Freeway Management System (FMS)

Communications Master Plan

For the Phoenix Metropolitan Area

August 2010

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1 EXECUTIVE SUMMARY

This Arizona Department of Transportation (ADOT) Freeway Management System (FMS) Communications Master Plan document was created as part of the solution to address issues of technology compatibility, upgrades to obsolete infrastructure and equipment, as well as integration of existing technology with new equipment deployments for the Phoenix Metropolitan Area. This FMS Communications Master Plan focuses on Node-to-TOC and Field-to-Node FMS communications. Node-to-TOC FMS communications is the communications infrastructure between the ADOT communications Node Buildings and the ADOT Traffic Operations Center (TOC); and Field-to-Node communications is the communications infrastructure between the Intelligent Transportation Systems (ITS) device cabinets along the freeways and the ADOT communications node buildings along the freeways This document also includes recommendations for adding the Alternate Traffic Operations Center (ATOC) into ADOT's Node-to-TOC communications backbone to facilitate managing freeway traffic operations from a location other then the TOC during an emergency event that limits the operational capacity of the TOC.

The focus of this FMS Communications Master Plan is on improving the operational performance and maintainability of existing and future ADOT FMS communications infrastructure. This FMS Communications Master Plan does not address the implementation of Center-to-Center connections between ADOT and other agencies and jurisdictions. Center-to-Center connections facilitate the exchange of data and information to advance the region's ability to achieve multi-agency coordination that is needed to support transportation, public safety, emergency response, Amber Alert and Homeland Security efforts within the region. The Regional Community Network (RCN) Feasibility Study and RCN Design Concept Reports have been adopted by ADOT as the primary method in achieving multijurisdictional Center-to-Center communications within the Phoenix Metropolitan Area. The integration of ITS applications between multiple jurisdictions is another area not addressed within this report as this has been addressed in the AZTech™ Transportation and Public Safety Center-to-Center Needs Assessment and Concept of Operations report developed by MCDOT and the AZTech™ regional partners, including ADOT.

ADOT FMS communications infrastructure must provide sufficient bandwidth for FMS and associated network applications between the TOC and ATOC, along with support of the FMS devices. Considerations must be evaluated for sizing the system to meet today's bandwidth requirements, along with future needs. Addition of cameras, Dynamic Message Signs (DMS), detector stations, and ramp meters, along with future ITS operational technologies must all be part of the assessment process for determining the appropriate bandwidth of the system.

A 10 Gigabit Ethernet multi-ring topology was chosen for the ADOT FMS Node-to-TOC communications which provides both a high bandwidth network that will meet existing and future needs and will also meet the network reliability and redundancy requirements. The proposed 10 Gigabit Ethernet infrastructure will also reduce the number of backbone fiber strands needed for Node-to-TOC communications, freeing up valuable backbone fibers for other applications. This technology will be used to replace existing Node-to-TOC technologies on the ADOT FMS such as Frequency Division Multiplexers (FDM) and Course Wave Division Multiplexers (CWDM).

During the development of this report, ADOT has made significant progress deploying the 10 Gigabit Ethernet multi-ring communications backbone topology. This Communications Master Plan recommends that the node-to-ATOC communications between the Node Buildings and the ATOC facility be established using the same 10 Gigabit Ethernet communications backbone being established for the Node-to-TOC communications.

Currently the ADOT FMS infrastructure for Field-to-Node communications consists of several types of communications media to include single-mode fiber cable, multi-mode fiber cable, and twisted-pair copper cable. It is the recommendation of this Communications Master Plan that the old twisted-pair copper infrastructure along with the multi-mode fiber infrastructure be replaced with single-mode fiber cable in the near future. The twisted-pair copper cable has been proven to be unreliable over the past several years because this aging infrastructure has surpassed its usable life. The existing multi-mode fiber optic cables have limited deployment areas and have sufficient capacity to only serve a single application (i.e., Field-to-Node Closed Circuit Television (CCTV)). This is an additional burden on ADOT maintenance staff and adds maintenance cost due to the need for shelf-ready spare equipment/cables. The single-mode fiber optic cables have proven to be extremely reliable, can support all Field-to-Node and Node-to-TOC/ATOC communications topologies, and will continue to be the communications media choice for the future.

Network reliability is another important requirement of the ADOT FMS. Network reliability is important to ensure that the required communications connections are available at all times. The most effective way to achieve network reliability in a communications system is by adding redundancy. A new type of topology called the Hybrid Flower topology is recommended as the new FMS standard for Field-to-Node communications. The Hybrid Flower topology is recommended to be deployed for future FMS phases and when replacing existing infrastructure that has reached the end of its usable life.

The Hybrid Flower topology will provide Ethernet switching capabilities at the cabinet level, allowing video encoders and serial servers to be deployed in the field, eliminating the need for Video Optical Transceivers (VOTRs) and Optical Transceiver Self Healing (OTR/SH) configurations in the field cabinet and at the Node Building. The Hybrid Flower topology also provides Field-to-Node redundancy in areas where only one fiber cable exists on one side of the freeway. This architecture is compatible with the new Ethernet backbone equipment at the Node Buildings as well as at the TOC, and is also compatible with the existing video decoders at the TOC.

The Hybrid Flower topology reduces the number of fibers needed for field-to-node applications, which will free up existing backbone fibers. This is especially true for the Ethernet video circuits. Currently, each video camera is running on its own dedicated fiber back to a Node Building. With the Hybrid Flower topology, the video signal for multiple cameras is sent in two directions on two shared fibers, thus freeing up point to point fiber for other uses.

The new ADOT communications standards, identified within this migration plan, will deploy Ethernet switches at the cabinet level, transmit video and data in two directions to two different Node Buildings and ultimately transmit from the Node Building to the TOC via the 10 Gigabit Ethernet ring, providing layers of redundancy, giving ADOT a state of the art IP network.

The more expensive areas for this type of deployment will be where twisted wire pair cable needs to be removed and replaced with fiber optic cable. Twisted wire pair cable still exists along I-10 between 83rd Avenue and SR 51. A joint venture project between the City of Phoenix and ADOT will soon be constructed that installs an ADOT owned 144-fiber cable on one side of the I-10 corridor in this area. It is recommended that ADOT adds a 144-fiber backbone cable on the opposite side of the I-10 highway to complete their fiber optic backbone cable needs along I-10 between 83rd Avenue and SR 51. The Segment 1 and 2 cost breakdown, that has been provided in this report, includes the cost of installing this 144-fiber cable, adding new 12-fiber branch cables between the field cabinets and the backbone fiber cable, and upgrading cabinet equipment to accommodate the Ethernet switches and supporting electronics.

For this migration plan, existing fiber cable infrastructure will be utilized in Segments 3-15, where the bulk of the expense will be re-splicing the existing fiber backbone to the branch cables for the new Hybrid Flower topology Field-to-Node communications standard and upgrading field cabinets with Ethernet switches, video encoders and serial to Ethernet servers. The cost estimates provided in Section 10.2 detail segment by segment estimated costs for upgrading ADOT existing Field-to-Node communications infrastructure to the new ADOT FMS standard. Because ADOT has made significant progress building their new 10 Gigabit Ethernet Node-to-TOC communications infrastructure, these Field-to-Node communications upgrades can be done in phases, segment by segment. It is recommended that the areas that have existing TWP cable be upgraded first (Segments 1, 2, and 3). Segments that have only one fiber cable on one side of the highway should be completed next, which includes, Segments 4, 7, and 8 along with sections of Segments 5 and 6.

This migration plan provides a blueprint for future FMS communications infrastructure build-out, and the new Ethernet based Hybrid Flower topology for Field-to-Node communications that will ultimately be more cost effective, reliable and technologically current than previous deployment methods.

2 INTRODUCTION

As part of the Loop 101 (Pima) FMS project, ADOT has determined that the current FMS Communications Master Plan was outdated and not sufficient to use as part of the contract documents to guide perspective designers and contractors on how to construct the communications infrastructure needed to support ADOT's FMS devices.

In recent Maricopa Association of Government meetings with the Intelligent Transportation System Committee, ADOT's regional partners have made requests for ADOT to update their FMS Communications Master Plan to facilitate improved traveler information sharing capabilities between ADOT and its regional partners.

The update to the FMS Communications Master Plan is necessary for ADOT to move forward in deploying FMS communications infrastructure components that are comprised of the most current technology selection decisions, that are cost-effective, provide a level of consistency to reduce ADOT's maintenance requirements, and deploy FMS infrastructure components to achieve an optimum level of operation while reducing re-work that may be required during future freeway expansion projects.

The primary goal established for this ADOT FMS Communications Master Plan project is to achieve a future vision of what ADOT needs to accomplish over the next several years to improve the operationally critical FMS communications infrastructure. The primary focus of this report is on the following:

- **Field-to-Node FMS communications** which is the communications infrastructure between the ITS devices cabinets along the freeways and the ADOT communications Node Buildings along the freeways;

- **Node-to-TOC FMS communications** which is the communications infrastructure between the ADOT communications Node Buildings and the ADOT TOC; and

- **Node-to-ATOC FMS communications** which is the communications between the Node Buildings and an ATOC that would be used to manage freeway traffic operations from a location other then the TOC during an emergency event that limits the operational capacity of the TOC.

This FMS Communications Master Plan does not address the implementation of Center-to-Center connections between ADOT and other agencies and jurisdictions. Center-to-Center connections facilitate the exchange of data and information to advance the region's ability to achieve the multi-agency coordination that is needed to support transportation, public safety, emergency response, Amber Alert and Homeland Security efforts within the region. The Regional Community Network (RCN) Feasibility Study and RCN Design Concept Reports have been adopted by ADOT as the primary method in achieving multijurisdictional Center-to-Center communications within the Phoenix Metropolitan Area. The integration of ITS applications between multiple jurisdictions is another area not addressed within this report because this has been addressed in the AZTech™ Transportation and Public Safety Center-to-Center Needs Assessment and Concept of Operations report developed by MCDOT and the AZTech™ regional partners, including ADOT.

This project will provide the necessary updates to the previous SONET Communications Master Plan that was created in 1999 as well as provide standards for how ADOT's regional partners will interconnect into ADOT conduit and fiber optic infrastructure backbone.

3 BACKGROUND

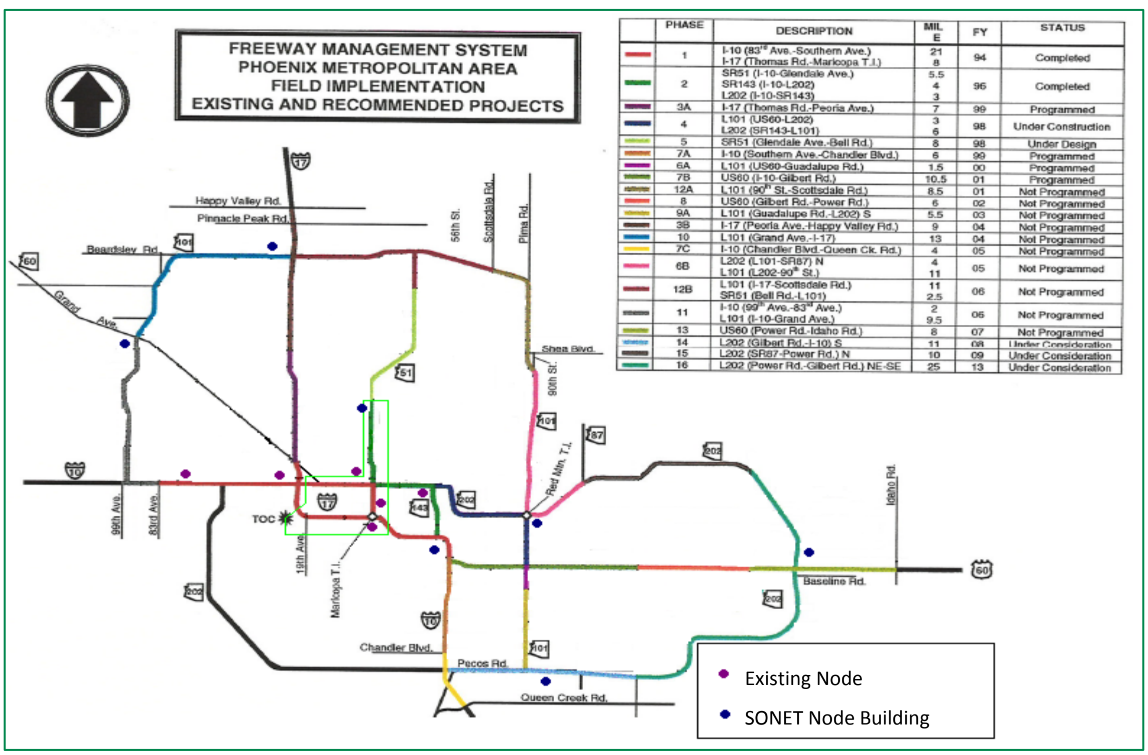
ADOT FMS Communications have been in existence for over 14 years. Since inception of the FMS, ADOT has deployed a variety of different types of technologies to transmit data from the field device cabinet locations back to the TOC, via the Node Buildings. As technology has advanced dramatically in the past 14 years, ADOT's FMS communications infrastructure requirements must be reassessed to ensure the existing networks can continue to support ADOT's current and future FMS needs. This section outlines the history of the ADOT FMS Communications, as well as, documents current conditions that will serve as a baseline for evaluating existing infrastructure and standards vs. current FMS communications needs and requirements.

3.1 Summary of SONET Communications Master Plan (1999)

The Synchronous Optical Network (SONET) Communications Master Plan was created in 1999 to serve as a guide to assist the expansion of the Phoenix Metropolitan Area FMS. The Plan outlined the ultimate goal of establishing a SONET backbone fiber ring along the outer loop of the freeway system and slower speed interworking rings that would connect the backbone to the nearest SONET node location. This goal would be accomplished in a series of phases that when complete, would provide the ability to send FMS field data obtained throughout the Phoenix Metropolitan Area to and from the TOC. As stated in the SONET Communications Master Plan, the nodal placement was obtained by using the following criteria:

- Distance between SONET nodes less than 35 miles;
- Distance from any camera to a SONET node less than 18 miles;
- Convenient tie-in to other TOCs per the AZTech Model Deployment Initiative;
- Order of planned FMS phases; and
- Backbone cable utilizing single-mode fiber with not more than .35 dB/km attenuation at 1310 nm.

Figure 3-1 illustrates the original SONET Communications Master Plan and shows the nodes and the deployment phases of the ADOT FMS program.



