an expensive solution and would generally be recommended only for high bandwidth communications such as between LCC and Hub or between LCCs. Figures 4-7 and 4-8 show two example applications.

Figure 4-7 Microwave (TMC/HUB to TMC/HUB Communication)

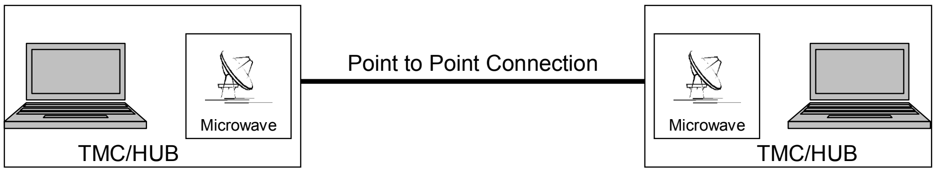
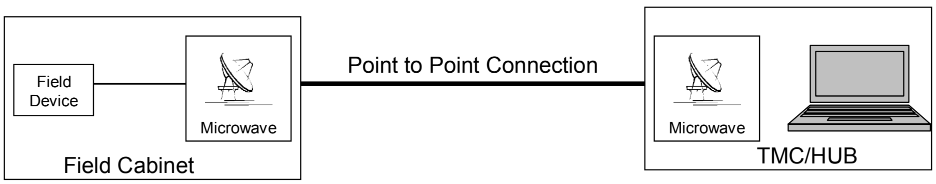


Figure 4-8 Microwave (Single Channel – Field Device to TMC/HUB)



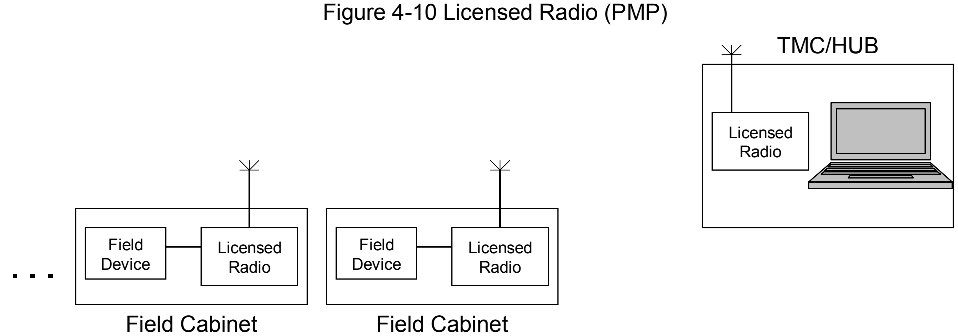
4.3.2 Licensed Radio

4.3.2.1. ITS Applications

Licensed radios are capable of either point-to-point (PP) or point-to-multipoint (PMP) low speed data communication, as shown in figures 4-9 and 4-10. They can be used as last mile alternative for field data communication. For controller status and control, the licensed radios can be typically setup with data rates of 1.2 to 9.6 Kbps.

Figure 4-9 Licensed Radio (PP)

Figure 4-10 Licensed Radio (PMP)



4.3.3 <u>Spread Spectrum</u>

Spread-spectrum radio (SSR) technology is a wideband radio frequency technique developed by the military for use in reliable, secure, mission-critical communications systems. Spread-spectrum is designed to trade off bandwidth efficiency for reliability, integrity, and security. In other words, more bandwidth is consumed than in the case of narrowband transmission, but the tradeoff produces a signal that is, in effect, louder and thus easier to detect, provided that the receiver knows the parameters of the spread-spectrum signal being broadcast. If a receiver is not tuned to the right frequency, a spread-spectrum signal looks like background noise. Spread-spectrum systems operate in the unlicensed 900MHz, 2.4GHz, and 5.7GHz ISM bands. Although these systems are designed to operate on a non-interference basis, if the RF noise floor in these bands is high enough the throughput will quickly degrade. This can be mitigated to a certain degree by using directional antennas and proper link engineering.

There are two types of spread spectrum technologies: frequency hopping and direct sequence. Frequency-hopping spread-spectrum (FHSS) uses a narrowband carrier that changes frequency in a pattern known to both transmitter and receiver. Properly synchronized, the net effect is to maintain a single logical channel. To an unintended receiver, FHSS appears to be short-duration impulse noise.

Direct-sequence spread-spectrum (DSSS) generates a redundant bit pattern for each bit to be transmitted. This bit pattern is called a chip (or chipping code). The longer the chip, the greater the probability that the original data can be recovered (and, of course, the more bandwidth required). Even if one or more bits in the chip are damaged during transmission, statistical techniques embedded in the radio can recover the original data without the need for retransmission. To an unintended receiver, DSSS appears as low-power wideband noise and is rejected (ignored) by most narrowband receivers. DSSS is the more common of the two SSR technologies.

Spread spectrum technology is less expensive than microwave and, because it operates in the ISM (industrial, Scientific, Medical) bands, it does not require licensing. Although it is designed to operate on a non-interfering basis and is generally immune from interference the overall relative RF noise in the operating band may affect performance. Like microwave, spread spectrum also requires line-of-sight.

Wireless Ethernet is a specialized application of SSR technology which is based on the IEEE 802.11 standard. The 802.11 standard refers to a family of specifications developed by the IEEE for wireless LAN technology. It specifies an over-the-air interface between a wireless client and a base station or between two wireless clients. The IEEE accepted the specification in 1997. There are several specifications in the 802.11 family:

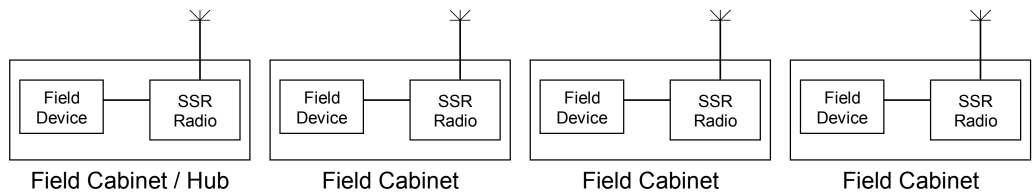
- 802.11 -- applies to wireless LANs and provides 1 or 2 Mbps transmission in the 2.4 GHz band using either frequency hopping spread spectrum (FHSS) or direct sequence spread spectrum (DSSS).
- 802.11a -- an extension to 802.11 that applies to wireless LANs and provides up to 54 Mbps in the 5GHz band. 802.11a uses an orthogonal frequency division multiplexing encoding scheme rather than FHSS or DSSS.
- 802.11b (also referred to as 802.11 High Rate or Wi-Fi) -- an extension to 802.11 that applies to wireless LANS and provides 11 Mbps transmission (with a fallback to 5.5, 2 and 1 Mbps) in the 2.4 GHz band. 802.11b uses only DSSS. 802.11b was a 1999 ratification to the original 802.11 standard, allowing wireless functionality comparable to Ethernet.
- 802.11g -- applies to wireless LANs and provides 20+ Mbps in the 2.4 GHz band.

4.3.3.1. ITS Applications

SSR supports both serial and Ethernet connected devices. It is therefore suitable for both PP and PMP field-to-hub serial communications, and for Ethernet field-to-hub or hub-to-LCC communications. It is also possible to transfer digital IP video using wireless Ethernet SSR technology. Spread Spectrum radios are capable of relaying data between locations and hence are suitable for devices like controllers along a road or corridor (see figure 4-11) where the distance between each controller is within the spread spectrum radio range.

SSR is most appropriate where existing cable-based infrastructure is lacking and line-of-sight is available. SSR is usually more cost-effective than installing additional cable, especially in low density applications. SSR may not be the best solution for critical links, such as those required for LCC to LCC communication due to Electromagnetic interference.

Figure 4-11 Spread Spectrum Radio Network



4.3.4 <u>Wireless IP Data Service</u>

Wireless IP Data Service is a connection provided by local cellular carriers. The Los Angeles metropolitan area including the I-5 Telegraph Road Corridor usually has good cellular coverage and hence should have good Wireless IP Data Service coverage. Before any final decisions are made about this type of service, a study of the coverage by different wireless providers is recommended. The most common type of wireless IP data Service currently is CDPD (Cellular Digital Packet Data). Many carriers are going away from the CDPD standard to Next Generation Wireless Service (NGWS). The discussion here is of the current existing standard which is CDPD, but is relevant to all Wireless IP Data Services.

