Pomona Valley
ITS Project

Project Deliverable 7.2.2
Communications Alternative Analysis Report

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HISTORY OF REVISIONS

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PROJECT DESCRIPTION

The County of Los Angeles, in cooperation with the cities within the Pomona Valley, has determined that development of an Intelligent Transportation System (ITS) in the Pomona Valley would help to reduce congestion, enhance mobility, provide traveler information during non-recurring and event traffic congestion, and manage event traffic. The Pomona Valley Intelligent Transportation Systems (PVITS) project was conceived as a recommendation from the Pomona Valley ITS Feasibility Study completed by the LACMTA in 1995. The ultimate objectives of the Project are to:

- Improve mobility by optimizing traffic management on arterials and freeways;
- Enhance Route 60 capacity by better coordinating freeway traffic with parallel arterials;
- Improve agency efficiency by coordinating management of operations and maintenance efforts among and between agencies; and
- Increase agency staff productivity by providing low-maintenance, high-quality communications and computational tools to assist in daily management and coordination activities.

Phase 1 of the PVITS project is the development of a conceptual design that defines solutions to enhance capacity, reduce congestion, and improve traveler information in the Pomona Valley.

1.0 BACKGROUND

1.1 Purpose of Report

Based upon the user and functional requirements set forth in previous reports, the purpose of this report is to conduct an examination and brief discussion regarding the viable alternative communications technologies available to serve the Pomona Traffic Forum area's ITS applications. The evaluation will especially consider both stakeholder and system requirements identified in Section 3 of Project Deliverable 5.6.1 - Communication User and Functional Requirements Report as well as estimated costs to implement the various alternatives.

1.2 Methodology

The methodology for evaluating the different communication alternatives includes the following key aspects:

- Consideration of any existing or planned communication facilities, central traffic control systems, ITS field elements, and stakeholder needs and objectives based upon information gathered and presented in previous reports.
- Conformance to the draft of the "area system architecture" that has been developed for the Pomona Valley subregion and presented in a previous report.
- Recognition of user and functional requirements for systems as set forth in previous reports such as the ATMS Functional Requirements Report, and local agency reports.
- Based on proven communication transmission technologies currently used for ITS and a geometric arrangement (topology) for the communication network that would be required to satisfy user and system functional requirements.
- Engineering and economic assessment of communication network alternatives
- Recommendation of the preferred communication alternatives

1.3 Report Organization

The information in this report is organized in the following manner:

Section 1 – Background
Section 2 – Existing and Planned Equipment
Section 3 – Communication Needs
Section 4 – Overview of Communication Technologies
Section 5 – Communication Alternatives Assessment
Section 6 – Recommendations

2.0 EXISTING AND PLANNED EQUIPMENT

2.1 Summary of Existing and Planned Field Equipment

The PVITS communication network will serve as an indispensable link between the field equipment and the control centers (field-to-center), and among different control centers (center-to-center). As the basis for the communication recommendations for PVITS, **Table 2.1** summarizes the estimated type and quantity of field devices based on information provided in the individual city reports. These types and quantities of field devices are being used for analysis of the alternative communication media, leading to a recommendation of the most feasible and cost-effective communications system design for PVITS. There is leeway for changes to these numbers by the stakeholders since minor changes would not significantly alter the recommendations presented in this report. **Figure 2.1** provides a graphical depiction of the estimated field device locations.

Table 2.1 PVITS Field Equipment Quantities

City	Existing Signals	Proposed Signals	Total Signals	Existing CCTV Cameras	Proposed CCTV Cameras	Total Cameras
Claremont	27	1	28	0	6	6
Diamond Bar	62	4	66	0	7	7
La Verne	25	4	29	0	6	6
Industry	38	0	38	0	7	7
Pomona	82	2	84	8	11	19
San Dimas	13	2	15	0	5	5
Walnut	19	0	19	0	2	2
LA County	45	0	45	0	2	2
Total	**311**	**13**	**324**	**8**	**46**	**54**
City	**Existing DMS**	**Proposed DMS**	**Total DMS**	**Existing Trail-blazers**	**Proposed Trail-blazers**	**Total Trail-blazers**
Claremont	0	2	2	0	5	5
Diamond Bar	0	5	5	0	14	14
La Verne	0	0	0	0	0	0
Industry	0	12	12	0	25	25
Pomona	0	8	8	0	24	24
San Dimas	0	7	7	0	10	10
Walnut	0	0	0	0	2	2
LA County	0	5	5	0	12	12
Total	0	39	39	0	92	92

Figure 2.1 ITS Field Devices

3.0 COMMUNICATION NEEDS

The first step of designing a suitable communications network for PVITS is to evaluate the needs of the network. It can be classified into two categories:

- Field-to-center – this is the communications from the field devices to the appropriate owning agency center (Local Control Centers (LCC), subregional TMC, or LA County TMC)
- Center-to-center – this is the communications among LCCs, the Pomona Valley subregional TMC, and the LA County TMC.

3.1 Field-to-Center

The communication system between the field equipment and the control center is influenced by the type of field equipment. Different equipment has different communication bandwidth requirements. The bandwidth is the "speed" or "size" (in kilobits or megabits per second for digital transmission or in megahertz [millions of cycles per second] for analog video transmission) of the communication channels for transmitting data and video. **Table 3.1** summarizes the bandwidth requirements of the different field equipment.