	PHASE	DESCRIPTION	MILE	FY	STATUS
	1	I-10 (83rd Ave.-Southern Ave.) I-17 (Thomas Rd.-Maricopa T.I.)	21 8	94	Completed
	2	SR51 (I-10-Glendale Ave.) SR143 (I-10-L202) L202 (I-10-SR143)	5.5 4 3	96	Completed
	3A	I-17 (Thomas Rd.-Peoria Ave.)	7	99	Programmed
	4	L101 (US60-L202) L202 (SR143-L101)	3 6	98	Under Construction
	5	SR51 (Glendale Ave.-Bell Rd.)	8	98	Under Design
	7A	I-10 (Southern Ave.-Chandler Blvd.)	6	99	Programmed
	6A	L101 (US60-Guadalupe Rd.)	1.5	00	Programmed
	7B	US60 (I-10-Gilbert Rd.)	10.5	01	Programmed
	12A	L101 (90th St.-Scottsdale Rd.)	8.5	01	Not Programmed
	8	US60 (Gilbert Rd.-Power Rd.)	6	02	Not Programmed
	9A	L101 (Guadalupe Rd.-L202) S	5.5	03	Not Programmed
	3B	I-17 (Peoria Ave.-Happy Valley Rd.)	9	04	Not Programmed
	10	L101 (Grand Ave.-I-17)	13	04	Not Programmed
	7C	I-10 (Chandler Blvd.-Queen Ck. Rd.)	4	05	Not Programmed
	6B	L202 (L101-SR87) N L101 (L202-90th St.)	4 11	05	Not Programmed
	12B	L101 (I-17-Scottsdale Rd.) SR51 (Bell Rd.-L101)	11 2.5	06	Not Programmed
	11	I-10 (99th Ave.-83rd Ave.) L101 (I-10-Grand Ave.)	2 9.5	06	Not Programmed
	13	US60 (Power Rd.-Idaho Rd.)	8	07	Not Programmed
	14	L202 (Gilbert Rd.-I-10) S	11	08	Under Consideration
	15	L202 (SR87-Power Rd.) N	10	09	Under Consideration
	16	L202 (Power Rd.-Gilbert Rd.) NE-SE	25	13	Under Consideration

Figure 3-1: SONET Communications Master Plan Node Locations Recommendations in 1999

3.2 Summary of ATOC Feasibility Study

ADOT completed two relevant studies evaluating the establishment of an ATOC. The first was a feasibility study to define the operations of the center, discuss the necessity of the ATOC, and to consider several alternatives for the design of the ATOC. The second study was a project assessment that delved into the physical options of the ATOC location and assessed the advantages/disadvantages of each option. The following subsections summarize the findings of the ATOC studies.

3.2.1 *ATOC Feasibility Study (2003)*

The ATOC Feasibility Study (2003) focused on determining the essential functions of the ADOT TOC, assessing how the essential functions of the TOC might be compromised in a disaster, and discussed options for providing an ATOC that could relieve the duties of the TOC should a disaster inhibit the regular operations of the TOC. The study produced the following table reproduced as **Table 3-1** to summarize the critical and important functions of the TOC:

Table 3-1: TOC Critical and Important Functions

Critical Functions	Important Functions
Urban and Rural VMS Control	Traffic Signal Control
Camera Control	Tunnel Control
Traffic Surveillance (4 Full Motion Video Images Minimum)	Traffic Surveillance (16 Full Motion Video Images Minimum)
Radio Dispatching Functions	Automated Incident Logging
Telephone Communications	AZTech Multi-agency Coordination
Paging	E-mail Communications
Facsimile Communications	Traffic Video Feeds to Broadcast TV
Public Information Officer/Media Desk (PIO)	Road Weather Condition Monitoring
Monitor Television News Stations	
511 Automated Voice Response System	
AZ511.com Traffic Information Web-site	
Highway Condition Reporting System (HCRS)	
Emergency Operations Center (EOC) Operations	
Mass Evacuation and Quarantine Functions	

The study then predicted how the functions in **Table 3-1** are affected during a man-made or natural disaster. Two potential threat situations were examined. The first situation analyzed when only the TOC is affected, and the second situation examined when both the FMS and TOC infrastructure is affected. **Table 3-2** and **Table 3-3** summarize the results of the potential threat situations that were analyzed.

Table 3-2: Availability of Critical Functions with Different Failures

Critical Functions	TOC Operational	TOC Fail No ATOC	TOC FAIL With ATOC	TOC and Infrastructure Fail With ATOC
Urban and Rural VMS Control	Available	Impaired	Available	Impaired
CCTV and Camera Control	Available	Not Avail.	Limited	Impaired
Monitor TV Broadcast Stations	Available	Not Avail.	Available	Available
Telephone Communications	Available	Impaired	Available	Available
Radio Dispatching	Available	Not Avail.	Available	Available
Paging	Available	Impaired	Available	Available
EOC	Available	Not Avail.	Limited	Limited
Mass Evacuation	Available	Impaired	Available	Available
511	Available	Not Avail.	Available	Impaired
AZ511.com	Available	Not Avail.	Available	Impaired
HCRS	Available	Not Avail.	Available	Impaired
Media Desk	Available	Not Avail.	Limited	Limited

Table 3-3: Availability of Important Functions with Different Failures

Important Functions	TOC Operational	TOC Fail No ATOC	TOC FAIL With ATOC	TOC and Infrastructure Fail With ATOC
Traffic Signal Control	Future	Not Avail.	Available	Impaired
Ramp Meter Control	Available	Not Avail.	Available	Impaired
Tunnel Control	Available	Impaired	Available	Impaired
Traffic Detection	Available	Not Avail.	Available	Impaired
E-mail Traffic Alerts	Available	Not Avail.	Available	Impaired
Computerized Incident Log	Available	Not Avail.	Available	Available
Video Feeds to Broadcast TV	Available	Not Avail.	Not Avail.	Not Avail.

Finally, the study considered three plausible ATOC options with several viable communications alternatives. These ATOC options were:

- Local fixed ATOC (within Phoenix Metropolitan Area);
- Mobile ATOC; and
- Outlying fixed ATOC (e.g. Tucson).

The communications alternatives evaluated were:

- Microwave;
- Fiber optic;
- Leased DS-3 to/from a single node;
- Leased dual T-1 from each node; and
- Satellite.

The satellite and the dual T-1communication options were immediately ruled out due to their high recurring costs. A cost analysis of the other options is summarized in **Table 3-4**.

Table 3-4: ATOC Cost Analysis Summary

ATOC Option w/ Communications	Capital Costs ($k)		Annual Recurring Costs ($k)		Net Present Value ($k)
	ATOC	Comm	Maint.	Lease	10 yrs @ 5%
Mobile w/ Tracking Microwave	2,715	215	99	21	3,839
Local w/ Microwave	2,600	184	84	60	3,909
Local w/ Fiber Optic (1 mile)		192	85	60	3,923
Local w/ Leased DS-3		10	67	102	3,925
Outlying w/ Leased DS-3		10	67	135	4,174
Outlying w/ Microwave		690	135	63	4,823
Local w/ Fiber Optic (5 miles)		720	138	60	4,858

Several generalized recommendations were made on the two threat scenarios (man-made or natural disaster), consideration of the three ATOC options, the analysis of the existing FMS infrastructure, and the cost analysis above. The first recommendation was to implement the ATOC in phases. The first phase called for starting out with a reduced capability (light) version of the ATOC. Then, strategically add on features in later phases until the system is fully completed. The second recommendation was based on whether the local ATOC was located near the existing FMS communications infrastructure. If so, fiber optic communications were recommended for connecting the ATOC as a node on the backbone. If not, microwave communications were recommended from a secure node. If the ATOC is located in an outlying area, then option to lease DS-3 communications was recommended for connection from a secure node. The study did not recommend using a mobile ATOC due to size restrictions and communications costs and challenges; however, a further assessment of the feasibility of deploying a mobile ATOC along with fixed location ATOC options was performed two years later.

3.2.2 ATOC Project Assessment Report (2005)

A second study was released in 2005 that focused on assessing viable options for an ATOC. The study narrowed down the options by looking at the top candidate designs for the following options: a local ATOC option, an outlying ATOC, and a mobile ATOC. The top designs for each area are outlined below.

Local ATOC:

The local ATOC would be located on the northeast corner of 85th Avenue and Mountain View Road and share space with the City of Peoria TOC. The facility has the following key advantages:

- Convenient access by local trained staff;
- Dedicated fiber optic communications;
- Shared use of resources with the City of Peoria;
- Local telephone access; and
- Planned adequate space for an Emergency Operations Center (EOC) and conference facilities.

The final cost estimate for this option including mobilization costs, contingencies, and design was estimated at $3,011,926. This estimate was recomputed in 2010 using current pricing and was determined to be $2,025,082.

Outlying ATOC:

The outlying ATOC would be located under the I-10/I-19 interchange in Tucson where the future ADOT campus of facilities was proposed to be built. The ATOC would communicate with the Phoenix Metropolitan Area FMS via a leased DS-3 line. The facility has the following key advantages:

- Beneficial if urban damage is widespread and severe; and
- Local control of ADOT FMS resources in the Tucson area.

The final cost estimate for this option including mobilization costs, contingencies, and design was estimated at $1,788,392.

Mobile ATOC:

The mobile ATOC consists of a motor home style unit that would connect to the FMS network via microwave radio. The mobile ATOC has the following key advantages:

- Operate from multiple locations;
- Use at scene of emergencies;
- Communications capability identical to fixed site when used with docking station; and
- Possibility of furnishing docking station at multiple points.

The final cost estimate for this option including mobilization costs, contingencies, and design was estimated at $1,956,094.

No recommendations were made in this report regarding the most feasible option for the ATOC. However, a decision was made at a later date to move forward with the Local ATOC option in the City of Peoria.

3.3 Summary of IP Video Report (2003)

The IP video report was divided up into five main sections. The first section detailed the existing video management system (2003) and the advantages/disadvantages coinciding with the system. The basis of this section stated that the video equipment was becoming outdated and limited in availability. In addition, there was a lack of interoperability and connectivity to surrounding agencies. The second section detailed the mandatory and optional requirements necessary in an ideal IP video management system. Primarily, the table of requirements focused around a system that could be smoothly controlled and managed, a system that could function with the existing equipment, as well as, with future equipment, and a system that is interoperable with surrounding systems. **Table 3-5** outlines the IP Video Report Video System Requirements.

Table 3-5: IP Video Report (2003) Video System Requirements

ID	Category	Requirement	Mandatory or Operational
1	Video Distribution	All video outputs from the system to DPS, Web server, Real Networks video server, TOC operator workstations, TOC video wall monitors, and TV stations must meet the NTSC standard for analog video.	M
2	Video Distribution	All digital video outputs from the system to the Web server and TOC operator workstations must meet the MPEG-2 standard for video compression.	O
3	Video Distribution	The systems must be able to identify the video image being displayed either through overlaying of titles on analog video or special framing on digital video	M
4	Video Distribution	The ADOT logo must be superimposed on the video being distributed on TV stations such that the receiving stations cannot remove it.	M
5	Video Distribution	Provide external connectivity to a video recording device located at each TOC operator workstation either by a serial interface or by Ethernet.	M
6	Camera Control	The video management must be able to communicate and control all currently deployed CCTV cameras, motorized zoom lenses, pan/tilt units, and receiver/drivers.	M
7	Camera Control	The video management system must be compatible with the existing Javelin communications protocol and also provide multi-vendor interoperability for future CCTV deployments without the use of external communications protocol translation equipment.	M
8	Camera Control	The video management system must be capable of controlling multi-vendor proprietary CCTV equipment functions such as alarms, heaters, integration, wipers, etc.	O
9	Camera Control	Aside from the multi-vendor CCTV equipment support, the video management system must also work with third-party vendors such as those for video CODECs and Ethernet switches	M
10	Config. of Video System	The video management system must provide administration capabilities to allow configuring, programming, and managing the system.	M
10A	Config. of Video System	The administration system shall have selectable sequencing capabilities that allow TOC operators to select video signals from any CCTV camera connected to the system and display them for a specified time before moving on to the next video signal.	M
10B	Conf. of Video System	The administration system shall provide for the establishment of user priorities as determined by ADOT to define user access levels and to handle contention issues for control and display of video.	M
10C	Config. of Video System	The administration system must facilitate the log in and log out process for each TOC operator and other ADOT-approved personnel.	M
10D	Config. of Video System	The administration system must provide a user account management function using a COTS database program	M
10E	Config. of Video System	Configuration of the video device connections communications, and system performance data should be accomplished through the use of a logical GUI	M
11	Config. of Video System	Scalable architecture to accommodate current 384 x 80 needs, but expandable to 872 x 112 for future needs.	M
12	Config. of Video System	High-density, modular arrangement of video management system components to conserve rack space in the TOC Equipment Room	M
13	Config. of Video System	Video management system communications shall be as follows (as applicable): • Controller-to-Switch CPU: Connected via Ethernet standard or RS-232/RS-422/RS-485 standard interface • TOC Operator Workstation PC-to-Switch CPU: Connected via Ethernet standard or RS-232/RS-422/RS-485 standard interface • Switch CPU-to-Switch: Connected via internal wiring if integrated or via Ethernet standard. • Switch CPU-to-CCTV Camera Receiver/Driver: Connected via RS-232/RS-422/RS-485 standard interface • TOC Operator Workstation PC-to-Encoder/Decoder: Connected via Ethernet standard.	M
14	Config. of Video System	Where printed circuit boards are used, they are to be accessible either from the front or back of each card cage.	M
15	Config. of Video System	Where printed circuit boards are used, they are to be hot swappable, as applicable, to provide maximum uptime.	M
16	Config. of Video System	Where CPUs are utilized in video switches, they should have the option to be operated in a primary/secondary spare arrangement to provide maximum reliability.	O
17	Config. of Video System	Where the video management system uses the existing PCs located at the TOC operator workstations for control and display functions, its software applications must be functional with the Microsoft Window 2000 OS used by ADOT TTG.	M
18	Config. of Video System	Where the video management system used the existing PCs located at the TOC operator workstations for control and display functions, it shall operate with a commercially available video graphics card to display video on a PC monitor	M
19	Config. of Video System	Where the video management system software uses a dedicated server; it shall support client/server functionality to allow multiple TOC operator workstations to control the same video-related devices over the existing TOC LAN	M
20	Config. of Video System	Where the video management system software uses a dedicated server, the software shall support connectivity to the devices requiring control data through RS-232, RS-422, or RS-485.	M
21	Config. of Video System	Where the video management system utilizes input and output card cages with ribbon coaxial cable between the patch panel and PCB connectors, the accidental damage of one pin on the ribbon cable connections shall not require replacement of the entire card cage.	M
22	Operator Controls	A PC with mouse control of the CCTV camera must provide for the control of the PTZ, focus, iris, speed, and any other vendor-proprietary functions.	M
23	Operator Controls	Selection of CCTV camera control and viewing by the TOC operator workstation must be menu driven through a GUI on the PC monitor or controller LCD/LED display	M
24	Operator Controls	The video management system must be able to program and recall CCTV camera preset positions from each TOC operator workstation	M
25	Operator Controls	The video management system must allow the TOC operators to activate any pre-programmed sequences.	M
26	Operator Controls	The video management system shall support selection of video inputs and outputs from the TOC operator workstations in a graphical format.	M
27	Operator Controls	Selection of CCTV cameras in the field for control from each TOC operator workstation shall be performed using camera icons overlaid on a geospatially accurate map background.	M
28	Operator Controls	Routing of video from a specific CCTV camera to a particular video wall monitor or TOC operator workstation PC shall be accomplished by dragging the selected camera icon to the chosen display equipment icon.	M
29	Operator Controls	Allow TOC operator to change his/her video display on their workstation monitor between full-screen and quad viewing.	M