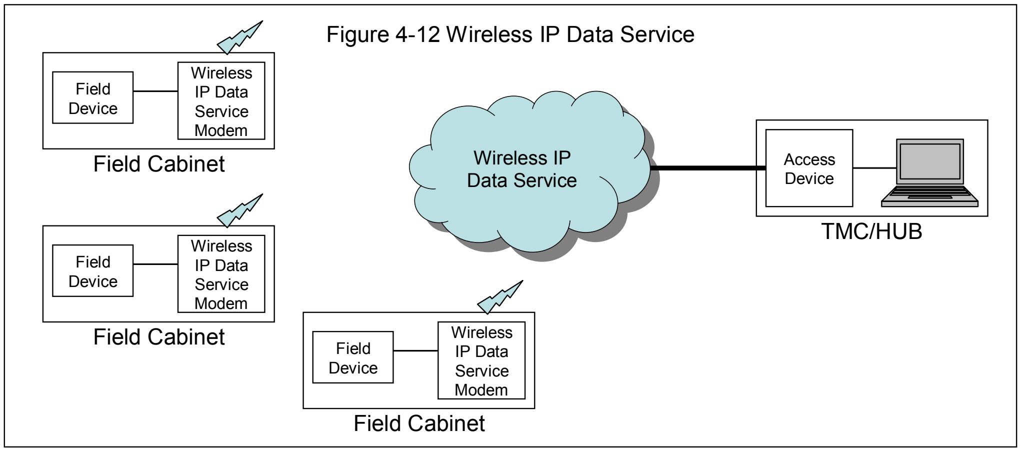
CDPD is a packet-data wireless technology developed by AT&T Wireless Services and other cellular carriers based on the familiar and ubiquitous Internet Protocol (IP) where data transmissions are sent as “packets” of information using digital radios installed in existing cellular sites. IP transmissions are typically non-deterministic with variable latency between communicating end points. This does not lend itself to the typical polling arrangements used in traditional traffic control systems. The traffic controller and central system would need to be able to operate within these characteristics. CDPD is a standard protocol that operates as an overlay to the Advanced Mobile Phone Service (AMPS) analog cellular networks. It enables analog AMPS networks to carry packetized data alongside voice, and operates on the 800 MHz frequencies. CDPD uses either idle voice channels or dedicated data channels depending on network configuration.

Data received by a CDPD equipped cellular site is forwarded to a main network switching center where the data is then either routed to another cellular site, out to a private wide area network, or out to the Internet. Independent of whether the CDPD modem is communicating to another CDPD from the same cell site or to a distant device on the Internet the data follows this same path.

Although CDPD was originally designed to send bursts of data or information during idle time on voice channels, most service providers now allocate dedicated channels for this purpose. Use of dedicated CDPD channels reduces the likelihood of blockage that often plagued earlier systems that shared voice channels. Unlike a circuit-switched cellular data connection, a user does not need to establish a connection every time data needs to be transmitted. The CDPD modem registers with the packet data network when it is turned on, and remains registered until it is turned off or leaves the service area. CDPD is a connectionless service that is best suited for short, bursty transmissions. Raw data throughput is 19,200 bps but actual throughput after the CDPD protocol overhead is about 10,000 to 12,000 bps.

CDPD is expected to be replaced by 2.5/3G (third generation) services in the next 2-4 years. Instead of being an overlay network like CDPD these services integrate both data and voice capabilities. Whereas CDPD is installed at only selected cell sites, 3G data services are automatically included at each cellular location. There are two predominant 3G standards (CDMA – 1XRTT, and GSM – GPRS). 3G services include higher bandwidth, and offer type of service, quality of service (TOS/QOS) differences. This allows for example low latency, high throughput, guaranteed delivery distinctions to support video or low bandwidth telemetry data.

Figure 4-12 Wireless IP Data Service



4.3.4.1. ITS Applications

Wireless IP Data service is provided by cellular carriers in most metropolitan areas including LA. Typical bandwidth is about 19.2Kbps. Wireless IP Data service can be used to communicate with devices that are remotely located and do not have any other means of communication to them. Wireless IP data can be setup as a point-to-point (PP) or as a point-to-multipoint (PMP) type of communication. This type of communication can be used by traffic controllers and CMS applications. Figure 4-12 shows a wireless IP data service network with multiple field devices connecting up to a single hub/LCC location. The hub/LCC connection is typically over a high-bandwidth leased line connection to the service provider network.

4.4 Leased Line Communications

Leased landline solutions are available from numerous local telephone and data service providers. Not all services may be available at all locations. Leased solutions offer alternatives where agency-owned facilities are not available and the cost of providing them is not cost-effective. A service demarcation point delineates the service provider network support responsibility from the user responsibility. This demarcation point is typically a service jack that terminates the line on the customer premise, with all connecting networking equipment (such as modem or router) being the customer support responsibility. Leased solutions include fixed installation and recurring monthly service fees. The advantage of leased solutions is that the provider is responsible for network management and support.

4.4.1 Leased Analog

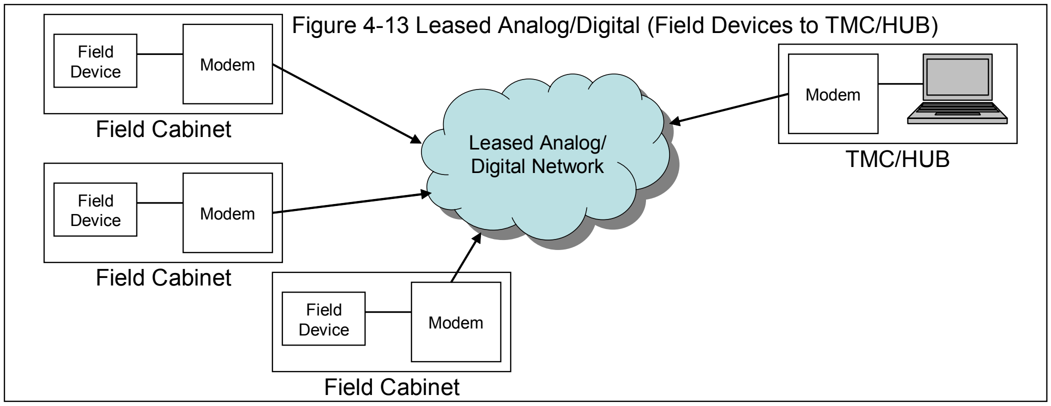
Leased line point-to-point or point-to-multipoint analog modems using the existing telephone infrastructure can be used to communicate to remote sites using low speed data. These are commonly referred to as 3002 data grade circuits in the telephone industry. The telephone cabling supports analog frequencies in the range 300Hz to 3400 KHz, and is primarily designed for speech. The available bandwidth of these circuits provided by telecommunication companies imposes limits on the available speed in bits per second that can be transmitted.

The most common leased line modem used in the traffic industry has been the Bell 202 compliant 1200bps modem. Some modems are also available that support up to 9600bps using special modulation and line equalization schemes.

4.4.1.1. ITS Applications

Leased analog solutions are very similar to agency-owned TWP analog modems in that they support low-speed PP or PMP communications. As such leased analog would be appropriate for similar field-to-hub applications such as traffic controller data, CMS and CCTV camera control. The leased connection needs to be established by the telephone company supporting 1.2 to 9.6 kbps connections. There is usually a fixed monthly fee for this type on connection. Leased analog services are being phased out by service providers in favor of leased digital services. Figure 4-13 shows a leased analog circuit connecting up multiple field devices to a hub/LCC location.

Figure 4-13 Leased Analog/Digital (Field Devices to TMC/HUB)



4.4.2 Leased Digital

Digital dedicated (leased) lines circuits are most commonly available from 9.6kbps up to 1.5Mbps. The most common ones are T1 with access speeds of 1.5Mbps and T3 of access speeds of 45Mbps. Service providers also support "bonding" of multiple T1s to provide incremental bandwidth between a T1 and full T3 (i.e. 2-8 T1s). Bonding aggregates the bandwidth to provide a single virtual connection (i.e. 4 bonded T1s to support 6MB). The higher the speed, the greater the cost, which is usually a fixed monthly service charge (does not include usage charges). There are two cost components: the local loop charge for each end of the circuit, and the distance between the servicing central offices of each end point. If the same central office serves both end points then only the local loop charges are assessed.

The advantages of digital leased lines over analog leased lines include support for higher data rates and better quality service.

4.4.2.1. ITS Applications

The lower speed circuits may be provisioned as either point-to-point (PP) or point-to-multipoint (PMP) connections and are ideal for supporting field-to-hub communications to traffic controllers and other low-speed field devices. The higher speed circuits are better suited to aggregate large amounts of data as point-to-point connections between LCC's.

Leased digital circuits would be suitable for any of the different application needs of the I-5 Telegraph Road project. For field-to-hub communications, leased digital connections can be provisioned from the telephone company at subrates of 9.6, 19.2, and 56Kbps. These lines would be suitable for communicating with field devices such as traffic controllers, CMS, and CCTV camera control, as shown in figure 4-13.

Fractional T1 at speeds of 128, 256, 384, 512 and 768Kbps are suitable for multiple devices mentioned above, or snap-shot video images. A full T1 or higher would be recommended for full motion video or LCC-to-LCC (IEN) network connection. Leased digital connection can also be used to bring back aggregated data from a group of controllers or other field devices.

4.4.3 DSL (via Internet)

Digital Subscriber Line (DSL) is a high speed solution that supports from 128kbps to several megabits of bandwidth from telecommunications providers to customers over existing copper cable, namely, the installed telephone pair to the customer's premises (called the *local loop*). DSL encompasses a number of different technologies that offer significant increases in connection speed and data transfers for access to information.