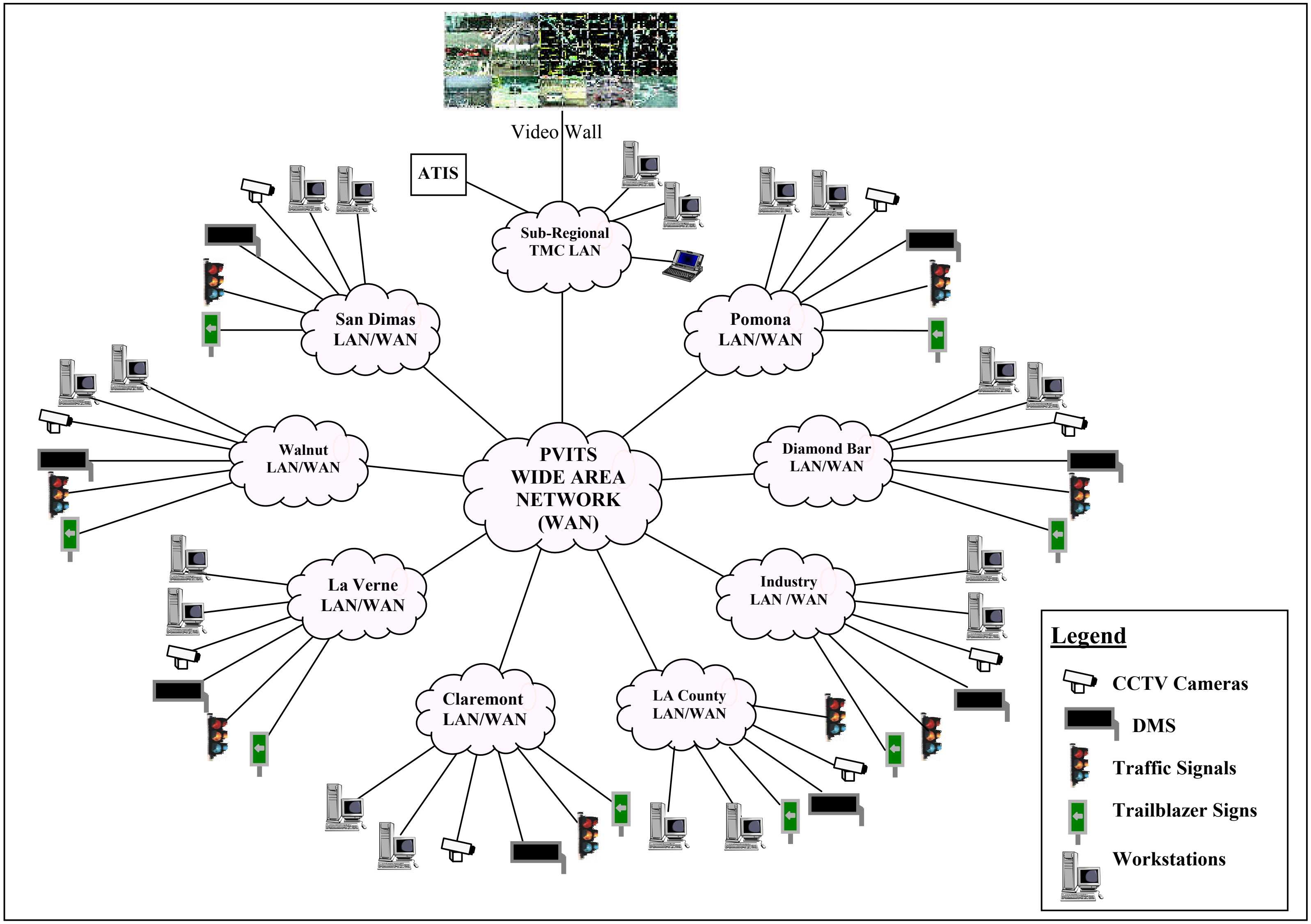
Table 3.1 Field-to-Center Bandwidth Requirements

Field Element	Bandwidth Requirement
Traffic Controller	1.2 kb/s to 19.2 kb/s
Traffic Detector	1.2 kb/s to 19.2 kb/s
Dynamic Message Sign	1.2 kb/s to 9.6 kb/s
CCTV Camera Control	9.6 kb/s to 19.2 kb/s
CCTV Camera Video	4.5 MHz (analog) or 3 Mb/s (MPEG2 digital) or 1.5 Mb/s (compressed digital)
Highway Advisory Radio	56 kb/s and/or voice network connection
Trailblazer Route Guidance Sign	9.6 kb/s

The field-to-center communication will provide for control and monitoring of field elements from the LCC, which is to be situated in each municipality's city hall.

The field-to-center communications network should be designed to accommodate the above bandwidth requirements. In general, this will likely consist of a standard office local area network (LAN) communications system for the workstations within each LCC, with an interface to a wide area network (WAN) for communicating with the field devices. There will also be an interface to a video surveillance system and an interface to the IEN. The network for the Subregional TMC should also furnish an interface to the Advanced Traffic Information System (ATIS), via the subregional TMC's LAN, which may include video feeds to the local media as well as provision of real time traffic information on the Internet. **Figure 3.1** provides a general illustration of the communication configuration of the PVITS.

Figure 3.1 Communication Configuration of PVITS



A communication network topology is the physical geometric arrangement of the communication network electronic devices. The topology for the wide area network supporting the field devices varies with different transmission technologies. There are four general topology types for communications transmission. They are Bus, Star, Ring and Mesh. **Figure 3.2** is a diagrammatic representation of the different topologies.