The third, fourth, and fifth sections of the report discussed three alternatives to adhere to the video system requirements, the cost of each alternative, and the advantages/disadvantages of each alternative, respectively. The first alternative was a full analog video solution. This alternative was the least expensive and required very little additional equipment, while still being able to meet the requirements. The second alternative contained both analog video and digital video. The analog signals would be fed to the Node Buildings where the signals were then digitally encoded and sent to the TOC. This alternative was significantly more costly ($1,170,000 as opposed to $200,000 for alternative 1) primarily due to the addition of video encoders/decoders. The third alternative contained only digital video. The video signal would immediately be converted to digital at the CCTV field cabinets and sent via Ethernet to the node and onward to the TOC. The third alternative was approximately $200,000 more expensive than alternative 2. The final recommendation was to choose alternative 1, since it met all mandatory requirements at the time the report was created, at a substantially lower cost and did not involve a significant change in technology which would have required more substantial staff training.

3.4 Summary of the FMS Project Assessment for Loop 101 Northeast (2006)

The Final Project Assessment developed by TransCore ITS, LLC. in March of 2006 documented communications infrastructure alternatives for the eventual FMS along Loop 101 (Pima) between I-17 and Loop 202 (Red Mountain). Primarily, the document looked at two phases, Phase 6B [from Loop 202 (Red Mountain) to Pima Road along Loop 101 (Pima)] and Phase 12A [North of Pima Road to I-17 along Loop 101 (Pima)] and how to establish Field-to-Node and Node-to-TOC communications. The assessment indicated that the following was needed to achieve full FMS deployment for Loop 101 (Pima):

- CCTV cameras at approximately one-mile spacing;
- DMS at approximately three-mile spacing by direction;
- Ramp meters (dual lane, constructed as part of standalone projects), integrated into the FMS as part of these projects;
- Ramp meters (dual lane, constructed as part of the respective FMS phase to fill in those ramp meters not included in standalone projects), constructed and integrated into the FMS as part of these projects;
- ADOT fiber optic cable (96-strand for the backbone and 12-strand branch cables);
- City fiber optic cable (96-strand for the backbone and 12-strand branch cables) in joint use conduit, where applicable;
- Load centers for equipment power, with the associated conductors, generally at one-mile spacing;
- New infrastructure (pull boxes and conduit), where needed;
- Rehabilitation of existing infrastructure where utilized; and
- Connection to the Traffic Interchange (TI) traffic signal controllers, where appropriate.

The Loop 101 (Pima) Project Assessment further evaluated Field-to-Node and Node-to-TOC communications alternatives. Two options were discussed for the Field-to-Node communications (1 - Serial Data/Analog Video, 2 - IP based data/video) and three options for the Node-to-TOC (1 - Serial Data/Analog Video, 2 – CWDM, and 3 - IP based data/video), although no recommendations were made.

The Loop 101 (Pima) Project Assessment looked at several options to implement the fiber optic network and ultimately concluded that the recommended option was to install the fiber on one side of the Loop 101 (Pima) within existing conduit. As documented in the assessment, the reasons for selecting this option were that this option provided relatively low initial costs, a quick implementation, moderate inventory work, and network redundancy. Although not documented in the Loop 101 (Pima) Project Assessment, "network redundancy" cannot be achieved with fiber on one side of the Loop 101 (Pima) unless ADOT moved forward with the IP based Field-to-Node communications option and either the IP based or CWDM based Node-to-TOC option.

3.5 Summary of the Loop 202 (Red Mountain) Design Concept Report (2007)

The Loop 202 (Red Mountain) Design Concept Report developed in June of 2007 gives the development, evaluation, and recommendation for providing additional general purpose lanes on Loop 202 (Red Mountain) from I-10 to Loop 101 (Pima). This Design Concept Report tabulated the existing FMS system elements along Loop 202 (Red Mountain) and recommended that the new FMS Design Guidelines allow three 3" conduits to be placed along one side of the freeway. Therefore, the recommendation was to abandon the conduits and fiber optic communications lines along the eastbound side of the freeway and only utilize the westbound conduits. The conduits at existing bridges were to remain and be reused.

The May 2009, FMS Design Guidelines states that "…trunkline conduits are required along both sides of the freeway…" and "single trunkline configuration will generally be limited to segments where communications redundancy is immediately available by means other than the second trunkline within the same corridor." This Loop 202 (Red Mountain) Design Concept Report did not address that the ADOT FMS was going to lose Field-to-Node and Node-to-TOC communications network redundancy by making the decision to abandon the conduit along the eastbound side of the freeway.

3.6 Existing Node Building Inventory

During the preliminary stages of preparing this Communications Master Plan, an inventory was taken at each Node Building so an accurate analysis of the system could be performed. The diagrams of the ADOT Node Buildings are included in **Appendix B** of this report.

4 SYSTEM ENGINEERING ANALYSIS

Following a system engineering approach is required by the Federal Highway Administration (FHWA) for ITS funding according to the Final Rule on ITS Architecture and Standards Conformity (CFR940) issued on January 8, 2001. This section describes how the various tasks completed within the FMS program map to system engineering, as shown in the "Vee" diagram in **Figure 4-1**. The goal of system engineering is to effectively define the goals and objectives of a project, define requirements of a project, design the system based on the requirements, test the system design, and install the design in a systematic and proven manner.

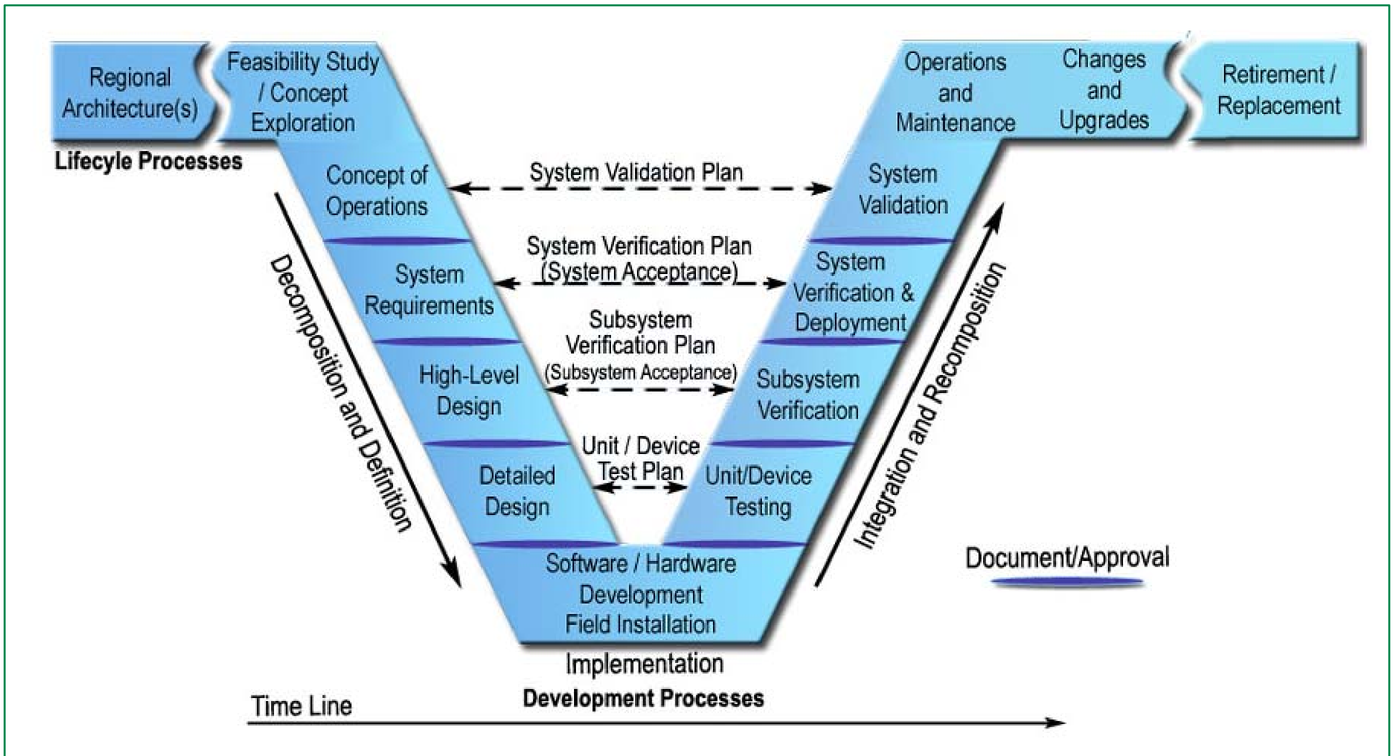


Figure 4-1: System Engineering "Vee" Diagram

4.1 Regional Architecture

The first step in the "Vee" diagram is to identify how ADOT's FMS fits within the overall regional ITS architecture for the Phoenix Metropolitan Area while keeping in mind operations and maintenance of the existing FMS infrastructure and the vision of expanding the geographical coverage area of the FMS. The current regional ITS architecture was developed by the Maricopa Association of Governments in 2009 and reflects the most updated status of IMS infrastructure interoperability. The goal of this step, as defined by the FHWA, is to produce the following information:

- List of project stakeholders and roles and responsibilities;
- List of inventory elements included in or affected by the project;
- List of requirements the proposed system(s) must meet;
- List of interfaces and the information to be exchanged or shared by the system(s); and
- Regional ITS architecture feedback as necessary.

The primary project stakeholders that have been identified for participation with the development of this FMS Communications Master Plan are ADOT TTG and ADOT District Maintenance. These two groups are the primary project stakeholders because they are ultimately responsible for additions, moves, and changes to the FMS communications infrastructure. The FMS network is not a regional communications network. The primary purpose of the FMS network is establishing communications between FMS field devices, FMS Node Buildings and the ADOT TOC and ATOC. When building FMS communications infrastructure, it has been ADOT's practice over the years to add additional capacity within ADOT FMS communications infrastructure (conduit and fiber) to support regional multi-jurisdictional communications initiatives like the RCN. This FMS Communications Master Plan address the needs/requirements for the FMS communications infrastructure to continue to support multi-jurisdictional communications while maintaining the security and reliability requirements of the FMS Field-to-Node and Node-to-TOC/ATOC network applications.

This FMS Communications Master Plan also covers the following other goals that are part of the "Regional Architecture Step" within the FHWA established Systems Engineering Analysis process:

- Provides an inventory of existing FMS communications elements and identifies how these communications elements need to be phased out due to reaching the end of their usable life cycle or how these elements will continue to play an important role within the FMS for the years to come;
- Provides requirements for the FMS communications infrastructure that the proposed system must meet; and
- Identifies interface requirements, interconnectivity topology alternatives, and capacity/bandwidth requirements/guidelines to support the exchange of information within the network.

4.2 Feasibility Study/Concept Exploration

The second step of the "Vee" diagram is the Feasibility Study/Concept Exploration. The goal of this step, as described by the FHWA, is to create a feasibility study that identifies alternative concepts and makes a business case for the project and selected concept. The feasibility study requires that alternative system configurations are explored and that different technology options are considered.

These aspects of the "Vee" diagram are handled in the FMS project in the development of the FMS Communications Master Plan. During the creation of the FMS Communications Master Plan, several system configurations are chosen and presented to the stakeholders involved. The considerations used in choosing a particular configuration include Center-to-Center connectivity, the use of existing infrastructure, and the cost of installing new communications media. Each system configuration has varying advantages over other topologies and configurations. The topologies and configurations explored will be described in Section 6 - Physical Network Topology Alternatives of this Communications Master Plan.

Different technology options are explored in the FMS Communications Master Plan in Section 7-Telecommunications Media Alternatives of this Communications Master Plan. Some of the technologies explored in this section are wireless options, satellite broadband communications, agency owned fiber, and leased-line technologies.

4.3 Concept of Operations

The Concept of Operations Step of the "Vee" diagram is intended to provide stakeholders with an understanding of the system to be developed and how it will be operated and maintained. The required outputs of this stage of the diagram, as stated by the FHWA, are as follows:

- Concept of Operations describing the who, what, why, where, and how of the project/system, including stakeholder needs and constraints; and
- System Validation Plan defining the approach that will be used to validate the project delivery, once the system has been developed and tested.

Much of the Concept of Operations portion of the "Vee" diagram is addressed within this FMS Communications Master Plan. The FMS Communications Master Plan addresses the specific project stakeholders and their needs and responsibilities as they apply to the FMS, what interconnections will be made between stakeholders, and the possible restrictions (geographic and otherwise) of the specific stakeholders.

Operations and maintenance will be handled by the various agencies involved in the FMS. It also states that both formal and informal agreements are in place to deal with operating and maintaining various sections of the FMS once it is operational.

4.4 System Requirements

This section provides a description of what the system will do, not how the system will do it. As described by the FHWA, the specific outputs of this stage of the "Vee" diagram are as follows:

- System Requirements Plan
- System Verification Plan
- Traceability Matrix
- System Acceptance Plan

The System Requirements Plan is intended to provide stakeholders with a plan of what the system will do without suggesting how it will be accomplished. This allows for the flexibility of different technologies to be used to address the same requirements and enhance the functionality of the systems engineering for expansion in the future. This portion of the "Vee" diagram is handled in the FMS Communications Master Plan by going into detail on the bandwidth requirements of the system. The goal of the FMS Communications Master Plan is not to recommend specific technologies and solutions, but to provide a general understanding of what is trying to be accomplished. The needs of the stakeholders are described in the FMS Communications Needs Assessment (Section 5) of the FMS Communications Master Plan.