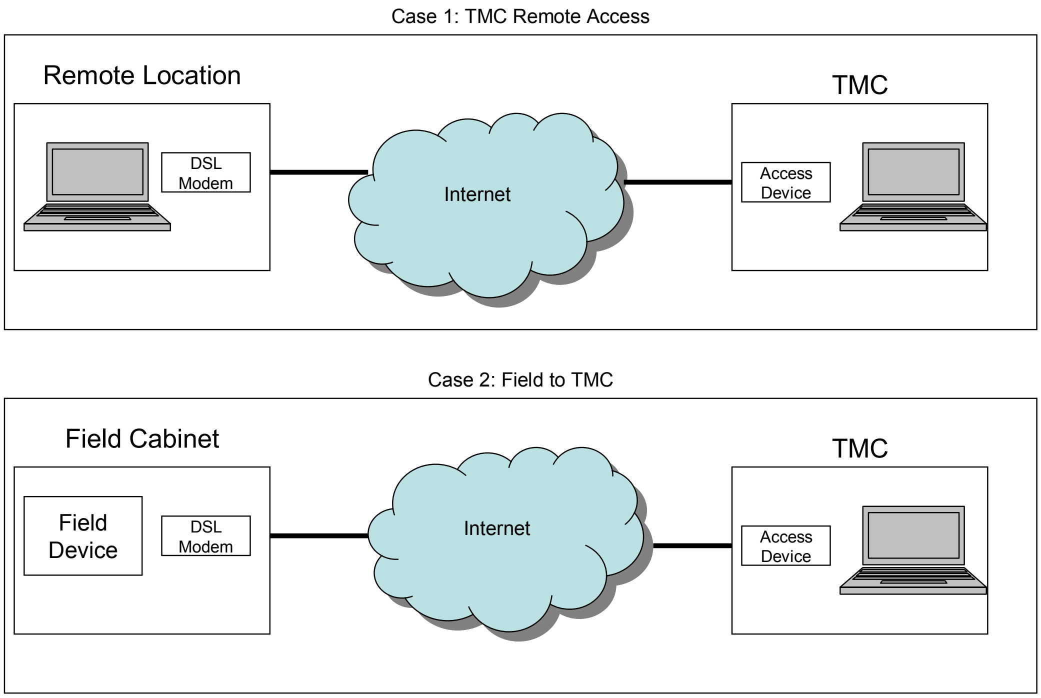
DSL is distance limited to about 3 miles from the telephone company serving central office with speed and distance inversely proportional. This technology works over non-loaded local loops (loaded coils were added by telephone companies on some copper cable pairs to improve voice quality). DSL coexists with existing voice over the same cable pair; the subscriber is still able to use their telephone, at the same time.

To implement DSL, a terminating device is required at each end of the cable, which accepts the digital data and converts it to analog signals for transmission over the copper cable. In this respect, it is very similar to modem technology.

DSL is typically provisioned as a local loop access technology for Internet access. Multiple DSL links may also be aggregated onto a high-speed leased line connection by the service provider for delivery to a common end point. Some service providers have also provisioned DSL as a point-to-point service although this is not a common configuration. Due to the high bandwidth and relative low cost of DSL it is a viable option for video transmission from camera locations. It is not recommended for an individual traffic controller support because of the high cost relative to other solutions that are better able to support lower speed data.

Figure 4-14 shows two different DSL applications using the Internet. This type of connection incurs recurring fees for the field device and for the LCC site if no existing Internet connection is available at the LCC. Also DSL may not be available at all sites and where it is available, the DSL modem may not be able to achieve the maximum speed due to distance limitations.

Figure 4-14 Leased DSL



4.4.3.1. ITS Applications

If a good connection exists, DSL could be a viable solution for any of the application needs of the I-5 Telegraph Road project. If only a single controller or CMS would be joined using Internet DSL then this could be a very costly but still viable solution. Since this type of a connection is via the Internet, some security/firewall precautions would need to be provided. A high-speed DSL connection to the LCC could be used as a backbone connection for the LCC to LCC (IEN) network. Ethernet-based IP addressable CCTV cameras could also be setup with high speed DSL Internet connections. Since the DSL modems are Ethernet based, any field devices, like the 2070 controllers, that use Ethernet could be setup with a DSL Internet connection. Although DSL Internet could be used for getting traffic controller data, CMS and CCTV video camera control applications, this may not be the most cost-effective solution. DSL internet connection can also be used to bring back aggregated data from a group of controller or other field devices.

4.4.4 Virtual Private Network (VPN)

Virtual private networks are secured private network connections built on top of publicly-accessible infrastructure, such as the Internet. VPN is a secure, cost-effective solution for high-bandwidth connections using Internet DSL or Digital Leased Lines. VPN typically employs some combination of encryption, digital certificates, strong user authentication and access control to provide security to the traffic they carry. VPNs may exist between an individual machine and a private network (client-to-server) or between two private networks (server-to-server). VPNs are also very flexible in the sense that if a location needs to be moved, only the hardware needs to be moved and a new leased line or DSL line subscribed to. Since the connection is established via the Internet, the hardware could be placed almost anywhere there is an Internet connection.

4.4.4.1. ITS Applications

As shown in Figure 4-15, a VPN can be used for connecting one or multiple field devices to a hub or LCC location. This type of connection gives a secure path for data using the Internet but not available to any unauthorized devices on the Internet. Figure 4-16 illustrates how the IEN network can use a VPN to connect two LCC locations. The data and video traffic from each LCC would be carried over secure channels and would not be accessible to unauthorized users on the Internet. Multiple VPN connections could be established between multiple LCC locations to provide a secure connection using the Internet.

Figure 4-15 Virtual Private Network (VPN) to connect Field devices to TMC/HUB)

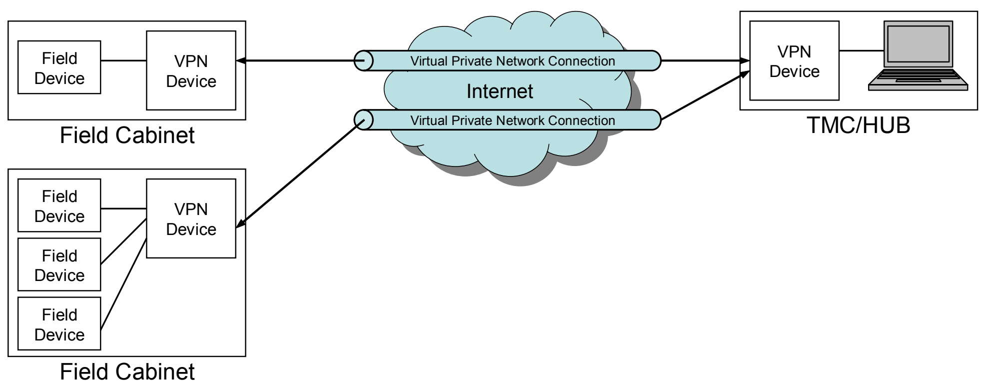
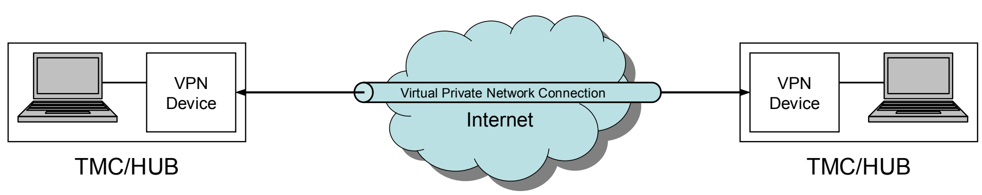


Figure 4-16 Virtual Private Network (VPN) to connect TMC/HUB to TMC/HUB



4.4.5 <u>Frame Relay</u>

Sometimes referred to as Fast Packet, Frame Relay (FR) is designed for multipoint meshed networks using VPN (virtual private networking) technology. The advantage of FR over standard point-to-point leased circuits is that there are no distance charges. It is a connectionless service where data packets are routed over a common network based on Private Virtual Circuit (PVC) identifiers. Pricing structure includes local loop charges, FR port charges, and PVC charges for each connection to the network. The local loop charges are equivalent to the local loop charge paid for an equivalent digital leased line service. The port charges vary dependent upon the speed connection. Typically one PVC is included with the service. Additional PVC can be added for a minor incremental charge.

FR may be provisioned at various data rates from 56 kbps to 1.5 Mbps (T1). Each network connection may be at a different rate depending upon bandwidth needs. Typically a FR router is used to connect to the network. The FR router typically provides an Ethernet interface for connecting to a local network, but it may also support low-speed serial lines.

Frame Relay's multiplexing of different data streams using PVC and ability to multicast data provides more flexible and efficient use of available bandwidth. The cost advantages of FR are realized in meshed or multipoint networks where the incremental cost of adding an additional connection is significantly less than would be required with a standard leased line solution. Also, for larger scope networks the lack of a mileage cost component may make this a more cost effective solution than traditional leased lines. Figure 4-17 shows an example of a field-to-hub configuration with multiple field devices connected to a LCC/hub location while figure 4-18 shows an example of two LCC/hub locations connected using a FR connection.