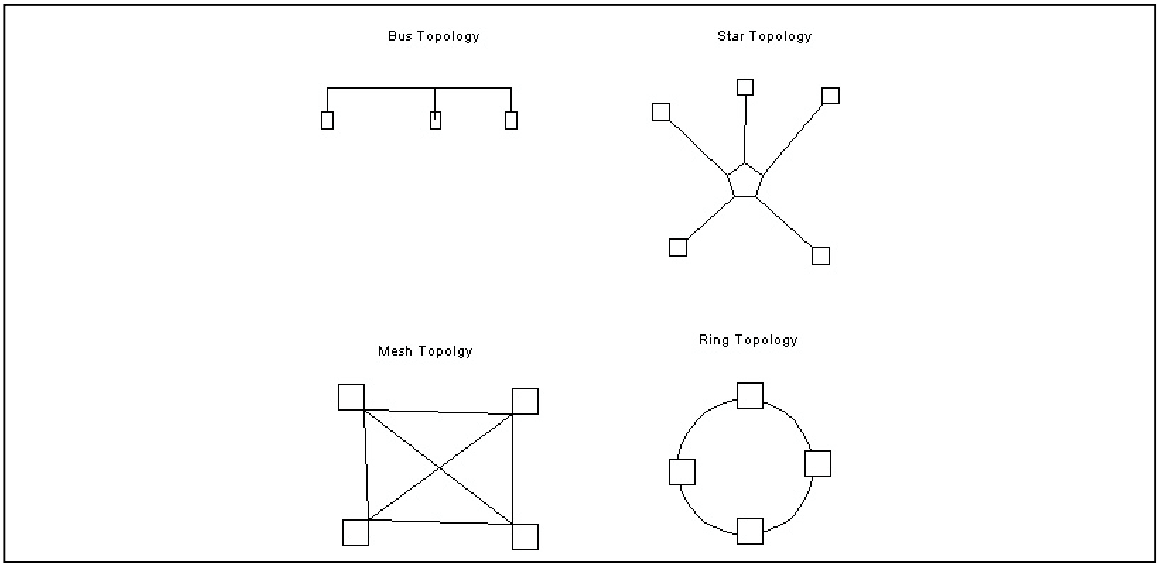
A **Bus** topology is a linear configuration connecting different equipment. This topology is most commonly used, for example, in an office local area network (LAN), and is commonly referred to as “Ethernet”. However, recent advances in transmission capabilities are moving this technology into support of wide area network (WAN) applications.

A **Star** topology is designed such that multiple transmissions radiate from a central equipment to connect to other equipment. This topology is generally used, for example, for closed circuit television transmission of video surveillance systems.

A **Ring** topology connects equipment in a fashion such that the first and last are connected together to form a continuous ring. This topology is used, for example, in a high speed, high capacity transmission system referred to as “SONET”, which stands for “synchronous optical network”. The ring configuration allows for a high level of service reliability, since any single point failure of the network can be re-routed in the opposite direction.

A **Mesh** topology connects any piece of equipment to all other similar equipment in a network. This topology is generally used, for example, with switched transmission systems such as ATM (“ATM” stands for “asynchronous transfer mode” which is another high speed, high capacity transmission system). It also provides a high level of service reliability. It is also worth noting that leased services furnished by a telephone company can be considered a mesh topology because of the ubiquitous nature of their facilities.

Figure 3.2 Communication Topologies



To achieve a high level of service reliability, the target topology for the PVITS communications network should be either a ring or mesh. However, for an agency-owned network to achieve the appropriate topology configuration, it will likely require the cooperation of the various stakeholders to share the maintenance of the network.

3.2 Center-to-Center

To support the communication requirements for traffic control and video surveillance between a LCC and the Subregional TMC, and between the Subregional TMC and the LA County TMC, it will likely require a high bandwidth transmission capacity. Assuming that the Subregional TMC needs to view at any one time up to 8 CCTV video images from the different LCCs, and each video transmission requires a minimum of 1.5 - 3Mb/s as stated in Table 3.1, a total of 12 - 24Mb/s is required between the Subregional TMC and each LCC. Assuming that the communications between the Subregional TMC to LA County TMC need to provide 8 video channels for ATIS, plus high speed graphical images and data transmission for IEN, it is estimated that a total of 14 - 30 Mb/s is required. Therefore, the Center-to-Center communications for PVITS should be configured to accommodate bandwidths described in **Table 3.2.**

Table 3.2 Center-to-Center Bandwidth Requirements

Center-to-Center	Bandwidth
Subregional TMC to LCC	12 Mb/s (compressed digital) 24 Mb/s (MPEG2 digital)
Subregional TMC to LA County TMC	14 - 30Mb/s

If the design calls for a common agency-owned network, the center-to-center communications should be designed to meet the above transmission capacities. If the design calls for leased facilities from a telephone company's public network, the nearest standard service provided by the telephone company that will satisfy the above transmission requirements should be leased.

4.0 OVERVIEW OF COMMUNICATION TECHNOLOGIES

This section furnishes a brief review of various communication technologies available to the PVITS stakeholders. On a high level of categorization, there are three alternatives:

- the leasing of facilities from public telecommunication companies;
- the development of a common agency-owned communication network, including all the conduit infrastructure, cables, and electronics; or
- a hybrid of both.

The key differences between the alternatives are the capital and annual operations and maintenance costs, and the maintenance responsibilities.

Within the agency owned communication network alternatives, various technology options are available, such as:

- Analog Transmission
- Digital Transmission
- Wireless Transmission
- Ethernet Transmission

The following paragraphs discuss the leased facilities option and each of the above technologies. Evaluation of these alternatives toward the PVITS communication needs are provided in Section 5, leading to our recommendations provided in Section 6.

4.1 Leased Facilities

Leased communication facilities can be obtained from a communications carrier franchised to provide service in the Pomona Valley of Los Angeles County. Currently, two telephone companies provide local services in this Region: PacBell and Verizon telephone companies.

The advantages of this alternative are twofold. First, the capital cost is low since it does not involve construction of a communication infrastructure. (It should be noted that, however, the annual operating costs will be higher than an agency-owned network). Second, network service reliability would be the responsibility of the telephone company, which is normally very good.

Telephone companies provide lease channels with the following standard bandwidths:

- Data channels at 56 kb/s (suitable for all data transmission).
- T1 channels at 1.544 Mb/s
- 45 Mb/s channels

Under this alternative, CCTV images would be “compressed” into digital video signals. The analog video output from cameras would be digitized and compressed using CODEC(coder/decoder) equipment designed for outdoor environments. By so doing, a leased T1 line (of 1.544 Mb/s rate) would be adequate for each CCTV camera. Transmission facilities for other field devices requiring only data communication would utilize data channels of 56 kb/s. All leased services would be furnished by the telephone company from a point adjacent to each field device to a point at the LCC.

Leasing telecommunication facilities requires laying conduits from each field equipment cabinet to a pullbox adjacent to the nearest telephone company's service provision point - normally a telephone pole. This is usually available within a reasonable distance (say, 300 feet on average) of a signalized intersection.