The System Verification Plan and System Acceptance Plan are not part of this FMS document, but should be created before deployment to provide a method for verifying that system requirements are working, as well as, creating a list of capabilities that must function successfully to achieve customer acceptance. The traceability matrix described by the FHWA in their system engineering report applies mostly to software systems. For this reason, a traceability matrix will not be included in the FMS project at this time. A traceability matrix will be created when new software is chosen to run the ITS equipment involved with the FMS.

4.5 High-Level Design

The High-Level System Design section of the "Vee" diagram is where many of the system recommendations are made. The high-level design for the FMS occurs in the Standard FMS Network Requirements and Guidelines (Section 8) of the Communications Master Plan. This section provides a high-level description of the required functionality for each subsystem or user group level of the FMS and also defines how appropriate ITS standards are applied to the components of the FMS.

4.6 Detailed Design

The detailed design, as described in the "Vee" diagram, is not included as part of the initial conceptual planning of the FMS Communications Master Plan. The detailed design will be created after the completion of the Implementation Recommendations (Section 9). After the conceptual planning stage, a detailed design of what centers will be connected and how those connections will occur within the FMS should be created. The detailed design should also include Unit/Device Testing procedures, which is another section of the "Vee" diagram shown in **Figure 4-1**.

4.7 Software/Hardware Development/Field Installation

This is the stage of the "Vee" diagram that deals with the development and installation of hardware and software that follow the detailed design. The outputs, as stated by FHWA, are as follows:

- Software/hardware development plans;
- Hardware and software components, tested and ready for integration; and

- Supporting documentation (e.g., training materials, user manuals, maintenance manuals, and installation and test utilities).

Any development and/or installation of hardware or software that may be necessary based on recommendations of the FMS Communications Master Plan will be defined further during detail design.

4.8 Unit/Device Testing

Unit device testing is not part of this FMS Communications Master plan. As previously mentioned, the process for unit/device testing will be described in a future detailed design report. This report will ensure that subsystems that are added to the FMS, including the inclusion of new agencies, will not disrupt the network as a whole.

4.9 Subsystem Verification and Deployment

The objectives of this step, as defined by the FHWA, are to integrate and verify the system in accordance with the high-level design, confirm that all interfaces have been completed correctly, and to confirm that all requirements and constraints have been met. Subsystem verification will be accomplished each time a new agency connects to the FMS. This will ensure that the FMS continues to meet the system requirements of the stakeholders even as it expands to include new locations and future stakeholders or agencies. Because the verification and deployment phases are clearly after the conceptual planning stages, this step will be handled at a later date.

4.10 System Validation

The objective of this stage of the “Vee” diagram is to ensure that all of the requirements of the system are being met, particularly those pertaining to the concept of operations. As with the previous stage of the system engineering approach, this step will be handled further at a future date.

4.11 Operations and Maintenance/Changes and Upgrades

After the system has been designed, deployed, and validated, it is important for the system to be operated and maintained sufficiently so that the system can be in used for the course of its operational life. As part of the conceptual planning stage, it is recommended that an Operations and Maintenance guide be created for the FMS. This plan will include the agreed upon expectations of the Service Level Agreements (SLAs), the operations and maintenance expectations of each of the stakeholders, the required Joint Participation Agreements (JPAs), and a high-level estimate of the Operations and Maintenance budget.

This level of the “Vee” diagram also states that once the system is in operation, the various stakeholders should keep performance reports, operational logs, and maintenance records in order to ensure the operability of the FMS. This level of record keeping should allow for the determination of needed changes and upgrades.

4.12 Retirement/Replacement

The final section of the “Vee” diagram is intended to provide for stability while the system is taken out of commission. Although it is envisioned that the FMS will last for the foreseeable future, it will likely become a legacy system at some distant point. The objectives of this step are to gracefully terminate the system, or subsystems, and to properly dispose of or replace the components of the system. The effectiveness of this transition is measured by the required downtime of the system to facilitate the transition, resources necessary, cost, and temporary communications alternatives until the transition is complete.

This process is demonstrated by retiring the existing Frequency Division Multiplexers at the Node Buildings and upgrading the equipment to a 10 Gigabit Ethernet ring.

5 FMS Communications Needs Assessment

Before ITS communication infrastructure can be prioritized for ADOT, the issues, concerns, and challenges with the ADOT transportation communications system and the associated needs of the operators, maintainers, and users of the system must be understood. Needs are identified by collecting information from existing documents and inventory analysis, and supplementing that information with stakeholder input. ADOT TTG IT staff supported the collection of an inventory of the existing systems as well as assisted with conducting network needs meetings to understand the requirements for present and future needs of the ADOT system.

5.1 FMS Communications Needs

ADOT has implemented fiber infrastructure as well as ITS devices to be monitored and operated by the ADOT TOC. Standards of implementing the ADOT communications network need to be defined in order to maintain consistency throughout the network and facilitate efficient deployment of infrastructure as it is added to the system. There are specific needs that are addressed in this section related to the Field-to-Node network, Node-to-TOC network, and TOC-to-ATOC network communications. This section discusses the specific communications needs of ADOT and the need to support a wide range of FMS devices and applications.

5.1.1 FMS Conduit and Cable Infrastructure Needs

Communications conduit infrastructure includes the conduit paths and existing fiber cable that serves as a foundation for the recommendations of ultimate build-out provided in this document. ADOT has established FMS Design Guidelines for deploying a duct bank of conduits (three-3") for use by ADOT FMS when major freeway improvement projects are implemented. Communications cables are installed in these conduit pathways for connecting FMS field devices to Node Buildings, for connecting Node Buildings to the TOC, and for connecting the Node Buildings and TOC to the ATOC. Communications cable also support multi-jurisdictional interconnectivity of various agencies/departments within the Phoenix Metropolitan Area. When one agency's communications conduit and cable infrastructure joins to neighboring agency's communications conduit and cable infrastructure, the integrated system provides a direct communications path to connect neighboring agencies together. The following communications conduit and cable infrastructure needs have been identified for the ADOT FMS:

- Need a trunkline of three-3" conduits on both sides of all freeways. If an alternate communications conduit and cable path is available and the current adopted Field-to-Node and Node-to-TOC communications standards can be supported by the alternate communications conduit and cable path, then the deployment of a trunkline on one side of the freeway may be acceptable.
- Need to establish a standard approach for interconnecting ADOT FMS communications conduit and cable infrastructure with neighboring agency's communications conduit and cable infrastructure.
- Need to minimize the number of different types of communications cable technologies that are deployed in order to reduce maintenance and new implantation integration complexity of the FMS.

5.1.2 Traffic Signal System Conduit and Cable Infrastructure Needs

The traffic signals on the arterial roads, at the freeway interchanges, are not part of the FMS. Some of these traffic signals are maintained by a separate group within ADOT (i.e., not the Transportation Technology Group responsible for FMS operations) and others are maintained by the local jurisdiction which is responsible for the traffic flow along the arterial roadway system. Although not a direct component of the FMS, the FMS conduit and cabling communications infrastructure is needed to help these other entities obtain traffic signal system communications connectivity to the freeway interchange traffic signals and to other signals within the local entity's traffic signal system. The following summarizes the traffic signal system network needs for the ADOT FMS conduit and cable infrastructure:

- Need to provide a communications conduit and cabling path to the traffic signal controller cabinets at the freeway interchanges.

- Need to provide a communications conduit and cabling path within the FMS Field-to-Node infrastructure to support other agencies/groups ability to achieve traffic signal system interconnectivity of other traffic signals along the arterial roadways systems within the Phoenix Metropolitan Area.

5.1.3 FMS Field-to-Node Communications Needs

The largest need that ADOT faces as it plans to build out the FMS network involves migrating off of old aging communications technologies and standardizing new types of communications technologies that will be used for FMS Field-to-Node communications. ADOT currently has deployed CCTVs, DMS, freeway detector stations and ramp meters along the urban freeway system within the Phoenix Metropolitan Area. ADOT has partnered with local agencies to implement traffic signals at the freeway interchanges that need to be connected to the Node Building as part of the FMS Field-to-Node network. Currently, there are many aging communications technologies in use by ADOT that have reached the end of their lifecycle or are becoming obsolete in the current telecommunications market. The following is a summary of the FMS Field-to-Node communications subsystem needs.

<u>CCTV Subsystem:</u>

ADOT has installed 140 analog pan/tilt/zoom (PTZ) CCTVs along Phoenix Metropolitan Area freeways. CCTV cameras are used for verifying the results of traffic management strategies, such as ramp meter timing changes or work zone diversions, and for identification, verification and assessment of traffic incidents. Real-time CCTV images facilitate rapid response to incidents that affect traffic congestion and flow. CCTVs have also been used for verifying the conditions of a crash scene, resulting in more effective dispatching of emergency services and clearing of crash scenes. The Field-to-Node communications needs to support bringing these CCTV video feeds back to the ADOT Node Buildings where they are forwarded on to the TOC for operator viewing and the Field-to-Node communications needs to support PTZ type camera control communications to the camera device locations. Due to the critical role that CCTV has in the operations of the FMS deploying path diversity in the CCTV Field-to-Node network is a need that ADOT should consider making a priority. The following summarizes the CCTV Field-to-Node network needs for the ADOT FMS communications system:

- Need to support CCTV video and PTZ control and status communications from the field.
- Need to deploy redundancy (path diversity) for CCTV Field-to-Node communications.
- Need to share CCTV images with other agencies.

<u>DMS Subsystem:</u>

ADOT has installed DMS at strategic locations within the Phoenix Metropolitan Area FMS. DMS are a critical part of implementing traffic management strategies, for informing the traveling public of traffic incidents and for in route real-time travel times so the traveling public can make informed decisions of the routes they take. DMS are also used to communicate important information, such as Amber Alerts and High pollution advisories to the traveling public. As with CCTV, DMS plays a vital role in the real-time management of the Phoenix Metropolitan Area freeways. Path diversity in the DMS Field-to-Node network is a need that the ADOT FMS requires to reduce down time of these ITS devices. The following summarizes the DMS Field-to-Node network needs for the ADOT FMS communications system:

- Need to support DMS control and status communications.
- Need to deploy redundancy (path diversity) for DMS Field-to-Node communications.

<u>Detector Stations and Ramp Meters Subsystems:</u>

ADOT has installed detector stations and ramp meters along the Phoenix Metropolitan Area freeways. The detector stations collect real-time vehicle data to generate current travel speeds and occupancy that are used by the FMS for detecting incidents and communicating congestion information to the traveling public through web based speed maps, 511, and third-party applications. Due to the number of subsystems that depend on detector station data and the resulting highly-visible impact on the traveling public that these stations have on reducing freeway traffic congestion, Field-to-Node communications to these devices is a priority to the successful operation of the FMS. The ramp meters are used to control the flow of traffic on to the freeways which helps alleviate traffic congestion at the interchange ingress points. The ramp meters currently run on a time-of-day schedule which changes the metering rate based on mainline detection data unless they are traffic responsive. The ITS industry is moving toward a real-time approach for ramp metering which incorporates real-time traffic conditions and automatically adjusts the metering rates based on these real-time conditions. The real-time traffic data collected by both the ramp metering stations and the detector stations are a key component in the successful operation of real-time ramp metering. Therefore reliable Field-to-Node communications to both detector stations and ramp meters is also a future need that ADOT will have to optimize the ramp metering operation within the FMS. The following summarizes the detector station and ramp meter Field-to-Node network needs for the ADOT FMS communications system:

- Need to support detector stations and ramp meter control and status communications.
- Need to deploy redundancy (path diversity) for detector stations and ramp meter Field-to-Node communications.
- Need to verify existing detector station functionality and support replacement if needed.

Future ITS Subsystems:

New technologies will emerge in the future to enhance freeway management. The most prevalent initiative currently emerging is Intellidrive which is fostering research and applications development for a series of technologies directly linking road vehicles to their physical surroundings. Intellidrive solutions combine technologies, such as advanced wireless communications, onboard computer processing, advanced vehicle sensor technologies, and navigation systems to enable drivers to identify and avoid threats on the road as well as communicate more real time information to centers about road conditions. The success of the Intellidrive program is based on widespread deployment of a dedicated short-range communications links, of which the FMS Field-to-Node communications infrastructure will most likely need to support at some point in time. The Intellidrive program is just one example of future ITS technologies that the FMS may be called upon to help support and/or become an integral part of the overall operations of the FMS. Without knowing the specific nature of ADOT's FMS role in the successful deployment of new traffic management technologies or how future technologies will become an integral part of the FMS, the most effective way for ADOT to prepare for the future is to incorporate spare capacity within the FMS Field-to-Node communications infrastructure that can accommodate future initiatives.

- Need to identify and retain spare capacity within the FMS Field-to-Node communications infrastructure that can accommodate future technology deployments.
- Need to more efficiently use existing communications infrastructure to free up some spare capacity for future ITS applications.

5.1.4 FMS Node-to-TOC Communications Needs

FMS Node Buildings are collection points where multiple lower bandwidth communications circuits from the field device cabinet locations are merged into a larger bandwidth communications channel (also known as a communications backbone) for transport to the TOC, and eventually to the ATOC at some point the future. When a Node-to-TOC communications link goes down, the impact to the overall FMS operations is significant because it affects much greater geographical areas and multiple subsystems within this area. Since inception of the ADOT FMS in the Phoenix Metropolitan Area, there have been various generations of backbone communications technologies that have been deployed as part of the overall FMS infrastructure over the years. Due to the high bandwidth nature of these backbone communications technologies, the cost to deploy and maintain these technologies is significantly higher when compared to the lower bandwidth Field-to-Node communications technologies.

The following is a summary of the FMS Node-to-TOC communications needs:

- Need to maintain path diversity for Node-to-TOC backbone communications links.
- Need to phase out older backbone communications technologies that are becoming cost prohibitive to maintain and deploy.
- Need to make more efficient use of the cabling infrastructure that is being used to support Node-to-TOC backbone communications.

- Need to deploy Node-to-TOC backbone communications technologies that provide sufficient bandwidth for future ITS applications, without very expensive upgrades to the equipment.