Figure 4-17 Frame Relay (Field Devices to TMC/HUB)

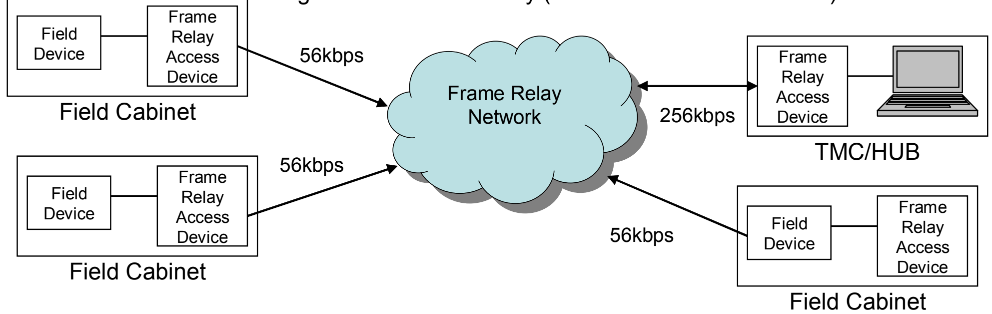
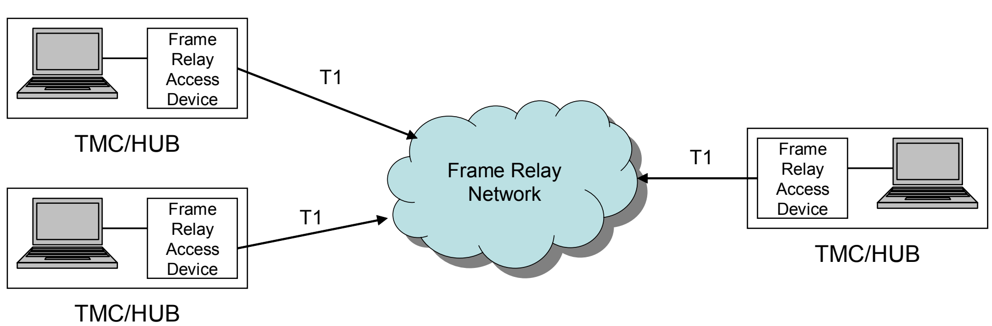


Figure 4-18 Frame Relay (TMC/HUB to TMC/HUB)



4.4.5.1. ITS Applications

FR may be used for both field-to-hub and LCC-LCC communications. Frame relay is suitable for high-bandwidth connections like the LCC to LCC (IEN) network connection and may also be a cost-effective solution for aggregating field data from a group of controllers or other field devices. Frame relay is not recommended for delay sensitive applications such as CCTV video control due to the non-deterministic nature of this technology. Non-deterministic is where the time taken for each message to reach the destination may be different, thereby affecting the apparent responsiveness of the camera control. The popularity of FR is waning due to more cost-effective alternatives such as private VPN over the Internet using either DSL or T-carrier Internet connections.

4.5 Dial-Up Analog Telephone

Field devices such as Changeable Message Signs (CMS) and Highway Advisory Radio (HAR) require a very low bandwidth analog type of connection and do not need constant connection to the devices. If there is no existing or planned communication to these types of field devices, an analog dial-up telephone could be adequate to fill this need. Analog dial-up telephone type of communication have not been evaluated in the general report since there is a performance requirement that was established for the I-5 Telegraph Road project for Center-to-Field communication that “The field-to-center communications shall be continuously available and not require an application to request connection”. This would eliminate an analog telephone dial-up type of connection, but it was thought important to mention it here since an analog telephone type of connection would be very cost-effective for occasional communication to CMS or HAR devices that are remotely located and do not have any plans of having any other type of communications to them.

4.5.1.1. ITS Applications

Dial-Up analog modems are very cost-effective for ITS applications with low usage, such as CMS and HAR. Dial up speeds vary from 1.2kbps to 56 kbps, but usually these ITS application only require a 9.6kbps connection. Field hardened analog modems are available from many vendors. The dial-up connection is only established when needed and hence the cost of connection is minimal. This type of connection is applicable when a continuous connection to the field device is not required or is very expensive to provide.

4.6 Summary of Candidate Technologies

Table 4.2 summarizes the communication characteristics of all the candidate technologies.

Table 4.2 Summary of Communication Characteristics

Technology		Application	Bandwidth	Installation	Maintenance	Scalability	Reliability	Cost
TWP	Analog Modem	Field-to-Hub PP, PMP Low-speed serial	1.2 – 19.2 Kbps	Easy	Lacks remote network management capability	Limited	Does not support fault tolerant topology	Low ($500/modem)
TWP	DSL	Field-to-Hub PP High-speed serial or Ethernet	128Kpbs – 2 Mbps	Easy, requires good condition cable	Includes SNMP network management	Limited	Does not support fault tolerant topology	Low/Moderate ($1000/modem)
Fiber Optic	Analog	Field-to-Hub PP, PMP Low-speed serial or video	9.6 – 38.4 Kbps, baseband video (6.2 MHz)	Easy	Lacks remote network management capability	Limited. Requires high fiber count.	Limited ring fault tolerant topology	Low/Moderate ($2000/modem)
Fiber Optic	SONET	Field-to-Hub, Hub-Hub PP, PMP low and high-speed serial, digital video, Ethernet	OC-3 (155M) to OC-48 (2.5G)	Difficult Requires circuit setup and configuration	Includes standards-based remote network management	Scalable interconnected rings topology; however no dynamic BW allocation	Highly reliable with 50ms failover to protected ring	High ($20-50k per node)
Fiber Optic	ATM	Field-to-Hub, Hub-Hub PP, PMP low and high-speed serial, digital video, Ethernet	OC-3 (155M) to OC-12 (655M)	Difficult Requires PVC circuit setup and configuration	Includes standards-based (SNMP) remote network management	Highly scalable using interconnected ring topology with dynamic BW allocation	Highly reliable with 50ms ring failover and higher layer cell routing	Moderate ($3-50k per node)
Fiber Optic	Ethernet	Field-to-Hub, Hub-Hub PP, PMP low and high-speed IP data and video	10M to 10G	Moderate May require VPN and QOS port setup and configuration	Includes standards-based (SNMP) remote network management	Highly scalable using mesh topologies, dynamic BW, and routing	Highly reliable with 30 sec failover and higher level routing	Low/Moderate ($2-3k per switch)

Technology		Application	Bandwidth	Installation	Maintenance	Scalability	Reliability	Cost
Wireless	**Microwave**	Field-to-Hub, Hub-Hub PP high-speed serial, video, Ethernet	1-5 to 45 Mbps	Requires FCC license and line-of-sight (LOS) Max distance supported up to 20 miles.	Requires periodic alignment	Limited	Susceptible to alignment and signal fade	High
	Licensed Radio	Field-to-Hub PP, PMP Low-speed serial	1.2 to 9.6 kbps	Requires FCC license and line-of-sight (LOS) Max distance supported up to 20 miles.	Lacks remote network management capability	Limited	Susceptible to interference	Low/Moderate ($3000/radio)
	SSR	Field-to-Hub, Hub-Hub PP, PMP low and high-speed serial, IP video, Ethernet	1.2-19.2 kbps serial 1-50 Mbps Ethernet depending upon distance	No FCC license required. Requires line-of-sight (LOS) Max distance up to 10 miles.	Lacks remote network management capability	Limited due to shared bandwidth	Susceptible to interference	Low/Moderate ($5000/radio)
	Wireless IP Data Service (CDPD)	Field-to-Hub PP, PMP Low-speed serial	19.2 kbps	Requires cellular coverage Easy to install and relocate.	Service provider network maintenance Remote modem monitoring and management	High	Cell tower and carrier diversity	Low ($60 / month / subscriber, $600/radio)

Technology		Application	Bandwidth	Installation	Maintenance	Scalability	Reliability	Cost
Leased	**Analog**	Field-to-Hub PP, PMP Low-speed serial	1.2-9.6 kbps	Service provisioned by carrier. Connect equipment at demarcation point.	Service provider network maintenance	Limited	Reliability is carrier dependent.	Low/Moderate ($75-200 / month). Distance sensitive
	Digital	Field-to-Hub, Hub-Hub PP, PMP low and high-speed serial, digital video, Ethernet	9.6-56 kbps 56k – 1.5 Mbps	Service provisioned by carrier. Connect equipment at demarcation point.	Service provider network maintenance Remote equipment monitoring and management	Limited. Complex network topologies expensive.	Highly reliable carrier service. Generally more reliable than leased analog.	Low/High ($75-800 / month). Distance sensitive
	DSL	Field-to-Hub, Hub-Hub PP Ethernet	128 kbps to several megabits	Service provisioned by carrier. End equipment typically installed by provider.	Service provider network maintenance Remote equipment monitoring and management	Highly scalable using Internet	Reliability is carrier and ISP dependent. Also dependent upon Internet	Low/Moderate ($50-300 / month)
	Frame Relay	Field-to-Hub, Hub-Hub PP, PMP low and high-speed serial, Ethernet	56k – 1.5 Mbps	Service provisioned by carrier. Connect equipment at demarcation point	Service provider network maintenance Remote equipment monitoring and management	Highly scalable using VPN capabilities	Highly reliable carrier service	Moderate//High

4.7 Cost Analysis for I-5 Telegraph Road

The IEN network is a high-bandwidth network for the exchange of data between agencies. It is envisioned that connections to the field devices will be concentrated at HUB locations and then the HUB locations have high-speed connections to LCC locations. Here is presented an order of magnitude comparison between fiber-optics and leased line communication for high-speed connections between LCC or hub locations. The costs presented here are based on connecting up two LCC locations, but this analysis could be used for connecting up any combination of LCC and field hub locations.

4.7.1 Cable-based Option: Fiber Optic (Sonet, ATM and Ethernet)

In the past, the cost of installing fiber-optic cable was much higher than twisted copper wire. Over the years, as the demand for fiber-optic cable has increased, the cost differential between the fiber-optic cable and twisted pair copper has become small. For systems where new communications media need to be installed, the cost of deploying fiber optic or copper wire can therefore be considered to be comparable.

Fiber costs

In the following analysis, the distances between LCC's are calculated and the cost to connect them using buried fiber are calculated. An average cost of $ 25 per foot for installing fiber-optic cable is assumed. Note that there is quite a variance in conduit installation costs depending upon location. Installing along unimproved roadway shoulders, such as freeways, installation can be $15-20/ft. Installing in urban environments with sidewalks and other obstructions installation can be as high as $80/ft.