4.2 Analog Transmission

Analog transmission is a continuous, sinusoidal, energy wave that can utilize either copper or optical fiber cables as the principal transmission media. It is a matured transmission technology that can furnish relatively low cost communications infrastructure (especially annual operations and maintenance cost when compared to digital transmission). However, analog transmission systems do not offer the service reliability of digital transmission systems. (Generally digital is more reliable because the network design can implement redundant paths in a straightforward manner, and because the digital signal can incorporate error correction so we are assured that what comes out one end is exactly the same as what went in the other end.) Analog transmission may be used in a small scale network, for example, where a city wants to furnish dedicated fiber to connect to its cameras in a star topology. For a multi-agency and multi-center network like Pomona Forum, this technology may not meet service reliability requirements.

4.3 Digital Transmission

Digital transmission is the transport of data in a binary code using the digits zero and one (hence "digital"). A set of digital transmission rate standards have been developed for North America that are divided between copper and optical transmissions. These are set forth below:

- Copper cable transmission rates:
  - DS 0 (Digital Signal Zero) = 64 kilobits per second (kb/s). DS0 channel supports one voice communication path or 56 kb/s data communication path.
  - DS 1 = 1.544 Mb/s - contains twenty-four (24) DS0
  - DS2 = 6.312 Mb/s - contains ninety-six (96) DS0
  - DS3 = 44.736 Mb/s - contains six hundred seventy-two (672) DS0
- Optical cable transmission rates:
  - OC 1 = 51 Mb/s - contains one (1) DS3
  - OC 3 = 155 Mb/s contains three (3) DS3
  - OC 12 = 622 Mb/s contains twelve (12) DS3
  - OC 48 = 2.4 Gb/s contains forty-eight (48) DS3

Within digital optical transmission, there are two primary technologies which can be considered: Synchronous Optical Network (SONET) and Asynchronous Transfer Mode (ATM).

4.3.1 SONET

SONET is a mature, high speed, high capacity optical fiber transmission technology based upon the North American telecommunications transmission standard. SONET technology is channelized (discrete path), with point-to-point transmission. SONET equipment is normally installed with a minimum transmission rate of OC 3. A SONET network utilizes electronics equipment known as "add-drop multiplexers" (ADM), which can operate for distances up to 43 miles, to develop a "ring" topology that can provide a high level of service reliability.

4.3.2 ATM

ATM technology also requires an optical fiber transmission infrastructure. It is a high-speed, high capacity switching technology. It can transport at a constant bit rate or a variable bit rate. ATM is an asynchronous technology because the signal transmitted is not necessarily periodic (synchronous). The transmission distance between an ATM switch and another ATM switch (or a field device) is limited by the characteristics of the optical interface of the ATM switch and the transmission media (fiber). Assuming the use of single mode optical fiber and a standard laser interface, the maximum transmission distance for an ATM switch is approximately 23 miles. Should the distance between ATM switch nodes exceed 23 miles, ATM can support a SONET interface that will then allow a longer transmission distance between switches. When ATM technology is utilized to develop a wide area network and the network contains multiple ATM switches, a mesh topology can be created that will ensure a high degree of reliability.

However, it is important to note that the use of ATM technology is in decline for privately owned networks because private network developers are rapidly moving to gigabit Ethernet technology (see Section 4.5) using optical fiber transmission media.

4.4 Wireless

Within the wireless technologies, three media may satisfy the PVITS communications needs. They are microwave radio, spread spectrum radio, and Cellular Digital Packet Data (CDPD). Each wireless media is discussed below.

4.4.1 Microwave Radio

Microwave technology offers broadband transmission capabilities that can accommodate both low speed data and video communication. Since it is a "line of sight" type radio transmission, the undulating terrain in the PVITS geographical area poses concern that this technology may only have limited application and does not appear to be suited as the principal (backbone) communications medium, at least for field-to-center communication. To provide a communication path between a control center and field devices, it may be necessary to construct numerous microwave towers. If no agency owned property were available to construct this facility, it would be necessary to purchase or lease private properties. Moreover, microwave frequency allocation generally requires FCC licensing, and in an urban environment such as the Pomona Valley area, it may be difficult and time consuming to do so. It should also be noted that microwave radio tower sites are generally constructed on hill and/or mountain tops or tall structures. Therefore, a transmission path would still have to be provided from the microwave radio tower site to a specific traffic control device.

Another drawback of microwave technology is that it does not readily lend itself to reliable communication paths unless multiple sites are constructed so as to establish a "ring" topology. This configuration would substantially increase the capital cost. Additionally, the fundamental service reliability of microwave is not as good as an optical fiber based communications because microwave radio communications is subject to weather interference (such as rain and fog) between tower sites as well as a high failure rate of electronic components.

4.4.2 Spread Spectrum Radio

Spread spectrum technology is also a high frequency, "line of sight" type, radio transmission similar to microwave radio. One advantage spread spectrum has over microwave radio is that it does not require FCC licensing. Using repeaters, it is relatively easy to construct a communication path. Spread spectrum transceivers and antennas can be mounted on top of signal poles or street light poles. However, its communications transmission capacity is an issue for both data and video transmission. Most spread spectrum equipment is designed to support a transmission rate of 9.6 kb/s, but selected spread spectrum systems are capable of supporting compressed video at a transmission rate of 1.5 Mb/s. Moreover, it cannot be arranged in a ring or mesh topology. Therefore, its service reliability is relatively poor. Spread Spectrum offers no switching capability, rather, it necessitates multiple, parallel systems to develop a mainline backbone system. Hence it is not suitable as a trunk backbone system for PVITS. However, this technology may be used to transport isolated equipment requiring low bandwidth communications within PVITS, especially equipment in remote, isolated sections of the network and for communications to an intermediate point.

4.4.3 Cellular Digital Packet Data (CDPD)

CDPD provides wireless data communication over public cellular telephone systems. It is an older technology offered by some cellular providers. With a CDPD modem, wireless access can be furnished between a field device and the LCC. CDPD furnishes an "always on" connection for continuous access. CDPD service has a practicable transmission rate limitation of 15 kb/s. Because of its inability to transmit high data rates, it is not suitable for video communications.