5.1.5 FMS ATOC Communications Needs

Although the ATOC is not fully operational, ADOT needs to continue to plan for ways to achieve high bandwidth communications links to the ATOC facility for future ATOC operations. High bandwidth voice, video, and data communications are needed between the ATOC and the TOC for initial implementation of the ATOC. However this approach still keeps the ATOC highly dependent on communications to and from the TOC. If communications to and from the TOC were lost in the event of a disaster, then the ability of the ATOC to maintain FMS operations would also be lost. As such, the FMS communications infrastructure also needs to support node-to-ATOC direct communications that are completely independent of TOC communications.

Currently, the communications infrastructure is in place for leased communications to between the ATOC and TOC which will support the immediate ATOC communications needs once the ATOC becomes operational. The resulting re-occurring operational costs of this leased communications approach may quickly become cost prohibitive when coupled with the increased node-to-ATOC communications need and communications redundancy need for these ATOC links. The following is a summary of the FMS ATOC communications needs:

- Need direct ATOC communications to the FMS backbone network that are independent of leased communications lines. The leased communications links should remain in place for bandwidth limited back-up operations, if the FMS network link(s) to the ATOC become impaired.
- Need to establish ATOC-to-node communications that are independent of communications to and from the TOC.

5.1.6 Inter-jurisdictional Connectivity

With the development of the RCN program and other region-wide initiatives such as the AZTech™ C2C software integration initiatives, it has become an important regional goal to share traffic, incident and traveler information between jurisdictions. The C2C software integration initiatives will ultimately provide each agency with access to view traffic signal timing plan information from other jurisdictions on an as needed basis without being able to modify their timing plans. The C2C software integration platform is currently utilizing web based communications links into the MCDOT Regional Archived Data System (RADS) as a means to share traffic management data between multiple jurisdictions. Through a combination of the RCN deploying agency owned high bandwidth communications links between jurisdictions and the C2C software integration initiative of getting all the jurisdictions on to a common CCTV control platform, many agencies within the region will have significantly improved capabilities of sharing freeway and arterial roadway camera views and camera control. ADOT has been a significant leader and champion of both of these regional programs and has committed staff resources and communications conduit and cabling infrastructure resources in support of these regional initiatives.

As previously discussed in Section 5.1.2 - Traffic Signal System Conduit and Cable Infrastructure Needs, the FMS communications infrastructure also plays a major role in helping other agencies and groups within ADOT achieve traffic signal system communications.

As with the all inter-jurisdictional communications connectivity needs, there is a need for the ADOT FMS to implement communications security and interconnectivity policies to protect the FMS from unwarranted down time that could result from these inter-jurisdictional connections to other agencies. The ADOT FMS network needs to be secured physically and logically at these inter-jurisdictional connection points.

The following is a summary of the FMS communications inter-jurisdictional connectivity needs:

- Need to continue to support RCN communications infrastructure within ADOT right-of-way.
- Need to continue to support other agencies and groups within ADOT achieve traffic signal system communications.
- Need to establish conduit and cabling interconnectivity standards with other jurisdictions.

- Need to establish communications security and interconnectivity policies to protect the FMS from unwarranted down time that could result from these inter-jurisdictional connections to other agencies.

5.2 Need for Network Security and Reliability

The vast majority of ADOTs outside plant communications conduit and cabling infrastructure within the Phoenix Metropolitan Area was built with State and Federal funding that was invested for the sole purpose of improving freeway operations by deploying intelligent technology to improve the operational efficiency of the freeways. As such, the ADOT TTG needs to maintain control over their existing FMS network infrastructure to ensure that the FMS application remains the primary function that this communications infrastructure supports. Interconnecting with other jurisdictions and State departments is a key component of the FMS because these interconnections help disseminate the traveler information data collected by the FMS to other entities that are an integral part of the overall traffic management operational strategies of the FMS.

Communications security and reliability are of primary importance for the FMS. With the appropriate safeguards, a municipal stakeholder's Internet and network activity will not adversely affect FMS communications when interconnecting other jurisdictions to the FMS communications infrastructure. Many governmental network links require highly secure telecommunications paths because they are vital to security efforts or public safety provided by the emergency response entities. Confidentiality of the information within the FMS is not essential for the majority of the video and data being communicated over the FMS network, but the integrity of the FMS network is essential to achieving its operational needs. Reliability must be built into the design of the FMS. The FMS links and access points need to be reliable and be able to support various levels of security to prevent a disruption to the operational performance of the FMS.

5.3 Other FMS Communications Infrastructure Needs

Most of the FMS communications infrastructure needs previously covered are needs that specifically apply to ADOT's FMS network within the Phoenix Metropolitan Area and may not be applicable to other similar ITS or agency networks within the State or country. The communications infrastructure needs within this section are "best practice" needs that can apply to any agency or department that is responsible for deploying, maintaining and operating a large communications network. These "best practice" needs are as follows:

5.3.1 Availability

The FMS communications infrastructure (including equipment and services) needs to be readily obtainable. Some communications products and services are not always readily available on demand. One example would be an outdated technology that is on the verge of becoming obsolete whose parts and support are becoming increasingly more challenging to obtain.

5.3.2 Avoid Unproven Cutting Edge Technologies

The FMS communications infrastructure needs to avoid using technologies that are so far on the cutting edge that they have not yet been widely deployed and proven. These technologies are often plagued with bugs that result in down time and added cost due to problems associated with the equipment, as well as integration costs due to the complexity and/or lack of familiarity of the equipment. The likelihood of the equipment becoming obsolete sooner also is more common with unproven cutting edge technologies due to changes that are adopted in the standardization process. There could also be maintenance and training problems with unproven technologies.

5.3.3 Avoid Aging Technologies

The FMS needs to avoid using technologies that are mature to the point that they are legacy systems which compromise system performance, are difficult to upgrade, and are difficult, if not impossible, to integrate with newer technologies. These types of technologies are typically slower and become saturated to maximum capacity much sooner, while providing fewer options for expansion. Finding replacement parts, integrating with other systems, and adequate customer support can at times be challenging and expensive with a dated technology.

5.3.4 *Interoperability*

The FMS communications infrastructure needs to work with existing and future network systems (or products) without significant additional effort or expense on the part of ADOT. This will increase the likelihood in achieving a longer life span of the system, as well as keeping the cost of using the FMS for other future applications at a minimum.

5.3.5 *Maintainability*

Maintainability refers to the level of maintenance required to support continued operation of the FMS communications infrastructure components. Maintainability takes into account the various maintenance impacts of communications alternatives. One example would be selecting a technology that is not widely adopted in the industry. Factors such as obtaining customer support, cost of spare parts, finding qualified technicians, and time to troubleshoot and repair would be more challenging.

ADOT also has a need to have “self-reliant” control for maintaining the communications infrastructure equipment (i.e., not requiring someone outside the department to maintain the infrastructure).

5.3.6 *Tiered Access*

It is important to minimize disruptions to FMS network by having a tiered approach of achieving multi-jurisdictional interconnectivity. Having tiers of access to the FMS communications infrastructure will increase flexibility for supporting other non-FMS regional initiatives, reduce the higher maintenance cost of the FMS network equipment, and will increase the level of control ADOT has in selecting an appropriate level of access into ADOT’s FMS communications infrastructure.

5.3.7 *Policy/Oversight of Planning/Design/Operations and Maintenance*

An oversight organizational structure should be in place to oversee and/or manage design, construction, and ADOT Operations and Maintenance activities for the FMS communications infrastructure. This oversight organizational structure would ensure that planning, design, operations and maintenance staff are all aware of adds, moves, or changes that have (or will take place) in the FMS communications network. This oversight organization structure would provide a method of sharing information that is needed between the planning, design, operations and maintenance staff.

5.3.8 *Scalability*

Scalability refers to the ease of which the FMS communications infrastructure can grow in either bandwidth-supported or geographical area. While flexibility is important, it is equally important to allow for network scalability without performing a costly network overhaul or replacement.

6 Physical Network Topology Alternatives

A network is best described as two or more devices connected together to share information. The simplest network is made up of two devices and associated interconnected cabling. There is no limitation to designing more complex networks. This section provides an overview of communications topology alternatives evaluated for FMS network architecture planning.

There are six primary communications topology alternatives to consider within the FMS communications architecture: point-to-point, daisy-chain, star, ring, Hybrid Flower, and mesh communications topologies. This section provides an overview of each of the communications topology alternatives, provides a brief description of how some of them are currently deployed within the existing FMS network, and ultimately provides a summary comparison of these topology alternatives.

6.1 Point-to-Point Topology

Networks comprised of Point-to-Point data links consist of exactly two endpoints with no data or packet formatting. A network device at either endpoint is responsible for data/packet formatting.

Point-to-Point communications links provide quick response times due to a dedicated channel between each point; however this presents a reliability problem such that if the communication medium is cut (or wireless connection is lost), the channel has no other path to maintain the connection. Most microwave communications technologies use a Point-to-Point communications topology. In the case of fiber optics, Point-to-Point communications require more fibers than a ring topology because one or more fibers are dedicated to each node point. In the case of microwave, separate pairs of microwave transceiver dishes are required for each path.

Currently the ADOT FMS Field-to-Node network uses a Point-to-Point topology for CCTV video communications between each CCTV field cabinet and the respective Node Building. As depicted in **Figure 6-1**, each CCTV cabinet has a dedicated fiber path to a single Node Building. If there are 10 CCTV camera locations along a stretch of freeway, then 10 separate fibers are needed to connect these CCTV locations to the Node Building.

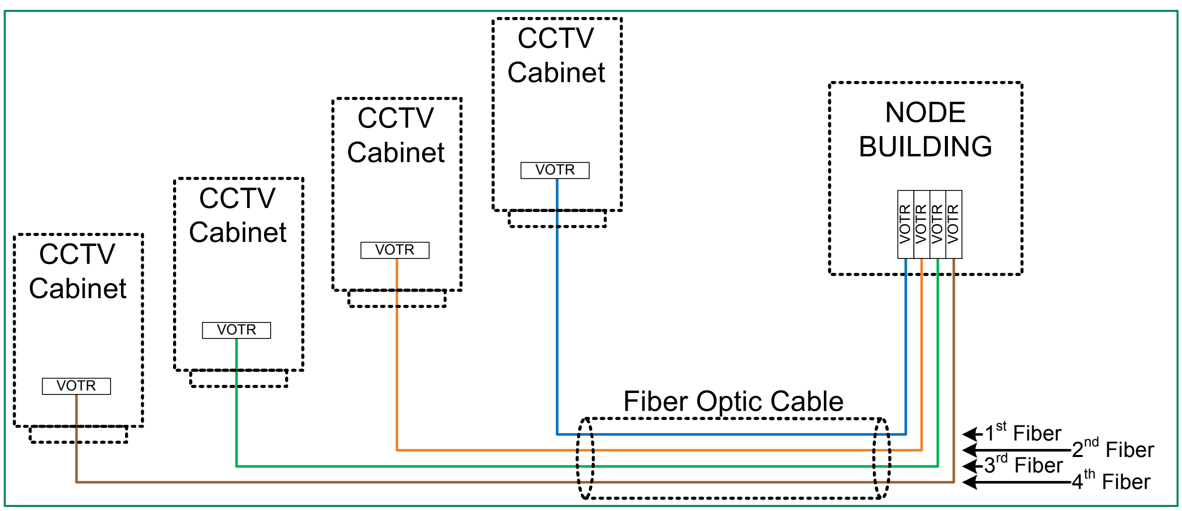


Figure 6-1: Point-to-Point Topology

The advantages of a point-to-point communications topology include;

- Quick response times because a dedicated channel/fiber is provided between each point.
- Provides field cabinet device fault tolerance, when compared to daisy-chain topology, to protect against a mid-ring device or power failure;
- A device failure at one location (i.e., one VOTR goes down) does not impact the other device locations; and

- Simplicity of design and configuration.

The disadvantages of a point-to-point communications topology include:

- Lack of cable fault tolerance; if the fiber cable is cut then all devices/CCTV downstream of the fiber break lose communications with the Node Building.
- Consumes a large amount of fibers within the fiber optic cable. For example, **Figure 6-1** is a simplified four camera deployment, but typically 10+ camera deployment per Node Building freeway segment would require 10+ fibers.

6.2 Daisy-Chain Topology

Similar to the point-to-point topology approach above, daisy-chain topologies have a single path downstream from the main hub to the end point. It is the network equivalent of a series electrical circuit. The basic daisy-chain topology is an extension of the point-to-point topology where a pair of fibers or a twisted-wire pair (TWP) of copper is used to create a multi-drop communications channel.

When ADOT decommissioned the secondary path of their TWP circuits out to the detector and ramp metering stations, ADOT effectively ended up with a daisy-chain topology for all their existing Field-to-Node circuits still using the old TWP copper cabling infrastructure. As depicted in **Figure 6-2**, each group of detector stations and ramp metering stations share a common TWP path to a single Node Building.

The primary difference between a point-to-point and daisy-chain topology is that multiple devices can share the same set of fiber(s) or TWP copper to create a multi-dropped circuit in a daisy-chain topology. On the surface this seems to be a more efficient use of deployed fibers and TWP; however, any fiber or TWP cut or failure, or even a modem failure on the near end of the circuit will inherently cripple the remaining devices downstream, thus reducing the overall reliability of the system.

The main advantage of a daisy-chain topology is its simplicity. Daisy-chains also offer a great deal of scalability without needing additional fibers or TWPs. More devices can be added anywhere along the chain up to a certain maximum depending on distance limitations and node device characteristics.

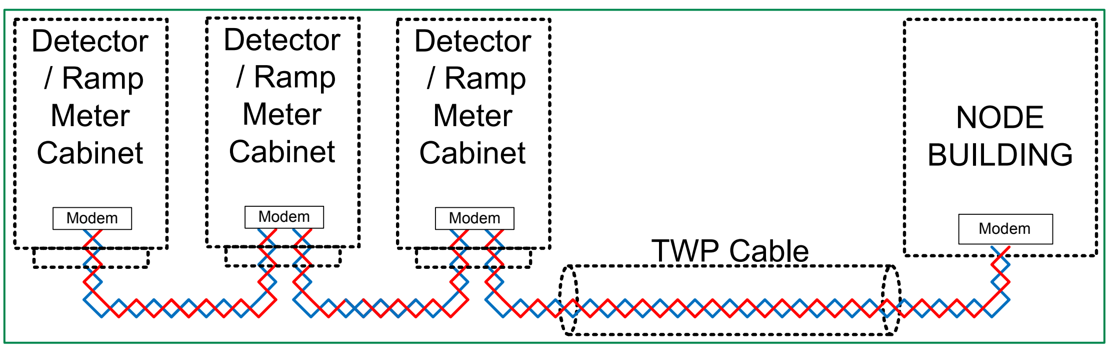


Figure 6-2: Daisy-Chain Topology

The advantages of a daisy-chain communications topology using serial communications include:

- Consumes less TWPs within the TWP cable. For example, **Figure 6-2** is a simplified four device location deployment, but typically there are more than four devices per circuit; as such, a more typical 10+ device locations deployment per circuit would only require a single set of TWP within the cable.