Table 4.3 Approximate distance in miles between LCC locations:

	Commerce	Downey	La Mirada	Montebello	Pico Rivera	Santa Fe Springs	LA County
Commerce	X	6	11.9	4.4	4.7	6.7	7.4
Downey	X	X	7.8	7.4	4.4	4.3	12.8
La Mirada	X	X	X	14.5	7.5	5.4	18.7
Montebello	X	X	X	X	4.7	7.5	7.8
Pico Rivera	X	X	X	X	X	3.3	12.4
Santa Fe Springs	X	X	X	X	X	X	13.5
LA County	X	X	X	X	X	X	X

From Table 4.3, the following can be derived:

Average distance between two LCC locations: 8.24 miles

Average distance between two LCC locations (excluding LA County Alhambra location): 6.7 miles

The distances calculated in Table 4.3 are translated into fiber–laying costs in Table 4.4.

Table 4.4: Approximate cost (in Thousands) of connecting each of the LCC locations Using fiber-optics (Trenching at $25/foot):

	Commerce	Downey	La Mirada	Montebello	Pico Rivera	Santa Fe Springs	LA County
Commerce	X	$ 792	$ 1,570	$ 580	$ 620	$ 884	$ 1,861
Downey	X	X	$ 1,030	$ 977	$ 581	$ 568	$ 1,690
La Mirada	X	X	X	$ 1,914	$ 990	$ 713	$ 2,468
Montebello	X	X	X	X	$ 620	$ 990	$ 1,030
Pico Rivera	X	X	X	X	X	$ 436	$ 1,637
Santa Fe Springs	X	X	X	X	X	X	$ 1,782
LA County	X	X	X	X	X	X	X

End-equipment costs:

The end-equipment costs vary according to the technology (Sonet v/s ATM v/s Ethernet) selected. However, in practice, the cost of the end equipment is dwarfed by the cable laying costs. For the purposes of this cost analysis the cost of the three technologies is represented by an average of $100,000 for all the hardware and installation costs at the two LCC locations.

Total Fiber-Optic Costs for connecting two LCC Locations

From the above:

Average cost of connecting two LCC locations		
[8.24 miles * $25 /foot * 5280 feet/mile]	(approx.)	$ 1,100,000
Average cost of end equipment for two LCC locations		$ 100,000
Total capital cost		$ 1,200,000

4.7.2 Leased Line for IEN (LCC-to-LCC) Communication:

Table 4.5 shows the estimated cost for various leased-line options. The rates quoted are provided by SBC for state government agencies. Negotiated rates may vary from the ones presented here. For rate calculation we are assuming an average distance of 8.24 miles between LCC locations.

Table 4.5: Leased Line Options between two LCC locations for a single IEN Connection

Communication Type	Bandwidth	Installation Cost	Monthly Cost
DSL	1.5 Mbps	$ 500 *2 = $ 1,000	$ 115 * 2 = $ 230
T1	1.5 Mbps	$ 900 *2 = $ 1,800	$ 90 * 2 channel termination $ 55 Fixed mileage $ 41.20 ($5/mile) customer location to CO fee (avg. distance between LCC = 8.24 miles) $ 276 Total per Month
T3	44 Mbps	$ 1,000 * 2 = $ 2,000	$ 1250 * 2 channel termination $ 385 Fixed mileage $ 288 ($35/mile) customer location to CO fee (avg. distance between LCC = 8.24 miles) $ 3173 Total per Month
Frame Relay	1.5 Mbps	$ 900 * 2 + $ 300 * 2 = $ 2,400	$ 90 * 2 T1-channel $ 283 * 2 FR Port $ 746 Total per month

4.7.3 Life Cycle Costs

Table 4.6 presents the costs which have been derived in the form of a 10-year life cycle cost. The annual maintenance cost for the fiber option is calculated at 5% of capital cost.

Table 4.6 10-year Life cycle Cost Analysis between 2 locations

Technology	Capital	Yearly Maintenance / Service Fees	10-Year Maintenance Cost	Total 10-Year Life-Cycle Cost
Fiber (min. 1 Gbps)	$ 1,200,000	$60,000	$ 600,000	$ 1,800,000
DSL (1.5Mbps)	$ 1,000	$ 2,760	$ 27,600	$ 28,600
T1 (1.5 Mbps)	$ 1,800	$ 3,312	$ 33,120	$ 34,920
T3 (44Mbps)	$ 2,000	$ 38,076	$ 380,760	$ 382,760
Frame Relay (1.5Mbs)	$ 2,400	$ 8,952	$ 89,520	$ 91,920

4.7.4 Analysis:

It should be made clear in assessing the above costs, that for each link between two locations a detailed analysis is required before a decision can be made as to which type of technology is most suitable and meets all the needs of that link.

Table 4.6 would indicate that on average, for the sample LCC-to-LCC configuration used, a DSL connection appears to be the most cost-effective. However, an independent preliminary analysis of the LCC locations has already indicated that some locations such as Downey, La Mirada and Santa Fe Springs, a High-speed DSL connection may not be available.

From the Table 4.6 we can also see that the average cost of installing fiber between two locations is, comparatively, high. Thus the final recommendation for the selection of technology would be dependant on the connection between two LCC locations being shared for other purposes, such as getting field data back on the same connection as the IEN network. If it is possible to support both field and IEN data along the same route between LCCs, the combined cost/benefit may make it advantageous to install fiber-optic cable – this would need to be determined on a case-by-case basis. A high level discussion of logical and physical network architecture is performed in Section 3.1.

In the above table Frame Relay appears to be more expensive than a dedicated T1 connection for the same speed. However, Frame Relay would become less expensive than a dedicated T1 when more LCC locations are added into the network or the distance increases between the LCC locations since the monthly cost of Frame Relay is not dependant on distance.

5 COMMUNICATION TECHNOLOGY ANALYSIS

In assessing the different candidate communication technologies for the I-5 Telegraph Road Corridor, the analysis has focused on finding a solution for the following applications:

1) Controller Status and Monitoring
2) Controller Upload and Download
3) CCTV Camera Images (field to LCC)
4) CCTV Camera Control
5) Monitoring and control of CMS
6) LCC to LCC Communication (for remote ATMS workstation)
7) IEN Network (Data)
8) IEN Network (Video)

The first five applications involve communication between the LCC and field devices. Item six involves a city that does not host its own ATMS system but has an ATMS workstation that needs to communicate with the LCC that is hosting the ATMS system. Items seven and eight involve the IEN network for data and video images that need to be transferred between the different LCC locations.

Table 5-1 compares all the candidate technologies and their suitability to the identified applications. Not all of the candidate technologies are suitable for each application either due to technical or practical limitations. The table indicates which technologies are most appropriate for each of the applications based on bandwidth capacity, distance limitations, and traditional application.

The evaluation of various technologies for comparison purposes are not based on formal empirical data, but rather on an understanding of technology limitations, equipment availability, standard industry practice, and experience from designing and integrating similar systems. Evaluation and scoring is based on typical system installations. The results are highly dependent upon on project-specific installation parameters and therefore a fair amount of variability should be expected.

For a single traffic controller or CMS sign the communication cost of installing private DSL, microwave and Internet DSL is comparably expensive to other communication alternatives and hence was down-selected. Analog Modem, licensed radio, wireless IP data service, and leased analog do not meet the bandwidth requirements of CCTV video and hence were down-selected. Analog modem, private DSL, fiber-analog, licensed radio, SSR, wireless IP data service, and leased analog, all do not meet the bandwidth requirement for connecting LCC to LCC, the IEN data network or the IEN video network.

The remaining part of this section compares all of the suitable technologies against the criteria developed in Section 2.4 that are based on the requirements established for the I-5 Telegraph Road corridor project.

Table 5-1 Communication Techniques and their applications

	TWP		Fiber Optic				Wireless				Leased			
Application	**Analog Modem**	**Private DSL**	**Fiber - Analog**	**Fiber - Sonet**	**Fiber - ATM**	**Fiber - Ethernet**	**Microwave**	**Licensed Radio**	**SSR**	**Wireless IP Data Service**	**Leased Analog**	**Leased Digital**	**DSL Internet**	**Frame Relay**
Traffic Controller	X		X	X	X	X		X	X	X	X	X		X
CCTV Video		X	X	X	X	X	X		X			X	X	X
CCTV Control		X	X	X	X	X	X		X			X	X	X
CMS	X		X	X	X	X		X	X	X	X	X		X
LCC to LCC (ATMS w/s)				X	X	X	X					X	X	X
IEN Network (Data)				X	X	X	X					X	X	X
IEN Network (Video)				X	X	X	X					X	X	X

5.1 Communication Technologies for Field Device to LCC

Field-to-LCC communications includes both slow speed status and control data, and high speed video surveillance. The field-to-LCC network is typically characterized as large in geographic reach in that it interconnects a large number of diversely located field devices, and heterogeneous in that various communication technologies are often used for cost and performance reasons. Equipment used in these networks must all be ruggedized to withstand the environment of unconditioned field cabinets.

Because CCTV video image bandwidth requirements are significantly higher that those of traffic controller data, CMS and CCTV camera control, two separate comparison tables have been drawn. Table 5-2 is a comparison of the communication technologies that are suitable for slower speed traffic controller data, CMS and CCTV camera control. Table 5-3 is a comparison of the communication technologies that are suitable to support CCTV images for traffic monitoring and surveillance. There is a high bandwidth requirement for supporting analog or digital CCTV video images from the field to LCC. Only those technologies that meet the bandwidth requirement to support video are considered. All technologies have been compared against the criteria developed in Section 3.4.