CDPD service is not offered in the PVITS geographical area by AT&T Wireless, Cingular or Verizon Wireless, which are the dominant cellular telephone providers in the area. Therefore, this technology has been dropped from further consideration.

4.5 Ethernet Transmission

Ethernet is a popular network technology. The original Ethernet technology operated at 10 Mb/s over a coaxial cable medium. The transmission medium has been subsequently improved such that Ethernet now operates over virtually every transmission medium including twisted-pair copper, optical fiber and wireless.

Formal specifications for Ethernet were published in 1980 by a multi-vendor consortium and were then adopted for standardization by the LAN standards committee of the Institute of Electrical and Electronics Engineers (IEEE 802). The IEEE standard was first published in 1985 as IEEE 802.3, and is periodically updated to include new technology.

Ethernet is a digital transmission technology originally developed as a simple transmission system for personal computers in an office environment. At its most basic, Ethernet technology uses a linear (bus) topology. The technology has evolved into a sophisticated transmission system that is capable of supporting voice and video transmission as well as data communications. Transmission rate improvements today permit operating speeds of 100 Mb/s and 1,000 Mb/s or 1 Gb/s (1 billion bits per second), hence the term "Gigabit Ethernet". Ethernet is well suited for the transmission of the National Transportation Communications for ITS Protocol (NTCIP), which is developed by the Federal Highway Administration (FHWA) for the specific purpose of supporting ITS communications. Its purpose is to simplify and standardize the equipment interfaces associated with traffic control systems.

With the advent of Gigabit Ethernet technology, switch systems have been developed that can interface to both copper and optical fiber media. Gigabit Ethernet is based upon a standard developed by IEEE. It is noteworthy that Gigabit Ethernet technology is making significant progress in becoming the technology of choice for privately owned wide area networks. Because of its low signal loss properties, optical fiber cable would the preferred transmission medium. Through the use of software controlled switches, and development of a ring or mesh topology, a high reliability network can be developed.

5.0 COMMUNICATION ALTERNATIVES ASSESSMENT

This section discusses the evaluation of the different communication alternatives. The evaluation is conducted in two levels. First, an evaluation of the communication alternatives is conducted against a set of general criteria in Section 5.1. Second, the feasibility of each communication alternative for specific application in PVITS is presented in Section 5.2.

5.1 General Evaluation

A general evaluation of each communication alternative is conducted using the following criteria:

- Communication Hardware Needs
- Data Transfer and Bandwidth Capacity
- System Performance
- Service Availability and Reliability
- Ease of System Expansion
- System Flexibility
- Maturity of Technology
- Ability to satisfy current and future needs, from the general ITS point of view
- Potential Bottlenecks and Weak Links
- Staffing, Maintenance & Training Requirements
- Estimated Capital Cost
- Estimated O&M Life-cycle Costs (10 Years)

A comparative matrix is provided in **Table 5.1** that concisely illustrates the benefits and limitations of each communication technology.

All the alternatives, except the lease and wireless alternatives, will require the development of a conduit infrastructure for optical fiber cable. In these cases, the capital costs include all the conduit, cables, hubs, electronics, and necessary equipment to construct the network, and are therefore very high.

Table 5.1 General Evaluation of Communications Alternatives

General Evaluation Criteria	Leased	Analog	SONET	ATM	Microwave	Spread Spectrum	Gigabit Ethernet
Communication Hardware Needs	Public Network	Individual Channels	OC3	OC3	Multiple Channels	Individual Channels	Wideband Bus
Data Transfer & Bandwidth Capacity	Up to 45 Mb/s	Up to 6 MHz	Up to 622 Mb/s	Up to 155 Mb/s	Up to 45 Mb/s	Up to 10 Mb/s	Up to 1 Gb/s
System Performance	Good	Good	Very Good	Very Good	Fair	Fair	Very Good
Service Availability & Reliability	Good & Good	Good & Poor	Good & Good	Good & Good	Fair & Fair	Good & Fair	Good & Good
Ease of System Expansion	Easy	Limited	Easy	Easy	Difficult	Easy	Very Easy
System Flexibility	Limited	Somewhat Flexible	Very Flexible	Very Flexible	Inflexible	Inflexible	Very Flexible
Maturity of Technology	Mature	Declining Popularity	Mature	Declining Popularity	Mature	Mature	Growing Popularity
Ability to Satisfy Current & Future Needs	Good	Fair	Good	Good	Fair	Fair	Very Good
Potential Bottlenecks & Weak Links	Video Transmission	Limited Transmission Capacity & Low Reliability	Depends on design	Depends on design	Low Reliability	Limited Transmission Capacity & Low Reliability	Poor Environmental Capabilities
Staffing & Training Requirements	Minimal	Minimal	Substantial	Substantial	Substantial	Minimal	Moderate
Capital Cost	Low	Very High	Very High	Very High	Very High	High	Very High
Estimated Annual O&M	Very High	Low	High	Medium to High	Medium	Medium	Low to medium

5.2 Communication Network Requirements for PVITS

The central technical requirements that should be satisfied by the communications network for PVITS are:

- Conforms to the IEN and PVITS system architecture
- Adequate bandwidth for LCC wide area network to field devices
- Adequate bandwidth for center-to-center communication among LCC, Subregional TMC and the LA County TMC.
- Ability to access the system from any LCC, Subregional TMC and the LA County TMC.
- Video standards supported for full motion full color video transmission
- Error free transmission of data
- Use of open (non-proprietary) video standards, such as MPEG2, and therefore, it can interface multiple vendor equipment available
- Geographic expandability
- Transmission capacity expandability (50%)
- High network service reliability
- Remote user access from locations outside of a LCC/Subregional TMC (e.g. from laptop computer users)

Each of the communication alternatives is evaluated for PVITS application against the above criteria, and a summary is provided in **Table 5.2**, with discussions of each technology evaluation provided in the following section.