The disadvantages of a daisy-chain communications topology using serial communications include:

- Lack of cable fault tolerance; if the TWP cable is cut then all devices downstream of the TWP cable break will lose communications with the Node Building.

- Lack of field cabinet device fault tolerance; loss of power at one device location (i.e. one ramp meter cabinet goes down) results in all devices downstream of the cabinet losing communications with the Node Building. Note that this may not always be the case if the TWP modem does not regenerate the signal for the next downstream drop (i.e. it is on a different modem channel/string).
- When using serial communications, more complex design/software and configuration is needed to manage which device can communicate at any given time.
- Lack of Node Building device fault tolerance; a device failure at the Node Building (i.e. one modem goes down) results in all device locations connected to the faulty modem also losing communications.

6.3 Ring Topology

Counter-rotating, self-healing rings, which are typically found only in fiber-based networks, were created to increase reliability and maximize bandwidth efficiency of the communications path. A ring topology also can be achieved with a microwave/wireless network through the use of several microwave dishes/towers/transceivers, but is generally expensive. The overall intent is to provide fault tolerance for individual equipment failures and cable cut protection, while reducing fiber cost. Most networking technologies rely on two fibers in the forward and return paths to create a ring; however, Wavelength Division Multiplexing (WDM) techniques can be used to reduce the fiber count down to one fiber in the forward and return paths. The self-healing nature of the ring is provided by the optical transceivers that are able to select the best communications path (particularly in the case of a fiber or optical transceiver [modem] failure).

6.3.1 Folded Ring

A *folded ring*, as shown in **Figure 6-3**, also referred to as a "collapsed ring", consists of a single cable routed along a single path that uses several fibers within the cable to create a ring. This configuration resembles a daisy-chain topology with a return path for added redundancy. The fiber count needed in the folded ring application is doubled when compared to the daisy-chain topology, because the forward and return paths reside in the same cable. A folded ring provides increased individual fiber reliability in comparison to a daisy-chain topology by adding protection against a mid-ring device or power failure. Because the forward and return fibers share the same physical cable, it is not as effective in safeguarding against a cable cut as a physical ring. When the decision was made, in recent FMS design segments along Loop 101 (Agua Fria and Pima) and Loop 202 (Red Mountain), to only install fiber on one side of the freeway this forced the FMS designers into using a *folded ring* topology which is less reliable than the *physical ring* topology described next.

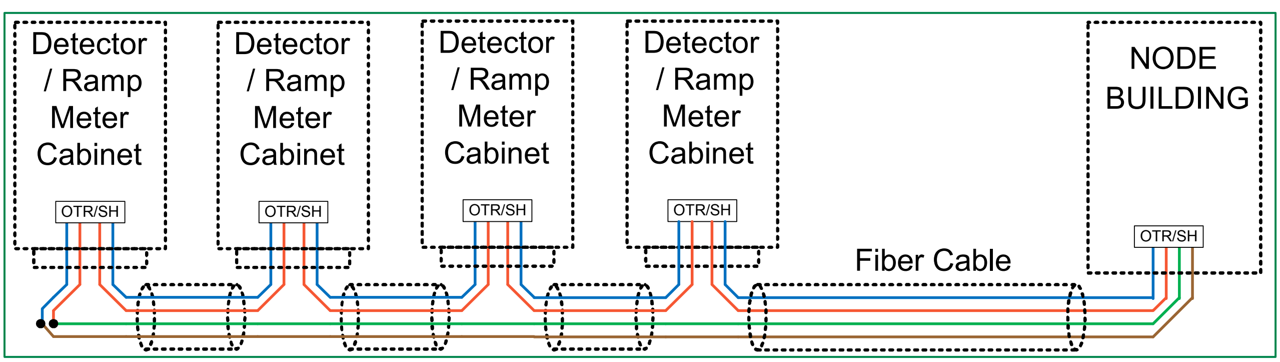


Figure 6-3: Folded Ring Topology

The advantages of a *folded ring* communications topology:

- Consumes fewer fibers within the fiber cable, when compared to the point-to-point topology.
- Adds field cabinet device fault tolerance, when compared to daisy-chain topology, to protect against a mid-ring device or power failure.

The disadvantages of a *folded ring* communications topology using serial communications include:

- Lack of cable fault tolerance; if the fiber cable is cut then all devices downstream of the fiber cable break will lose communications with the Node Building.
- When using serial communications, it requires more complex configuration to manage which device can communicate at any given time.
- Lack of Node Building device fault tolerance; a device failure at the Node Building (i.e. one OTR/SH goes down) results in all device locations connected to the faulty OTR/SH also losing communications.

6.3.2 Physical Ring

A *physical ring*, as shown in **Figure 6-4**, is comprised of separate cable paths (also known as path diversity) from end to end. This affords a highly reliable fiber-based topology by protecting against cabinet power failure and optical transceiver [modem] device failures, as well as a cut in the fiber cable. In contrast to a folded ring, two fibers are routed around the two separate paths rather than four fibers along one path, thereby reducing overall fiber requirements in each cable.

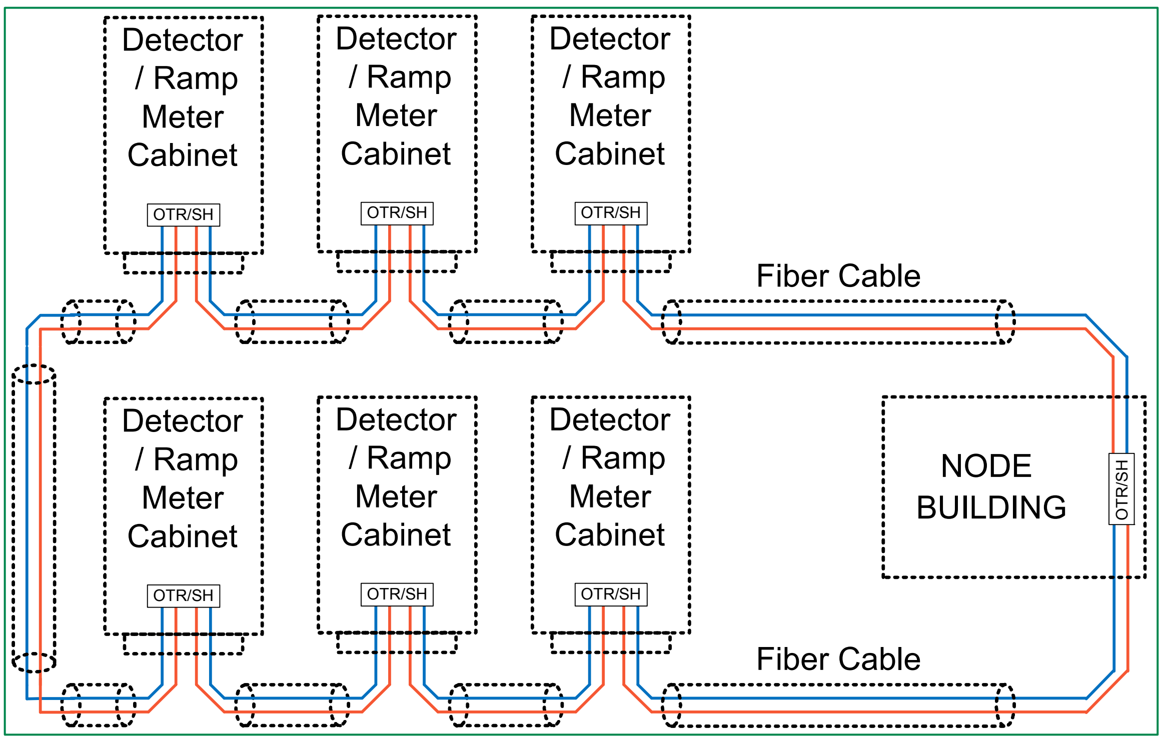


Figure 6-4: Physical Ring Topology

The advantages of a ring topology include:

- Minimized fiber usage, when compared to the point-to-point topology. Full ring functionality is provided with only two fibers in each fiber cable.
- Adds field cabinet device fault tolerance, when compared to daisy-chain topology, to protect against a mid-ring device or power failure.
- Adds cable fault tolerance, when compared to daisy-chain and *folded ring* topologies. If the fiber cable is cut at one location, then all devices downstream of the fiber cable break still maintain communications with the Node Building.

The disadvantages of a ring topology include:

- When using serial communications, more complex configuration is needed to manage which device can communicate at any given time.
- Lack of Node Building device fault tolerance; a device failure at the Node Building (i.e. one OTR/SH configuration goes down) results in all device locations connected to the faulty OTR/SH also losing

communications. (NOTE: This is also true for Ethernet aggregation switches connecting multiple field switches together at a Node Building in this fashion.)

6.4 Star Topology

The basic star topology is comprised of a main node point with many point-to-point, daisy-chain, and/or ring extensions. All communications between the network devices are directed through this node point. Thus, the star configuration is limited in size and performance due to the number of devices competing for access to the node point. ADOT currently uses a Star Topology within the Node Buildings for CCTV PTZ control and for detector, ramp metering, and DMS circuits. The current CCTV configuration shown in **Figure 6-5** are CCTV control signals connected to the Node Building over point-to-point fiber links. Each of these point-to-point fiber links are connected to a single node point called a Star Distribution Unit, thus creating the Star Topology.

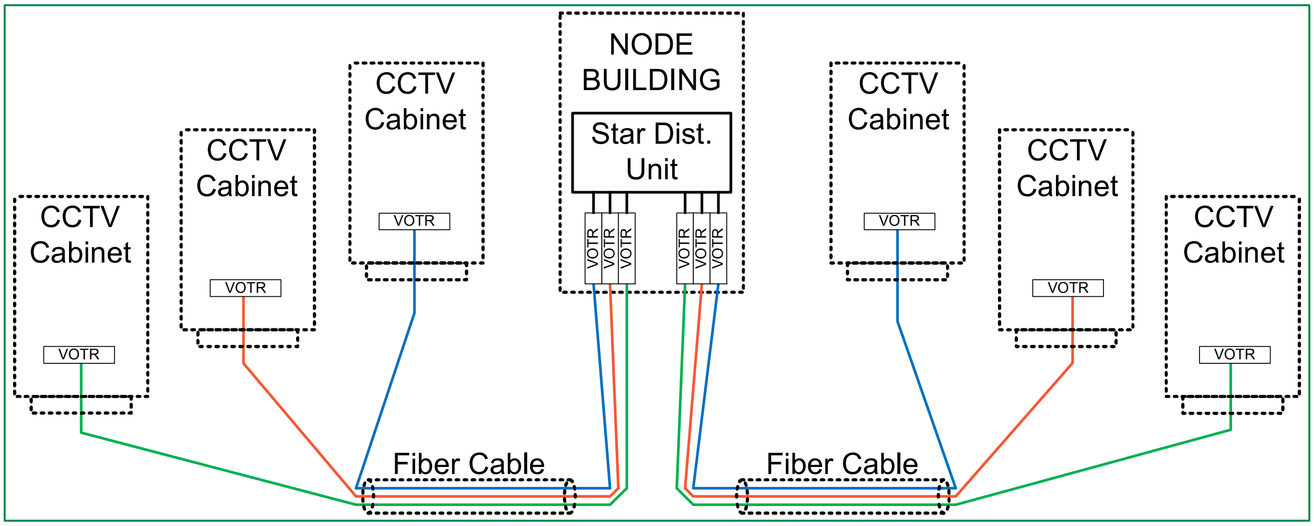


Figure 6-5: CCTV PTZ Control Using a Star Topology

A Star Topology is also used by ADOT for connecting detector, ramp meter, and DMS circuits within the Node Building. As shown in **Figure 6-6**, ADOT currently uses either TWP copper links in a daisy-chain configuration or fibers in a ring configuration to connect these devices with the Node Building, but within the Node Building all these Field-to-Node links are connected to a terminal server which is the node for these devices within the star topology.

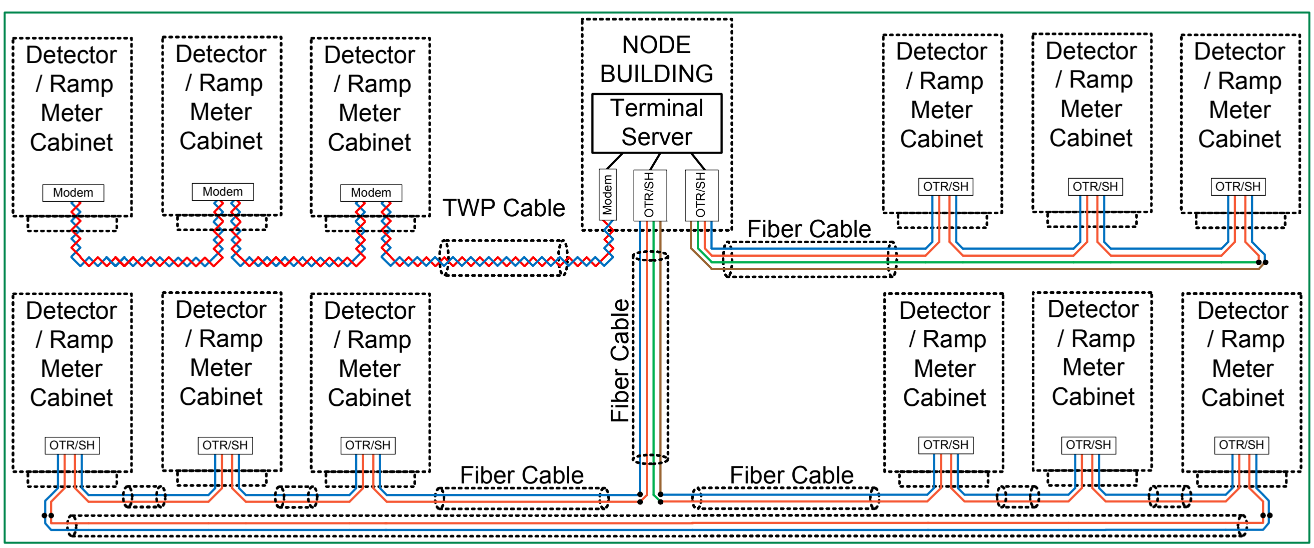


Figure 6-6: Detector and Ramp Meter Station Links Using a Star Topology

The advantage of a star telecommunications topology is:

- Simplicity of design and configuration.