Table 5-2 Field Device (traffic controller, CMS and CCTV control) Communication Options

Criteria	TWP – Analog	DSL – Private	Fiber - Analog	Fiber - Sonet	Fiber – ATM	Fiber - Ethernet	Microwave	Licensed Radio	SSR	Wireless IP Data	Leased Analog	Leased Digital	DSL Internet	Frame Relay
Life Cycle Costs	++	+/-	+	+/-	+/-	+	+/-	+	++	+/-	+/-	-	+/-	-
Operations and Maintenance	++	+	+	+	+	+	+/-	+/-	+/-	+	+/-	+	+/-	+
Expandability	-	-	+/-	+	++	++	-	-	+/-	++	-	+/-	+/-	+
Bandwidth	+/-	+	++	++	++	++	+	-	+	+/-	-	+	+	+
Reliability	+/-	+/-	+	++	++	++	-	+/-	+/-	+	-	++	+/-	++
Redundancy	--	--	+	++	++	++	-	--	-	++	--	+/-	+	+
Performance	+	+	++	++	++	++	+/-	+/-	+	+	+/-	+	+/-	+

++	performs exceptionally well	-	does not perform well
+	performs well	--	performs poorly
+/-	performs adequately		

Table 5-3 Field Device (CCTV Video Images) Communication Options

Criteria	TWP – Analog	DSL – Private	Fiber - Analog	Fiber - Sonet	Fiber - ATM	Fiber - Ethernet	Microwave	SSR	Leased Digital	DSL Internet	Frame Relay
Life Cycle Costs	+	+/-	+	+/-	+/-	+	+/-	++	-	+/-	-
Operations and Maintenance	++	+	+	+	+	+	+/-	+/-	+	+/-	+
Expandability	-	-	+/-	+	++	++	-	+/-	+/-	+/-	+
Bandwidth	-	+	++	++	++	++	+	+	+/-	+/-	+/-
Reliability	+/-	+/-	+	++	++	++	-	+/-	++	+/-	++
Redundancy	--	--	+	++	++	++	-	-	+/-	+	+
Performance	-	+	++	++	++	++	+/-	+	+	+/-	+

++	performs exceptionally well	-	does not perform well
+	performs well	--	performs poorly
+/-	performs adequately		

5.1.1 TWP

TWP often represents the largest communications infrastructure investment of any agency. Since TWP has been used exclusively for many signal systems over the past 20 years, many agencies have a substantial investment in this medium. Where TWP exists it is a cost effective solution for slow speed data applications using analog modems in either a point-to-point or point-to-multipoint topology. It can even be used as a “last mile” point-to-point solution for video using either private DSL or special video analog modems. Since TWP solutions are distance-limited their application is restricted to smaller diameter networks. TWP may also be used in combination with other technologies as “last mile” solutions. For example, using TWP to a fiber node location (i.e. communications hub) where channels are aggregated for transport back to the LCC.

If there is no existing TWP and new cable will be installed for the project, it is better to install fiber due to the higher bandwidth obtainable with fiber.

5.1.2 Fiber Optic

Fiber optic media is the preferred hardwire media solution for all types of data because of its versatility and ability to accommodate any possible future network need. The disadvantage of fiber based solutions is the initial installation cost of the fiber cable and supporting infrastructure. Where fiber does exist any of the fiber-based technologies discussed would be suitable. Analog fiber is a cost-effective solution for small sized systems supporting standard serial communications devices and video. These systems are easy to understand for setup, configuration, and troubleshooting purposes. The disadvantage of analog is that it is not very fiber efficient in that it requires a separate pair of fibers for every channel, and that it does not support more advanced network monitoring capabilities. SONET/ATM is better suited for larger systems where fiber efficiency, network redundancy, and network management are more important. Also, if SONET/ATM is used on the LCC-LCC network then this can lead to a homogeneous flat network design that is easier to manage and maintain. Ethernet is a newer technology in field-to-LCC networks. It provides all the same benefits of SONET/ATM and the promise of network simplification by extending the LCC networking standard out to the field cabinet. This would be a suitable solution for Ethernet/IP-based field equipment such as the Model 2070/ATC controller or IP capable video cameras. Although SONET, ATM and Ethernet provide many advantages over analog fiber solutions, these are complex networking technologies that require special training to configure, operate, and maintain.

5.1.3 Wireless

Wireless technologies provide an inexpensive and flexible means of extending the reach of the field network beyond any existing cable plant. Wireless technologies can be used as “gap fillers” where cable plant does not exist, or as an inexpensive alternative to installing new cable plant. It provides a great deal of flexibility in that it can often be easily redeployed in the event of network reconfiguration. SSR is a very popular wireless technology because of its deployment simplicity and unlicensed operation. Interference is always a concern within the unlicensed bands; however, with proper design the possibility of interference can be reduced. SSR can be used to support both low-speed data and video. Microwave and licensed (narrowband) radio are less desirable because of the licensing restrictions. In the LA Metro area it is unlikely that licensed spectrum would be available for this purpose. Wireless IP data services have only recently been used for field-to-LCC purposes. Like Ethernet, this technology although usable with serial devices, is best suited for Ethernet/IP supported equipment. Wireless IP may be appropriate where line-of-sight restrictions may limit the use of the other technologies, or where an agency does not want to maintain their own private wireless network. Wireless IP technology is readily available in most large markets, including the LA Metro area, and is very easy to deploy and move if necessary.

5.1.4 Leased

Leased technologies are often used as a last resort solution due to the recurring monthly costs associated with this service. However, where agency cable or wireless are not possible, feasible, or desired, then this provides a good alternative.

5.2 Communication Technologies for the IEN Network (LCC to LCC)

LCC-to-LCC communications includes both slow speed status and control data, and high speed video surveillance. The LCC-to-LCC network typically uses a limited number of high-bandwidth, highly-reliable and redundant, point-to-point connections interconnecting both LCC and hub locations. These networks may include a combination of heterogeneous links using different communications technologies at the physical layer (i.e. Fiber/Ethernet and Digital Leased Line); however, a uniform set of higher layers protocols (i.e. TCP/IP and MPEG digital video) are used to form a transparent layer for servicing applications.

The IEN supports the permanent interconnection of agency ATMS systems while remote access links provide workstation access for agencies without an ATMS to the same system. Of the two types of data support requirements across the IEN, the CCTV video images (Requirement UR IS 11) will require the highest bandwidth. Streaming CCTV video images require a bandwidth between 0.5Mbps and 3Mbps depending upon desired quality. Event devices status and control data when aggregated at the ATMS can represent a substantial data load across the LCC-to-LCC network. To accommodate such high bandwidth and to provide the desired reliability we have considered only the following technologies: Fiber-SONET, Fiber-ATM, Fiber-Ethernet, Microwave, Leased Digital, DSL Internet, and Frame Relay. Table 5-4 compares these technologies against the criteria's developed in Section 3.4.

5.2.1 Fiber Optic

Fiber optic media is the preferred hardwire media solution for LCC-to-LCC communications because of its versatility and ability to accommodate any possible future network need. The disadvantage of fiber based solutions is the initial installation cost of the fiber cable and supporting infrastructure. Where fiber does exist any of the advanced technologies such as SONET, ATM, and Ethernet would be suitable. All three are well suited to support high bandwidth requirements where fiber efficiency, network reliability and redundancy, and network management are important. Analog fiber would not be appropriate because of its comparatively lower bandwidth capabilities, and its limited ability to cost-effectively support integrated data. Both SONET and ATM have been used extensively in backbone LCC-to-LCC networks. Of the two ATM offers improved performance and bandwidth efficiencies over SONET. Ethernet over fiber is a relatively new technology for LCC-to-LCC networks. It offers similar efficiencies as ATM and the promise of network simplification by maintaining a consistent Ethernet standard both in the LAN and WAN environment. With Ethernet, data no longer requires protocol translation between the LAN (Ethernet) and WAN (SONET/ATM) networks thereby simplifying network design/troubleshooting and improving performance. Ethernet is also becoming a popular standard in the commercial MAN (metropolitan area network) market due to its cost, ease of installation, O&M, and scalability. The popularity of Ethernet has resulted in cost-effective solutions from multiple vendors. Overall Ethernet offers the best choice among the fiber-based technologies.

Table 5-4 IEN (LCC-to-LCC) Communication Options

Criteria	Fiber – Sonet	Fiber – ATM	Fiber - Ethernet	Microwave	Leased Digital	DSL Internet	Frame Relay
Life Cycle Costs	+/-	+/-	+	+/-	-	+/-	-
Operations and Maintenance	+	+	+	+/-	+	+/-	+
Expandability	+	++	++	-	+/-	+	+
Bandwidth	++	++	++	+	+	+/-	+/-
Reliability	++	++	++	-	++	+/-	++
Redundancy	++	++	++	-	+/-	+	+
Performance	++	++	++	+/-	+	+/-	+

++	performs exceptionally well	-	does not perform well
+	performs well	--	performs poorly
+/-	performs adequately		

5.2.2 Wireless

Of the various wireless technologies only Microwave offers the bandwidth and performance required in the LCC-to-LCC network. Microwave has the potential to provide a cost-effective and flexible means of linking LCC locations depending upon line-of-sight (LOS) restrictions and facility infrastructure buildout to support antennas and other equipment. Microwave also requires FCC licensing, which in the LA Metro area may be difficult to obtain due to spectrum saturation. High-bandwidth digital microwave has the ability to support all types of WAN traffic and is a popular technology among both commercial carriers and private networks.