5.3 Alternatives Evaluation

5.3.1 Leased Telecommunication Services

A leased communication network conforms to all the network technical requirements. It can be used for both field-to-center communication and center-to-center communication. The greatest advantage of leased services is that it does not require a high capital cost, although the annual operating costs would be higher than some of the other alternatives. (A full comparison of the costs of different alternatives are presented in Section 6.3) Another advantage of leased services is that the PVITS stakeholders do not have to bear the maintenance and service reliability responsibilities, as the telephone companies would be responsible for it.

One key concern with leased telephone services is that it has a very limited set of video transmission capabilities. Notably, these are either compressed video at a rate of 1.544 Mb/s (T1) or a rate of 45 Mb/s (DS3). A leased T1 line can support MPEG-2 or Motion JPEG, which is somewhat inferior in quality to VCR quality video. A 45 Mb/s line can provide very good quality video, but its costs are substantially higher. While some telephone companies may state that they would lease "dark fibers", Pacific Bell indicates that they would only lease channels, not fibers, because they will not allow other users to access their hubs and facilities for maintenance purposes.

Remote user access from locations outside of a LCC/Subregional TMC can be provided by suitable design of the LCC system with a dial-up connection to accommodate laptop computer access.

5.3.2 Analog Network Transmission

An analog communication network is a network utilizing a continuous, sinusoidal, energy wave. It is based upon the technology developed by the Bell System some 40 years ago. This type of network will not conform to several of the network technical requirements. These are:

- Adequate bandwidth for center-to-center communication –
  Center-to-center communication would be limited to use of channel banks which can support twenty-four(24) 56 kb/s data communication circuits plus a frequency division multiplexer for video which can support up to 32 analog video channels.
- Industry standard communication network interface –
  Communication interfaces are limited to the current set of standard interfaces such as RS232/422 or RS 485.
- Video transmission –
  There is very limited set of video transmission capabilities for analog services. Notably, these are either analog video at 6 MHz per channel or compressed digital video at a rate of 1.544 Mb/s.
- Transmission capacity expandability (50%) –
  Transmission capacity of an analog network is fixed. The only means to expand the network capacity is to install additional media and hardware.
- High network service reliability –
  An analog network is not highly reliable. As with any hardwire communication network, in the event of an equipment failure or cable cut, service is completely lost.
- Remote user access from locations outside of a LCC/Subregional TMC –
  An analog network, for the most part, furnishes a point to point service between a field device and the LCC. There is no provision for remote access.

5.3.3 SONET

A SONET communication network conforms to all network technical requirements. The degree of service reliability depends on the design. A well designed SONET network will include multipath redundancy that provides a high level of service reliability.

5.3.4 Asynchronous Transfer Mode (ATM) Transmission

An ATM communication network conforms to all the network technical requirements. It should be noted that the essential difference between SONET and ATM is that SONET transmission is dedicated channel (circuit) oriented and ATM is switching oriented (which means that electronic switches are used to route signals to the proper equipment in a mesh network). For an agency owned network, ATM may not be desirable because of the ease of installing and maintaining other types of technology that easily support multimedia applications (voice, data and video). It is worth noting that industry trends indicate privately owned wide area networks are moving away from ATM in favor of gigabit Ethernet.

5.3.5 Microwave Radio

A microwave radio communication network will not conform to several of the network technical requirements. These are:

- Error free transmission of data communication –

  Microwave radio networks are subject to partial loss of signal due to the signal "fading" between tower sites caused by rain, fog or misalignment of an antenna. This fading can cause various degradation of the communication transmission from the introduction of high bit error rates to complete loss of transmission.
- High network service reliability –

  A microwave network can be designed to be reliable with the development of extra communication paths so as to create a ring network topology. However, it may necessitate the construction of additional radio towers that might not be strictly needed for PVITS network purposes.
- Open communication network interface –

  Communication interfaces are limited to the current set of standard communication interfaces.
- Video standards –

  There is limited set of video transmission capabilities for microwave services. Notably, these are either analog video at 6 MHz per channel, compressed digital video at a rate of 1.544 Mb/s or 45 Mb/s. If 45 Mb/s is selected as the compression rate, this may necessitate a design option for the installation of a SONET transmission microwave system. If this is the case, obtaining FCC approval is conjectural because the applicant would have to demonstrate need as well as high utilization of the system capacity.
- Transmission capacity expandability (50%) –

  Transmission capacity of a microwave network is fixed. The only means to expand the network capacity is to install additional sets of radio system hardware.
- Remote user access from locations outside of a LCC/Subregional TMC –

  Remote access is not possible with microwave communications.

5.3.6 Spread Spectrum

A spread spectrum radio communication network will not conform to several of the network technical requirements. These are:

- Error free transmission of data communication – Depending upon the frequency spectrum selected, spread spectrum radio network may be subject to partial loss of signal due to signal "fading" between antenna sites caused by rain, fog or misalignment of an antenna.
- High network service reliability – Spread spectrum radio network reliability is limited to the mean time between failure performance of the network equipment. In the event of an equipment failure, service is completely lost to that network segment.

- Remote user access from locations outside of a LCC/Subregional TMC – A spread spectrum radio network, for the most part, furnishes a point to point service between a field device and the LCC. There is no provision for remote access.
- Transmission capacity expandability (50%) – Transmission capacity of a spread spectrum radio network is fixed. The only means to expand the network capacity is to install additional media and hardware.

5.3.7 Gigabit Ethernet Transmission

A Gigabit Ethernet communication network has the capability to conform to all the technical requirements for support of the PVITS communication network. The service reliability, which is similar to that of a SONET network, depends on the design. However, unlike SONET, the availability of discrete Gigabit Ethernet links may be available for lease from the operating telephone company so as to furnish the desired network topology and subsequent reliability.