The disadvantages of a Star topology include:

- When using serial communications, more complex configuration is needed to manage which device can communicate at any given time.
- Lack of Node Building device fault tolerance: in the event of a node point failure (i.e. a terminal server or star distribution unit failure) all communications would be lost because no alternate path is available to maintain the connection.

6.5 Hybrid Flower Topology

Due to the unique nature of Field-to-Node communications prevalent within the transportation industry, a relatively new form of communications topology started to emerge as transportation departments around the nation began to migrate off serial communications and started deploying IP-based Ethernet communications to the field cabinet level. This topology is referred to as the Hybrid Flower topology, within this report, since no formal name of this topology has yet been adopted by the telecommunications industry. As depicted in **Figure 6-7**, in order to achieve Field-to-Node communications fault tolerance that protects against a single device failure within the Node Building and achieve cable cut fault tolerance when conduit and fiber infrastructure is only deployed on one side of the freeway, this Hybrid Flower topology makes use of two Node Buildings. Therefore if a Node Building, or device in a Node Building, has a power or device failure, then all communications to the field device locations are maintained through the second Node Building. In the event a cut occurs somewhere between the two buildings, the devices on either side of the cut will still maintain communications through their respective Node Building that is still actively connected.

In addition to achieving complete Field-to-Node fault tolerance (field device/power failure, cable cut failure, and node device/power failure protection), the Hybrid Flower topology also significantly reduces the number of fibers needed since all device DMS, ramp meters, detector stations, and CCTV can share the same pair of fibers between any two Node Buildings. This is made possible due to the elimination of serial communications out to the field cabinet and replacing it with a shared Ethernet channel. The minimum number of fibers that the ADOT FMS would need for both Field-to-Node and Node-to-TOC communications is four (blue and orange fibers for Node-to-TOC/node-to-node, and brown and green fibers for node-to-field are illustrated in **Figure 6-7**) along any freeway segment between two node points. Using Ethernet communications also eliminates the complexity in managing which device can communicate at any given time, because this is accomplished automatically by the Ethernet network switches. As with serial communications, the Ethernet communications response times are dependent on the number of device locations connected to each Ethernet path. If multiple Ethernet paths are created then communications delay can be reduced.

Thus, advantages of a Hybrid Flower topology include:

- Least amount of fiber usage.
- Adds field cabinet device fault tolerance, when compared to daisy-chain topology, to protect against a mid-ring device or power failure.
- Adds cable fault tolerance, when compared to daisy-chain and folded ring topologies. If the fiber cable is cut then all devices downstream of the fiber cable break still maintain communications with the Node Building.
- By using Ethernet communications, the complexity of managing which device can talk at any given time is eliminated.
- Adds Node Building device fault tolerance, when a device failure occurs at the Node Building (i.e., one Ethernet switch goes down) or a power failure of the entire Node Building occurs then all device locations can still communicate through the other Node Building path.

When compared to the other communications topologies discussed, all the disadvantages of these other topologies are solved by using a Hybrid Flower topology. This topology is most advantageous for new installations.

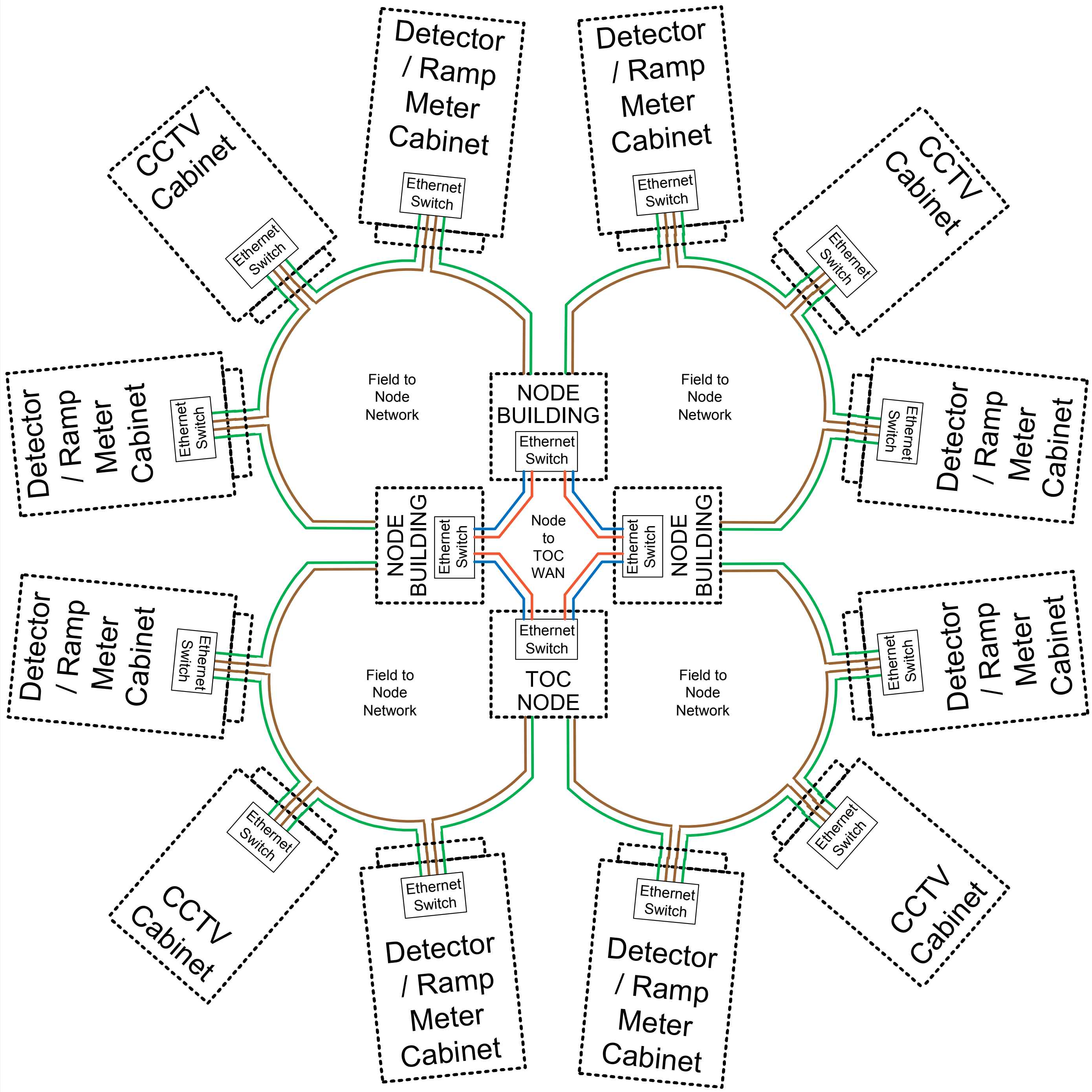


Figure 6-7: Hybrid Flower Topology

6.6 Mesh Topology

A mesh topology provides an increased level of redundancy when compared to a ring and Hybrid Flower topology, because a mesh network has more than two redundant paths. It is typically not practical in a Field-to-Node network because it consumes a significant number of fibers within a shared cable route to many device locations. These additional fiber paths are necessary in a mesh to provide the additional redundant paths. Mesh topologies are more complex to design and manage. The additional level of redundancy inherent in a mesh topology comes at a premium in terms of additional fiber infrastructure and Operations and Maintenance costs; therefore, it is only a viable communications alternative in Node-to-TOC communications. **Figure 6-8** shows an example of a mesh topology.

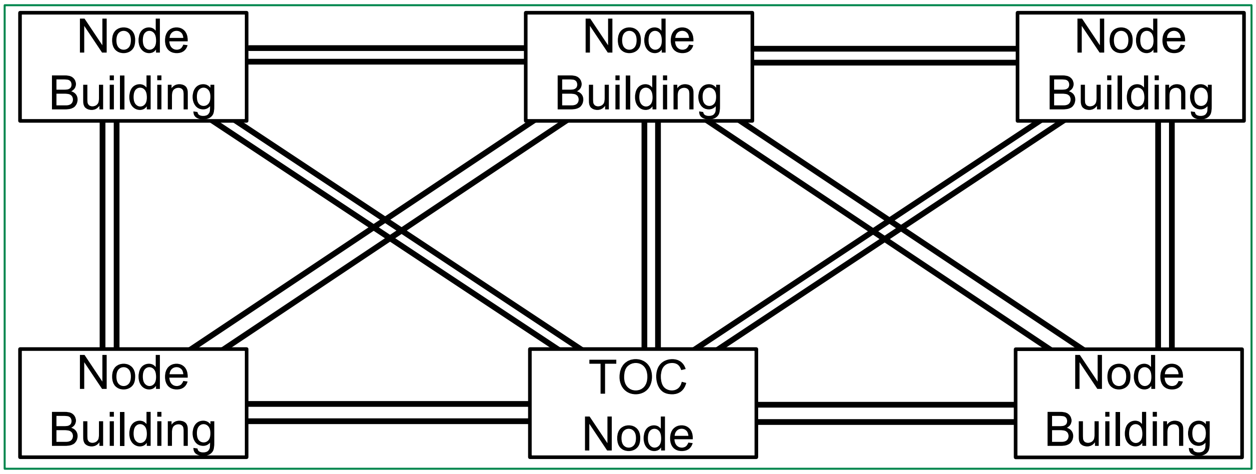


Figure 6-8: Mesh Topology

The advantage of a mesh topology is:

- Additional reliability is offered through three or more communications paths between nodes.

The disadvantages of a mesh topology are:

- Multiple cable paths add more complexity to network design and configuration management
- Requires more infrastructure (e.g. fibers and communications ports on a switch)

6.7 Summary Comparison of Topology Attributes

A separate comparison of communications topologies is provided for Field-to-Node and Node-to-TOC communications applications. Since the quantity of field device locations is significantly greater than the quantity of Node Building locations and a loss of a Node Building has a much greater impact in FMS operations than the loss of a field device location. **Table 6-1** provides a comparison of the topology options that are practical for Field-to-Node networks.

Table 6-1: Comparison of Topology Attributes (Field-to-Node Application)

	Consumption of Fibers	Field Cabinet Device Fault Tolerance	Cable Fault Tolerance	Node Building Device Fault Tolerance
Point-to-Point	Poor	Yes	No	Yes
Daisy-Chain	Moderate	No	No	No
Folded Ring	Moderate	Yes	No	No
Physical Ring	Moderate	Yes	Yes	No
Star	Poor	Yes*	No*	No
Hybrid Flower	Best	Yes	Yes	Yes
Mesh	Poor	Yes	Yes	Yes

Table Note: The * is to note that a point-to-point topology is assumed between Node Buildings and field cabinets.

The loss of an ADOT FMS Node Building significantly impacts FMS operation on a much greater scale, when compared to losing a small quantity/group of field devices, fault tolerant communications between the Node Buildings and the TOC has always been ADOT's policy since inception of the first FMS deployment project. In the past ADOT has achieved fiber cable fault tolerance by deploying fiber on both sides of the freeway and creating a physical ring topology directly between the Node Building and the TOC. However, recent decisions to deploy conduit and fiber on a single side of the freeway has forced ADOT to temporarily forgo achieving fiber cable loss fault tolerance for some Node Buildings. This temporary loss of cable fault tolerance between some nodes and the TOC is currently being corrected through ADOT's recent activities of deploying IP-based Ethernet switches within the Node Buildings and interconnecting these Node Building switches in a physical ring topology that spans multiple freeway segments. However, it is important to note that this IP-based Ethernet network solution only solves the cable loss fault tolerant problem for Node-to-TOC communications; in areas where fiber is only deployed on one side of the freeway, fiber cable breaks will still have a significant impact to Field-to-Node communications.

With ADOT's current initiative to build-out an IP-based Ethernet Node-to-TOC network and ADOT goal to regain cable loss fault tolerance for all communications between the TOC and Node Buildings there are only three topology alternatives available: ring topology, Hybrid Flower topology (adding Node Buildings between Node Buildings) and mesh topology. With the current fiber limitations within some of the ADOT cable paths, a full mesh topology is not practical at this time. ADOT can achieve some multi-path cable loss fault tolerance through the deployment of multiple rings that span different freeway segments or a partial mesh topology in areas where fiber availability exists.

7 Telecommunications Media Alternatives

There are various considerations that must be taken into account before choosing a specific telecommunications media alternative. Agency owned fiber optics, wireless technologies, and leased lines all have advantages and disadvantages associated with their deployment. The following section provides background information on specific technologies for each telecommunications media alternative as well as attributes that are unique to each alternative.

7.1 Overview of Fiber Optic Technologies

Fiber optics provides the capability of transmitting significant amounts of voice, data, and video over extremely long distances. In general, the capacity (both bandwidth and distance) and flexibility provided by fiber optic cables far exceeds the higher installation costs when compared to the other media alternatives.

Two types of fiber optic cables are available for use: Single Mode Fiber Optics (SMFO) and Multi Mode Fiber Optics (MMFO). SMFO is two to five times less expensive than MMFO. SMFO requires more expensive terminal equipment due to the smaller optical core and higher laser precision. However, for transportation Field-to-Node and Node-to-TOC applications the cost savings in the actual fiber cable of SMFO generally negate this difference. Despite the higher equipment costs, SMFO is recommended over MMFO due to its lower attenuation, ability to transmit data over much greater distances, and lower cable costs.

An agency-owned fiber optic Field-to-Node and Node-to-TOC distribution network would generally consist of separate fiber paths routed longitudinally along the ADOT roadways. To reduce the number of fibers necessary, each fiber path would be terminated at Node Building locations as opposed to routing them all back to the TOC building. At the at Node Building locations these Field-to-Node communications links would be connected to the Node-to-TOC backbone network for optical transmission back to the TOC. The following sections outline fiber optic technologies and attributes. Additional information is located in Appendix A.