The disadvantage of microwave over other landline technologies is the need for periodic preventive maintenance includes alignment and tuning.

5.2.3 Leased

Leased technologies are often used as a last resort solution due to the recurring monthly costs associated with this service. However, where agency cable or wireless are not possible, feasible, or desired, then this provides a good and very reliable alternative. Because of the link distances involved in a LCC-to-LCC network leased services are often more cost-effective than a private fiber solution. Leased digital services offering point-to-point connections between LCC locations have been a popular solution in the past. The limitation of this solution is the cost associated with creating a new point-to-point link for each new LCC node location. If a mesh network is desired for redundancy and load balancing reasons than the cost of adding a new node can be substantial. Leased digital is a good alternative for point-to-point connections supporting a limited number of nodes.

DSL over the Internet and Frame Relay (FR) use virtual private networking (VPN) technology to cost-effectively connect multiple node locations. The difference between the two is that DSL over the Internet is a public Internet solution, while FR is a private network solution. DSL is provisioned by public carriers as an Internet access technology. The VPN capability is added as an overlay by customer premise equipment such as a VPN capable firewall/router. DSL provides an inexpensive means of creating a mesh (any-to-any) network among various node locations. FR is similar except that the VPN capability is provided by the carrier in the form of permanent virtual circuits (PVCs). Although FR is more expensive than a DSL solution, it is typically more reliable as well. Therefore, FR is recommended for critical links while DSL may be appropriate for remote access workstation connections. DSL is offered in many types of configurations depending upon traffic load and pattern. Basically, asymmetrical and symmetrical DSL (ADSL, SDSL) are the two to be considered. ADSL offers a higher downlink bandwidth (from the Internet) than the uplink bandwidth (to the Internet) and would be appropriate for a remote location where the predominant data flow is inbound. SDSL offers the same bandwidth in both directions and would be appropriate where either the predominant data flow is outbound or where the data flow is balanced.

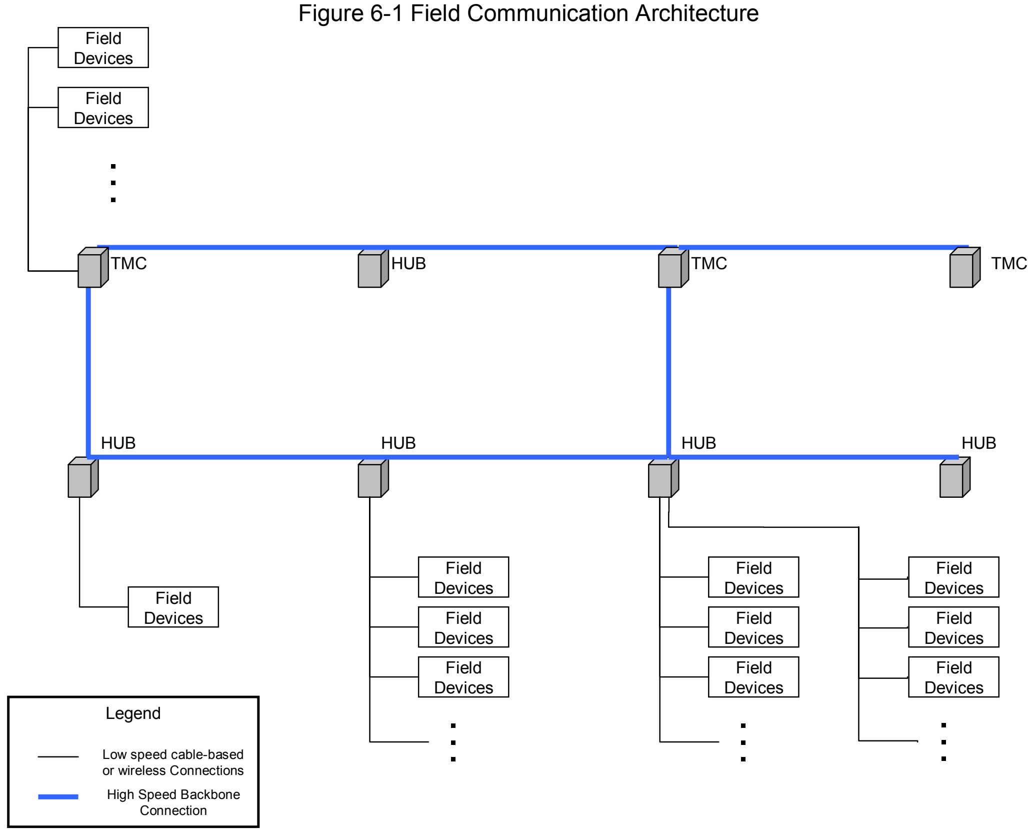
6 RECOMMENDATIONS

This section presents the recommendations for communication techniques based on the different applications as derived earlier in the report. The recommendations presented are to be considered in conjunction with an existing communication network, location of the devices and LCC/SRTMC locations. As such, this section provides guidance for the definition of the communications network to be presented later in the Conceptual Design. The recommendations have been categorized into scenarios with each scenario representing a possible configuration for communication.

6.1 Field Communications

Figure 6-1 shows an example of the field communication architecture. Field devices communication could be aggregated at 'Hub' locations where appropriate. High speed connections could be provided between Hub and LCC locations. Also, it is possible that some field devices may have a direct connection to the LCC.

Figure 6-1 Field Communication Architecture



6.2 Field to Central Communication (CCTV Video Images)

The following suggests scenarios that address the transport of CCTV video/data and data for control and monitoring from the field. The scenarios are not mutually exclusive and a combination of two or more scenarios combined together is possible. For example one option could be used from the CCTV camera to a hub location while another option is used between the hub and the LCC.

Scenario # 1: Hardware cable media exists or will be installed

If there is existing media or new media will be installed between the camera and the Hub or LCC location, this communication media could potentially be used for getting the CCTV video images back to the LCC location. Each individual connection would need to be evaluated for bandwidth and cost considerations. The two hardware cable media's are further discussed here:

<u>Fiber:-</u> If fiber media exists or is being installed to the camera location, it is very possible to use it. The choice of the fiber communication techniques between Analog, Sonet, ATM and Ethernet would be very dependent on factors like; existing fiber equipment and overall fiber network architecture. If no existing architecture is present, the recommended choice would be for an Ethernet-based IP addressable video camera.

<u>TWP (DSL Private):-</u> If new trenching is involved, the better option is to install fiber. But if existing good quality TWP is available between the camera and the LCC location, it is possible to use DSL modems to achieve enough bandwidth for bringing back CCTV video. There is an inverse relationship between the highest speed achievable by private DSL modems and the distance between the two LCC locations. A high enough bandwidth will not be attainable for two private DSL modems that are more that two to three miles apart.

Scenario # 2: No existing communication and distance greater than 300 feet

Installation cost can be justified (for example, due to sharing of the communication link with other applications):- under these circumstances the best choice for getting the highest bandwidth for new media installation is with fiber. The choice of the fiber communication techniques between Analog, Sonet, ATM and Ethernet would be very dependent on factors such as existing fiber equipment (if any) and overall fiber network architecture.

Recommendation: Ethernet-based IP addressable video camera.

Installation cost is a factor:- If initial cost for installing fiber or TWP is a factor, then the solution should include wireless options or T-Digital Leased options such as Fractional T1, DSL Internet or Frame Relay.

Recommendation: DSL, if a high speed DSL connection is available otherwise Fractional T1. For wireless, microwave is a suitable option.

Scenario # 3: No existing communication and distance to closest Hub or LCC is less than 300 feet.

This is a case of choosing the best solution for the last-mile link which has to transport video images over a short distance. Limiting the distance opens up the possibility of using the high-speed wireless service which effectively replicates a LAN. Note that for longer distances, fiber or microwave links would need to be used.

Recommendation: Ethernet based IP addressable video cameras over a Spread Spectrum Wireless network.

6.3 Field to Central Communication (controller data, CMS, and CCTV control)

Scenario # 1: Hardware cable media exists or will be installed

If there is existing media or new media will be installed between the field device and the Hub or LCC location, this communication media could potentially be used for getting the field device data back to the LCC location. Each individual connection would need to be evaluated for bandwidth and cost considerations. The two hardware cable media's are further discussed here:

Fiber:- If fiber media exists or is being installed to the field devices location, the this should be used. Sonet and ATM type of connection would not likely be cost-effective for individual field devices. Analog modems could be used for slower speed connections.

Recommendation: Ethernet ready devices like 2070 controllers over an Ethernet network

TWP:- If new trenching is involved, the better option is to install fiber. But if existing good quality TWP is available between the field device and a hub or LCC location, it is possible to use analog modems for communicating with the field devices. Several field devices including controllers can be connected to a single TWP, depending upon the communications protocol used. This allows devices to be placed on the same channel with different drop addresses.

Recommendation: Analog modem with multiple field devices on same channel

Scenario # 2: No existing communication and distance greater than 300 feet

Installation cost is justified:- Under these circumstances, the best choice for future expandability and for getting the highest bandwidth for new media installation is with fiber. The choice of the fiber communication technique (Analog, Sonet, ATM or Ethernet) would be dependent on factors such as existing fiber equipment, overall fiber network architecture, and the end field device. Installing TWP copper is also an option; while this option is cost-comparable to fiber, it limits future expansion.