Table 5.2 Evaluation of Communication Alternatives for Application to PVITS

Evaluation Criteria for PVITS	Leased	Analog	SONET	ATM	Microwave	Spread Spectrum	Gigabit Ethernet
Conforms to the IEN and PVITS system architecture	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adequate bandwidth for LCC wide area network to field devices	T1 for video is acceptable	Yes	Yes	Yes	Yes, but impractical	Limited to T1 for video	Yes
Adequate bandwidth for center-to-center communication among LCC, Subregional TMC and the LA County TMC.	Yes	Limited	Yes	Yes	Yes, with line of sight established	No	Yes
Ability to access the system from any LCC, Subregional TMC and the LA County TMC.	Yes	Yes	Yes	Yes	Need line of sight transmission	No	Yes
Video standards supported for full motion/full color video transmission	MPEG-2 Compressed to 1.5 Mb/s	NTSC	MPEG-2 Compressed to 1.5 Mb/s	MPEG-2 Compressed to 1.5 Mb/s	MPEG-2 Compressed to 1.5 Mb/s	MPEG-2 Compressed to 1.5 Mb/s	MPEG-2 Compressed to 3 Mb/s
Error free transmission of data	Yes	Yes	Yes	Yes	No	No	Yes
Use open video standards	Yes	Limited to analog video	Yes	Yes	Yes	Yes	Yes
Geographic expandability	Yes	With more capital investment	With more capital investment	With more capital investment	No	With more capital investment	With more capital investment
Transmission capacity expandability (50%)	Yes	No	Yes, provide spare fibers	Yes, provide spare fibers	No	No	Yes, provide spare fibers
High network service reliability	Very good reliability	Not fault tolerant	With suitable design	With suitable design	Fair	Fair	Yes
Remote user access from locations outside of a LCC/Subregional TMC (e.g. from laptop computer users)	With suitable design for dial-up	No	Remote users need to connect to system	Remote users need to connect to system	No	No	Remote users need to connect to system

6.0 RECOMMENDATIONS

6.1 Background

Seven communications technology alternatives have been identified as candidates for the Pomona Valley Forum's Intelligent Transportation system (PVITS). This section provides a detailed discussion on each alternative, and recommends the most viable technology to be utilized.

6.2 Communication Alternatives Screening

Due to the deficiencies listed under Section 5.3, analog, microwave radio, spread spectrum radio and CDPD Radio are not considered viable candidates to be the principal transmission technology for the PVITS communication network. However, from a technical point of view, the principal transmission technology for the communications network could be comprised of one of the other 4 alternatives (leased services, SONET, ATM or Gigabit Ethernet technology), or a combination of these technologies.

Nevertheless, the selection of a specific technology should weigh the ease of implementing a technology, ease of maintenance, and most importantly, cost. To this end, the four remaining candidate transmission methods are further evaluated in detail for identification of a preferred communication strategy. This examination should consider the ability to manage and control a network, modifying or enhancing a network as well as the ease of training staff to support the network. This is summarized below and a cost comparison is provided in Section 6.3.

6.2.1 Leased Network

A leased network will be relatively easy to install and has low capital cost. There will be no need for any network management capability from the PVITS stakeholders, as the service reliability and maintenance is the responsibility of the leased service provider. Use of leased services will have the least operation and maintenance staffing requirements for the stakeholder agencies when compared to the other alternatives.

From a technical perspective, the most significant issue in leasing network service is the limitation of video transmission. The lease line services offered by telephone companies have a significant gap in their bandwidth. The choice is either a 1.544 Mb/s (T1) or 45 Mb/s (DS3) service. Transmission at T1 speed would require compressed video, which leads to a relatively limited, but possibly acceptable quality of video. It is worth noting that a number of transportation agencies are using T1 video transmission, such as New York Department of Transportation, Massachusetts Department of Highways, and Caltrans District 12. On the other hand, from a video quality perspective, DS3 can provide a very high quality of full motion, full color video. It is, however, very expensive. (Typically, DS3 lines costs over 12 times that of T1). Video transmission quality is a purely subjective matter and it is considered adequate for PVITS operators to view compressed video transmitted over T1 lines.

The cost estimate for leased service in this study presumes the use of T1 service for video communication between CCTV cameras to the LCC, and DS3 service among operations centers so as to support simultaneous viewing of multiple sessions of video surveillance transmission as well as access to multiple traffic control devices.

6.2.2 *SONET Network*

As discussed in Section 5.3, SONET technology meets all the technical criteria for a PVITS communications network. Although SONET has high reliability characteristics, these characteristics are dependent upon the construction of a physical ring topology that provides redundancy. If this technology is selected, the design must take into account the need to develop a physical ring that could significantly increase the capital cost of an agency owned network.

6.2.3 *ATM Network*

ATM technology also meets all the technical criteria for the PVITS communications network. However, it should be noted that basic ATM devices are a switched technology as opposed to the point-to-point circuit technology of SONET. Switching oriented technology features the temporary establishment and then relinquishment of a circuit connection for routing of communications traffic. Therefore, in order to achieve a high reliability network, it would be necessary that each switch be connected to all other switches so as to develop a mesh topology for routing of communication traffic. This will mean a significantly more complicated infrastructure and possibly excessive construction costs if applied to PVITS. Also, even more noteworthy, ATM technology is on the decline for the development of privately owned wide area networks because it is being supplanted by a more cost-effective technology known as Gigabit Ethernet.

6.2.4 *Microwave*

As discussed in Section 5.3, microwave does not meet many of the technical criteria for the PVITS network. It is not suitable for field-to-center communications because of the local distribution problems and costs associated with microwave radio transmission. The only potential practical application of microwave technology in the PVITS network may be connecting some center-to-center communications. For example, the communication link between the Subregional TMC and the LA County TMC in Alhambra may not require the same level of service reliability as from a LCC to the local field elements, and a temporary disruption of service may not have a great impact to the overall operation of PVITS. However, LA County would still rely on this link to access its field equipment. Therefore, microwave is not considered a feasible alternative for PVITS.

6.2.5 *Gigabit Ethernet Network*

Gigabit Ethernet technology meets all the technical criteria for the PVITS communications network. From a technical perspective, Gigabit Ethernet is by and large a switched technology. However, unlike ATM, it does not require that each switch be connected to all other switches to form a mesh network for providing a high level of reliability. Network topology can be consistent with a ring topology, which means a smaller infrastructure and lower cost. The most notable aspects of the use of Gigabit Ethernet technology for the PVITS network is the simplicity of the network architecture and the abundance of devices that could easily interface to an Ethernet network. Moreover, since Ethernet is an almost ubiquitous technology in the office LAN environment, there are numerous personnel who can easily be trained to maintain it.

6.3 Cost Evaluation

Two principal components comprise the economic view of the communication costs:

- the estimated capital expenditure, and
- the estimated operations and maintenance "life cycle" cost.

The annual operations and maintenance (O & M) costs are estimated based on an industry-wide planning level approach of :

- 15% of the capital cost for electronic equipment
- 2% of the capital cost for optical fiber infrastructure (conduits, cables, etc.)

The life cycle O&M costs has been estimated over 10 years, since this is the average life cycle of modern communications equipment.

Estimated costs of the various communication alternatives are presented in **Table 6.1**.

Table 6.1 Ten-year Life Cycle Estimated Communication Costs

Communication Alternative	Estimated Capital Cost	Estimated O&M Life Cycle Costs	Life cycle Capital and O & M Cost
Leased	$ 4M	$12.2M	$ 16.20M
Analog	$14.5M	$2.8M	$ 17.30M
SONET	$16.1M	$8.0M	$ 24.10M
ATM	$17.3M	$9.9M	$ 24.10M
SONET Microwave Radio	$16.5M	$9.3M	$ 25.80M
Spread Spectrum Radio	$13.5M	$8.9M	$ 22.40M
Gigabit Ethernet	$15.3M	$6.3M	$ 21.60M

It can be seen that the "Leased Service" alternative has the lowest capital cost, and lowest overall 10-year life-cycle cost. While this analysis indicates that leased service should be favored from the cost perspective, it should be noted that some infrastructure built for the other alternatives, such as the conduit system and fiber optic cables, would last much longer than the 10 year life cycle adopted for electronics equipment. Therefore, many agencies still prefer to build their own dedicated fiber optic networks.

6.4 Communications System Recommendation

From an economic perspective, the selection of a leased network is logical. Although there are limitations on video transmission quality, the significant cost differences between the leased network alternative and others makes it the desirable alternative.

For the agency owned network alternatives, although they have a higher life-cycle cost, another aspect to be considered is the useful life of an optical fiber infrastructure. Although the average use life for communications electronic equipment is 10 years, the optical fiber infrastructure has a useful life of 35 to 40 years. Consequently, the amortization of these funds can be spread over a longer period of time.

Among the agency owned network alternatives, SONET and ATM technologies are technically sound, but the implementation of these type of networks will necessitate the construction of an underground conduit infrastructure which will incur a substantial capital cost. Additionally, construction of either of these networks as currently envisioned would not ensure all of their technical capabilities are being utilized without expenditure of additional funds to develop a "ring" or "mesh" physical topology for redundancy. Therefore, this diminishes the desirability of these candidate alternatives. Additionally, the need for development and retention of a technically sophisticated maintenance staff for these technologies would likely be a continual challenge for the Pomona Valley stakeholder agencies.

The next most viable alternative when considering the ease of development and potential for utilization of the network by stakeholders for applications beyond transportation, would be the Gigabit Ethernet technology. Although this technology has a high capital cost, it has the best potential to satisfy all requirements of PVITS stakeholders as well as the architecture and protocols of the transportation sector. Besides, maintenance staffing for this technology should be less demanding than SONET or ATM, since Ethernet is the prevailing technology for standard office LANs, so existing office LAN maintenance staff would be able to maintain the ITS network as well.

With regard to the development of an agency owned communication network, one key consideration for the PVITS stakeholders is maintenance. The municipalities within the Pomona Valley Forum will need to hire maintenance staff or outsource to maintenance contractors for routine maintenance of the network infrastructure, including the conduits, fiber optic cables, and all electronics equipment. This is a long-term commitment. The decision to develop an agency owned network should be made only if the municipalities jointly commit to support the long-term maintenance of the network.

Therefore, the recommendation of this study is as follows:

- Leased service for field-to-center communications
- For center-to-center communications, two recommendations are made. If the municipalities of Pomona Valley Forum agree to jointly maintain an agency owned network, then it is recommended to develop a Gigabit Ethernet network for the principal communication among control centers, and for logical routes that are adjacent to the mainline trunk that may have a large number of CCTV cameras. If the municipalities do not wish to commit to a long-term maintenance responsibility for the network, then leased service should be used for center-to-center communications as well.

This recommendation will lead to development of a conceptual communication network design, which will be presented in a separate report.

LIST OF ACRONYMS

ACE	Alameda Corridor East Construction Authority
ATIS	Advanced Traveler Information System
ATMS	Advanced Traffic Management System
b/s	Bits per second
Caltrans	California Department of Transportation
CAMS/IEN	Los Angeles County Countywide Arterial Management System/ Information Exchange Network
CCTV	Closed Circuit Television
DMS	Dynamic Message Sign
giga	Billion
ITS	Intelligent Transportation System
kb/s	Kilo (Thousand) bits per second
LA	Los Angeles
LACDPW	Los Angeles County Department of Public Works
LACMTA	Los Angeles County Metropolitan Transportation Authority
LAN	Local Area Network
LCC	Local Control Center
LCMOS	Local City Monitoring Only Site
Mb/s	Mega (Million) bits per second
MPEG-2	Moving Picture Experts Group Standard – Second Generation
MOU	Memorandum Of Understanding
NTCIP	National Transportation Communications for ITS Protocol
NTSC	National Television System Committee Standard
O&M	Operations and Maintenance
PC	Personal Computer
PTZ	Pan, Tilt and Zoom
PVITS	Pomona Valley Intelligent Transportation System
TMC	Traffic Management Center
TOD	Time-of-Day
UFR	User Functional Requirements

UIR	User Interjurisdictional Requirements
UOR	User Operational Requirements
USR	User Supplementary Requirements
WAN	Wide Area Network
WWV	National Institute of Standards and Technology Time & Frequency shortwave radio station that broadcast accurate real time