Recommendation: Fiber Analog modem for serial based field devices and Fiber-Ethernet for Ethernet-ready devices like 2070 controller and some CMS's.

Installation cost is a factor:- If the initial cost for installing fiber or TWP is a factor, then the solution would have to include wireless options such as microwave, licensed radio and wireless IP data services. Where there is a need to aggregate many devices onto a single channel high-bandwidth, solutions like T-Digital and Frame relay would be considered.

Recommendation: If available, Leased analog connection or Wireless IP Data service is suitable.

Scenario # 3: No existing communication and distance to closest Hub or LCC is less than 300 feet.

This is another case of choosing the best solution for the last-mile link, as in 6.2 scenario #3 above, but this time only data has to be transmitted. Again, limiting the distance opens up the possibility of using the high-speed wireless service which effectively replicates a LAN.

Recommendation: Ethernet based field devices over a Spread Spectrum Wireless network.

6.4 LCC to LCC (IEN Network) Communication

The IEN Network will link up the different LCCs in the I-5 Telegraph Road project. In general there are two components to the IEN Network communications requirement. The first is the transfer of live video images between LCCs and the second is the data. Where existing communication infrastructure is present, it should be evaluated for its value to interconnect the different LCCs together. The IEN network is envisioned as a high-speed VPN network backbone with local links potentially being made up of leased or agency owned circuits depending upon the local topography and ability to aggregate logical connections into physical links.

Scenario # 1: High Speed connection (e.g. intranet) exists between two LCC locations

Recommendation: If bandwidth requirements are met use existing connection.

Scenario # 2: Hardware cable media exists or will be installed between two LCC locations

If there is existing media between two LCC locations, this could potentially be used for the exchange of IEN data. Each individual connection would need to be evaluated for bandwidth and cost considerations. The two hardware cable media's are further discussed here:

Fiber:- If fiber media exists between two LCC locations, it is very possible to use that as a part of the IEN network. The choice of the fiber communication techniques between Sonet, ATM and Ethernet would be dependent on factors such as existing fiber equipment and overall fiber network architecture.

Recommendation: Ethernet using Fiber media

TWP (DSL Private):- If new trenching is involved, it would be better to install fiber. But if existing good quality TWP is available between two LCC locations, it is possible to use DSL modems to achieve enough bandwidth for an IEN network connection. As there is an inverse relation ship between the highest speed achievable by private DSL modems and the distance between the two LCC locations, a high enough bandwidth may not be attainable for two private DSL modems that are more that two to three miles apart.

Recommendation: Ethernet using Private DSL using TWP

Scenario # 3: High Speed Internet connection exists to one or more LCC locations

If there is an existing high speed Internet connection between a LCC location and the Internet, this connection could be used as a part of the IEN network. Each high-speed Internet connection should be evaluated for possible use as a part of the IEN network.

Recommendation: Use existing Internet connection if at least two agencies have a high speed (at least 1.5Mbps) connection. Frame relay would be the most cost-effective since cost is dependant on usage.

Scenario # 4: Distance between two LCCs is less than 5 miles and there is no existing communication infrastructure.

<u>No communication infrastructure and installation cost justifiable:-</u> Under these circumstances, the best option is to connect the locations with a fiber link. The fiber communication technique recommended for a new communication infrastructure is Ethernet.

Recommendation: Ethernet using Fiber

<u>No communication infrastructure and installation cost is a factor:-</u> If capital cost is a factor then the solution could be some sort of leased option depending on which leased option is most cost-effective and available to the LCC location. Each LCC location should be evaluated for Leased Digital including fractional T1 lines, DSL Internet and Frame Relay.

Recommendation: Frame Relay

7 APPENDIX – ACRONYMS

ATM	Asynchronous Transfer Mode
ATMS	Advance Traffic Management System
Baseband video	Raw, unprocessed, un-modulated analog video
CCTV	Closed-Circuit Television
CMS	Changeable Message Sign
CODEC	COmpressor / DECompressor
DSL	Digital Subscriber Lines
DTMF	Dual Tone Multi-Frequency
HAR	Highway Advisory Radio
HAT	Highway Advisory Telephone
HUB	Concentration of device in one location
IEN	Inter-agency Exchange Network
IP	Internet Protocol
JPEG	Joint Photographic Experts Group
Kbps	Kilo Bits Per second
LAN	Local Area network
LCC	Local Control Center
Mbps	Mega Bits Per Second
MPEG	Moving Picture Experts Group
NTCIP	National Transportation Communications for Its Protocol
QOS	Quality of Service
SNMP	Simple Network Management Protocol
SSR	Spread Spectrum Radio
SRTMC	Sub-Regional Traffic Management Center
TWP	Twisted Wire Pair
WAN	Wide Area Network

8 APPENDIX – DISPOSITON OF COMMENTS

Draft Page #	From	Description	Disposition
1-1	Pat Smith	Update scope	Scope updated to reflect additional "expanded area"
4-1	Pat Smith	Attach NTCIP diagram. Why no Co-ax?	Added NTCIP reference. Indicated inapplicability of installing new co-ax cable
5-1	Pat Smith	Reference for comparison?	Added evaluation justification in text, and reasons for down-selecting communication techniques based on the application.
5-3	Pat Smith	Who performed tests?	Added evaluation justification in text, and reasons for down-selecting communication techniques based on the application.
2-1	Jane White	Formatting and spelling	Done
2-3	Jane White	Formatting and spelling	Done
2-4	Jane White	Formatting and spelling	Done
2-7	Jane White	Doesn't sound like a requirement	Changed into the format of a requirement
2-8	Jane White	Formatting and spelling	Done
2-9	Jane White	Formatting and spelling	Done
2-10	Jane White	Formatting and spelling	Done
3-14	Jane White	Formatting and spelling	Done
3-17	Jane White	Formatting and spelling	Done
3-19	Jane White	Why? Explain?	Reasons were added and explanations provided
3-20	Jane White	Baseband video?	Baseband video is unprocessed, un-modulated, raw analog video (explanation also added in the first reference to it in the text)
3-20	Jane White	If you increase comm. do you increase performance?	Yes, up to a point.
3-21	Jane White	General questions	Have been addressed directly in the document by adding

			explanations.
3-21	Jane White	How do these compare? Is it the same thing?	An individual video server at each LCC is listed as a disadvantage for option 2 since each LCC that has video coming in will have to procure a video server and maintain it. As opposed to a network of video servers in option 3 that could be placed anywhere on the network. To prevent failures, redundant video servers could be installed as an option but are not necessary for regular operations.
3-22	Jane White	Should address what would be provided? Critical?	Analog circuits to the field in option 2 would provide Baseband video in the local LCC.
4-1	Jane White	Formatting and spelling	Done
4-2	Jane White	Remote monitoring and management - What do you mean?	Added explanation of remote monitoring and management.
4-4	Jane White	Comments	Addressed in document text
4-5	Jane White	Remote monitoring and management - What do you mean?	Added explanation of remote monitoring and management.
4-6	Jane White	High-fiber count?	Explanation added of how large systems will need pair of fiber for each pair of modems.
4-8	Jane White	Collapsed ring design?	Where SONET links run over fiber within the same cable.
4-11	Jane White	Formatting and spelling	Done
4-12	Jane White	Half-duplex?	Added explanation of half-duplex
4-12	Jane White	Single collision domain?	Added explanation of single collision domain.
4-12	Jane White	What did previous versions do?	Previous versions were not capable of performing point to point full duplex over a fiber connection.
4-13	Jane White	What is QOS?	Quality of Service
	Jane White	What is IP multicasting?	IP Multicasting is a bandwidth-conserving technology that reduces traffic by simultaneously delivering a single stream of

			information to multiple users
4-16	Jane White	Formatting and spelling	Done
4-19	Jane White	Formatting and spelling	Done
4-24	Jane White	Why?	Added reason.
4-25	Jane White	Conflict with previous statement.	Explained the confusion. DSL Internet is a viable solution for any application, though it may not necessarily be a very cost-effective solution for a single controller or CMS sign.
4-27	Jane White	Formatting and spelling	Done
4-28	Jane White	What does this mean?	Added explanation of non-deterministic network
Table 4-2	Jane White	What about installation costs/	Installation costs are considered in the analysis, but only approximate monthly recurring costs are mentioned in this table
Table 4-4	Jane White	Sounds low?	This is an approximate cost for an urban installation taken from experience gained from deploying communication networks throughout the country.
4-4	Jane White	Section 4.7.4 - provide sample analysis?	A high level discussion of logical and physical network architecture is performed in Section 3.1.
5-2	Jane White	Provide discussion	Discussion is added in the text before the table
5-3	Jane White	Formatting and spelling	Done
6-2	Jane White	Can’t sharing occur with other technologies?	Yes
6-3	Jane White	So you replacing controller too?	If new field devices are being purchased or old ones are replaced, the new devices should be Ethernet-capable devices
6-3	Jane White	If life-cycle costs says to lease why are you proposing to install?	If installation cost is a factor, leased analog connection or wireless IP data service is suitable.
6-4	Jane White	Formatting and spelling	Done
6-5	Jane White	Still seems like recommendations isn’t based on life cycle cost analysis.	Life-cycle costs is only one of the factors used to come up with the recommendations, other factors

		on life cycle cost analysis.	include operations and maintenance, expandability, bandwidth, reliability, redundancy, performance. These criteria's were developed in section 2.4 and are based on the requirements of the project.