7.1.1 Key Fiber Optic Technologies

There are several key fiber optic technologies available for consideration for the deployment in Field-to-Node applications. These technologies include:

Analog Video and Serial Data Optical Transmission:

OTRs are in widespread use in the ITS field where fiber optics is the communications media. Two common types of OTRs are:

- Data Optical Transceiver (OTR) – Data OTR are used to transmit low-speed serial data (i.e., EIA-232/422) bi-directionally over fiber. Data OTRs may be configured as point-to-point, daisy-chained, or self-healing rings, depending on the number of devices being communicated with, network topology, and desired level of fault tolerance. These devices also use proprietary protocols; therefore, they must be identical for entire communications circuits.
- Video Optical Transceiver (VOTR) – The purpose of the VOTR is to deliver one or more analog NTSC video and control signals over a single fiber. VOTRs are typically point-to-point devices, with the transmitter at the CCTV cabinet and the receiver at the Node Building. These devices use proprietary protocols and therefore must be used in pairs.

Optical Ethernet Transmission of Video and Data

In the past, Ethernet equipment (e.g., switches, routers, etc.) were not environmentally hardened to the level needed to support harsh field conditions, which made deploying Ethernet-to-field devices (data or video) an impractical approach; however, in today's market, manufacturers are offering field hardened Ethernet equipment to support stringent environmental National Electrical Manufacturers Association (NEMA) standards. As a result of new Ethernet equipment, installing an Ethernet Field-to-Node distribution network is considered a viable option for future ADOT FMS deployments.

An Ethernet standard Field-to-Node distribution network would generally have an environmentally hardened Ethernet switch for transmitting 10/100/1000Mbps (or greater) Ethernet data bi-directionally over fiber to the field devices. Each Ethernet switch requires electrical ports to connect local devices and fiber ports for upstream and downstream for daisy-chain and ring topology paths.

In data applications (i.e., DMS, detector and ramp meter, and CCTV PTZ control data applications) an Ethernet port can be used in the field device controller for connection into the Ethernet network. If the field device controller cannot support an Ethernet port, then a field hardened bridge (i.e., terminal server) between Ethernet and serial standards can be used to make the connection.

In CCTV video applications the analog signal from the camera needs to be digitized and compressed (coded) into an IP-based format before it can be sent through the Ethernet switch. The device used to convert the analog video signal into the digital Ethernet format is commonly referred to as an Encoder, or more generically a "CODEC" which is an acronym for encoder/decoder.

7.1.2 Fiber Optic Technology Attributes

Fiber optic technologies share the following attributes:

- *Scalability and Backward Compatibility*: These are salient features of fiber optic networks because single mode fibers have yet to reach a quantifiable limit in bandwidth capacity. Standards such as Ethernet continue to migrate to higher bandwidths while maintaining backward compatibility.
- *Interoperability*: The backbone environment is also afforded by fiber optic networking equipment. Multi-manufacturer interoperability tests have been performed in independent labs for fiber based Ethernet equipment. Basic network management is accommodated between multiple vendors, but configuration and circuit provisioning generally must be performed using each vendor's proprietary tools.
- *Security*: In general, fiber optic telecommunications is highly secure. However, the level of security depends largely upon the technologies deployed on the fiber optic cable network.
- *Cost*: Initial installation cost of Agency-owned fiber networks is high, but the recurring operating and maintenance costs are relatively low.

7.1.3 Fiber Optic Technology Conclusions

Fiber optic media has a nearly unlimited capacity compared to any other telecommunications media. Earlier in this report, communications topologies were shown under different configurations (i.e., point-to-point, daisy-chain, star, ring, etc.). These topologies are the basis for establishing communications links between the field devices and the Node Building; as well as, between Node Building, TOCs and/or outside agencies. If everything in the field or all key facilities of ADOT and participating agencies were all connected directly to a central location, the required number of fibers would be costly and also become a limiting factor for future network expansion. For this reason, a distributed architecture involving communications nodes is often employed to distribute elements onto a fiber optic backbone. Network nodes are placed strategically throughout the Phoenix Metropolitan Area at the locations with the highest network demands. Beyond these primary node locations, the communications could be extended to field device locations with less expensive equipment that provides a lower communications speed/bandwidth.

The costs presented in **Table 7-1** are the 2009 costs associated with deploying a fiber optic based network for Field-to-Node and Node-to-TOC connectivity.

Table 7-1: Unit Costs for Fiber Optic Technology

Facility Type	Capital Cost	Recurring O and M Cost (Annual)	Notes
Conduit Installation	$180,000	Annual costs can vary significantly depending on installation locations (arterial streets versus freeway right of way. Previously documented costs range from $500/mi/yr to $2800/mi/yr.	Cost is per mile
Fiber Optic Cable Installation (96 Fiber SMFO)	$50,000		Cost is per mile

The lists below summarize the advantages and disadvantages of fiber optics.

Advantages:

- Ability to carry full-motion video, high-speed data, and voice telecommunications
- Fault tolerance capabilities
- High bandwidth capacity
- Not susceptible to Electromagnetic Interference (EMI)/Radio Frequency Interference (RFI)
- Long distances supported
- No monthly operational fees
- Low maintenance costs

Disadvantages:

- Higher cost to deploy infrastructure
- Longer time required to deploy
- Requires physical path to all elements

7.2 Overview of Wireless Technologies

Wireless telecommunications are an attractive alternative for the design of telecommunications networks extending over large geographical areas. Wireless data transmission does not require trenching or boring for the installation of conduit for fiber optic or twisted-pair cable. This can be advantageous in rugged terrain, over bodies of water, in environmentally sensitive areas where the cost of right-of-way acquisition is high, where there is a lack of right-of-way, or in temporary installations. Wireless telecommunications can be described in terms of low bandwidth point to multi-point systems and high bandwidth point-to-point systems. Point-to-multipoint systems have the ability to communicate with multiple locations/devices from a single access point radio.

For reliable microwave transmission, most systems require direct line of sight between antennas, the range being limited by atmospheric absorption. Microwave range is dependent on frequency and signal strength and typically varies from approximately one to 45 miles under ideal conditions; however, adverse weather conditions can have a significant effect on system performance if the system was designed for ideal conditions. Typical bandwidth can be up to 155Mbps, although higher bandwidth transceivers are available at a much greater cost and/or much lower distance range.

Cases in which security, exclusivity, and long-term reliability are an issue, licensed radio systems are the preferred type of radio system. The owner receives a frequency by the Federal Communications Commission (FCC) and theoretically should never experience problems with radio emissions from other systems. The downsides of licensed bands include acquisition and study costs; as well as, a lengthy licensing process. Frequency searches must be performed and preliminary notices must be filed before an FCC license is issued. However, licensed wireless systems have a long history of success. For years, point-to-point microwave systems have been deployed for phone companies, cable TV companies, utilities, railways, and public sector agencies, and they will continue to be an important part of the national telecommunications infrastructure.

7.2.1 Key Wireless Technologies

There are several key wireless technologies available for consideration in a Field-to-Node and Node-to-TOC type applications. These technologies include:

Broadband Microwave:

A 45Mbps microwave system would be needed along each roadway segment a device load that is comparable to a fiber based system. For Field-to-Node applications this type of high bandwidth system, the cost per microwave link does not apply because the values are based on lower capacity microwave devices that do not require deployment in environmentally controlled cabinets. Typical in 2009, deployment costs for one point-to-point 100BaseT (45Mbps throughput) microwave link is approximately $55,000 (price includes pole, antennas, radios, power service and network switch).

Installing an SMFO network in an underground conduit system is expected to cost approximately $230,000/mile. Consider a sample five-mile length of roadway with 15 elements equally spaced apart. A point-to-point broadband microwave solution would cost approximately $825,000 versus the fiber cost for the five miles at $1,150,000. From this simple comparison it is clear that a broadband microwave system would be less expensive than a fiber based system from a capital cost perspective; however, deploying a broadband microwave system has the following intangible negative factors that were not factored into this comparison:

- The more stringent line of sight requirements of a broadband microwave system might prove to be impractical along many areas of the planned corridors;
- A broadband wireless solution with this many links is not aesthetically pleasing and pose potential deployment risks when the public voices environmental concerns;
- If an increase of field elements were determined necessary in the future, the additional microwave distribution would cost more per element; whereas the fiber solution would only require splicing equipment and optical transceivers to tie-in to the network; and
- If an increase in bandwidth capacity were determined necessary in the future, the upgrade cost to a microwave system would be significantly higher than a fiber-based solution that has spare bandwidth and fiber capacity.

Spread Spectrum Wireless Technology (Unlicensed Frequencies):

This section compares the two different methods of managing the spread-spectrum radio transmissions and provides a comparison of the three frequency bands.

Direct-Sequence Spread Spectrum: Direct-sequence spread spectrum (DSSS) combines a low data-rate signal at the sending station with a higher data-rate bit sequence, which yields a processing gain. Higher processing gains reduce the likelihood of signal interference. The minimum linear processing gain that the FCC allows is 10, and most commercial products operate under 20.

DSSS uses a high-speed code sequence, along with the basic information being sent, to modulate their radio frequency (RF) carrier. The high-speed code sequence is used directly to modulate the carrier, thereby directly setting the transmitted RF bandwidth. Binary code sequences can be as short as 11 bits or as long as 288; however, most commercial spreading codes are between 11 and 100. As the data stream is transmitted, the corresponding replacement code is actually sent (i.e. transmission of a “1” data bit might result in the sequence 01010101100 being transmitted). This is also referred to as a binary phase shift keyed signal, which is the most common modulation signal type in direct sequence systems. In the current market, DSSS makes up approximately 75% of the installed base of spread-spectrum systems. A summary of DSSS system characteristics is as follows:

- Higher cost;
- Higher power consumption;
- Higher potential data rates (2Mbps at 900Mhz to 11Mbps at 2.4/5.8GHz);
- Lower frequency re-usability due to the limited number of channels; and
- Lower distance/range than frequency hopping.

Frequency Hopping: Frequency hopping is the process by which a data signal is modulated with a carrier signal that hops from frequency to frequency as a function of time over a wide band of frequencies. The frequency hopping technique does not spread the signal so there is no processing gain. Because there is no processing gain, frequency-hopping systems require more power to achieve a signal-to-noise ratio comparable to DSSS. The carrier frequency changes periodically. This technique is designed to reduce interference from other systems. Interference between the systems will only affect the spread spectrum signal if both are transmitting on the same frequency channel at the same time. Through frequency hopping the total interference will be much lower, thereby reducing the overall bit error rate.

Frequency hopping is accomplished by establishing a “hopping code” that determines the frequencies the transceivers will transmit, and in the order that they will be used. The transmitter and receiver both must be set to same hopping code to operate and communicate with one another. FCC regulations require manufacturers to use 75 or more frequencies per transmission channel with a maximum dwell time (the time spent at a particular frequency during any single hop) of 400ms. This requirement for the number of different transmission frequencies allows frequency hopping radios to have many non-interfering channels. If the radio encounters interference on one frequency, then the radio simply retransmits the signal on a subsequent hop on another frequency. The wide-band transmitters utilized for direct sequence data communications will in fact fail to maintain communications when the level of interference at the receiver exceeds the received signal power by even a small margin. Frequency hopping technology, on the other hand, will sacrifice the highest possible data rates to ensure communications is maintained even during the most severe interference, albeit at a lower data throughput. Even worst-case transmission speeds of 9.6kbps to 19.2kbps are achieved under such extreme interference situations.

The bandwidth of a frequency hopping signal is simply "x" times the number of frequency slots available, where "x" is the bandwidth of each channel hop. Frequency hopping also is more difficult to synchronize transceivers since both the frequency and time must be in tune with one another. A summary of frequency hopping system characteristics are as follows:

- High signal interference tolerance;
- Lower cost;
- Lower power consumption;
- Lower data rates (up to 2Mbps); and
- Longer distance/range than direct sequence.

Unlicensed Frequency Bands: Spread spectrum technologies are grouped into three unlicensed frequency bands: L-Band (902-928MHz), S-Band (2.400-2.4835GHz), and the C-Band (5.725-5.850GHz). Concerns have been raised that the rapidly increasing usage of the L-Band is leading to saturation and, in turn, deterioration in data transmission capability. It also is evident that the frequency hopping technique dramatically reduces interference problems that result from saturation. As the L-Band becomes increasingly crowded, additional radio link control techniques will serve to maintain the viability of data transmission reliability and integrity as well as the data throughput rates required for typical industrial data acquisition and control applications. Implementation of the technology in the S-Band, intended to be license free virtually worldwide, will serve to alleviate saturation in the lower band.

7.2.2 Wireless Technology Attributes

Wireless technologies share the following attributes:

- *Scalability and Backward Compatibility*: Wireless networks are not generally scalable in bandwidth without adding completely new disparate radios. The equipment/transceivers are configured for a specific bandwidth capacity and application and rarely allow for upgrades other than replacement. However, when considering the use of mesh technology radios some have made the case that deploying more radios improves scalability in terms of geographic coverage area and bandwidth.
- *Interoperability*: Interoperability in the WLAN environment is well established through IEEE standards-based equipment. In the backbone environment, microwave and millimeter band equipment is largely proprietary over the wireless interface, which requires each link to be configured with matching equipment.
- *Security*: The security of WLAN telecommunications is highly debatable due to the wide availability of Ethernet monitoring tools, industry standard wireless WLAN transceivers, and the large existence of networks that have been deployed without the proper security configurations. On the other hand, security of microwave and millimeter band transmissions is a great deal higher because they are more directional, require proprietary equipment, and require a direct line-of-sight to intercept transmissions.
- *Cost*: Initial installation cost of spread-spectrum low-speed data networks is fairly low in comparison to fiber and leased lines. Installation cost of microwave and millimeter link are high and largely depend upon the associated cost of towers in specific locations to achieve line-of-sight. Recurring costs for wireless networks are moderate, as they require more frequent maintenance than fiber optics.

7.2.3 Other Wireless Considerations

Fresnel Zone:

A Fresnel zone describes the volume in the radiation pattern of a circular aperture such as a microwave radio link. Fresnel zones are important to consider because they can negatively impact point-to-point communications even when a direct line of site is present. This degradation can occur because waves that are out of phase with the main signal can be deflected toward the receiver and decrease the overall power of the radio signal. Likewise, deflections that are in phase with the original signal can add to the overall power of the desired transmission. Objects that could interfere with signal transmission could include trees, buildings, hills, or even the curvature of the earth. Objects located in even numbered Fresnel zones have a phase-canceling effect, while odd numbered deflections can actually add to the signal power. An example of a wireless telecommunications path with three Fresnel zones is graphically displayed in **Figure 7-1**. As shown in the figure, a tree is protruding into Zone 2 and Zone 3 in this example, while a building is in Zone 3. The most important zone for telecommunications, Zone 1, is clear of obstructions. A good rule of thumb for adequate transmission strength is that the first Fresnel zone should be at least 60% clear of obstructions.

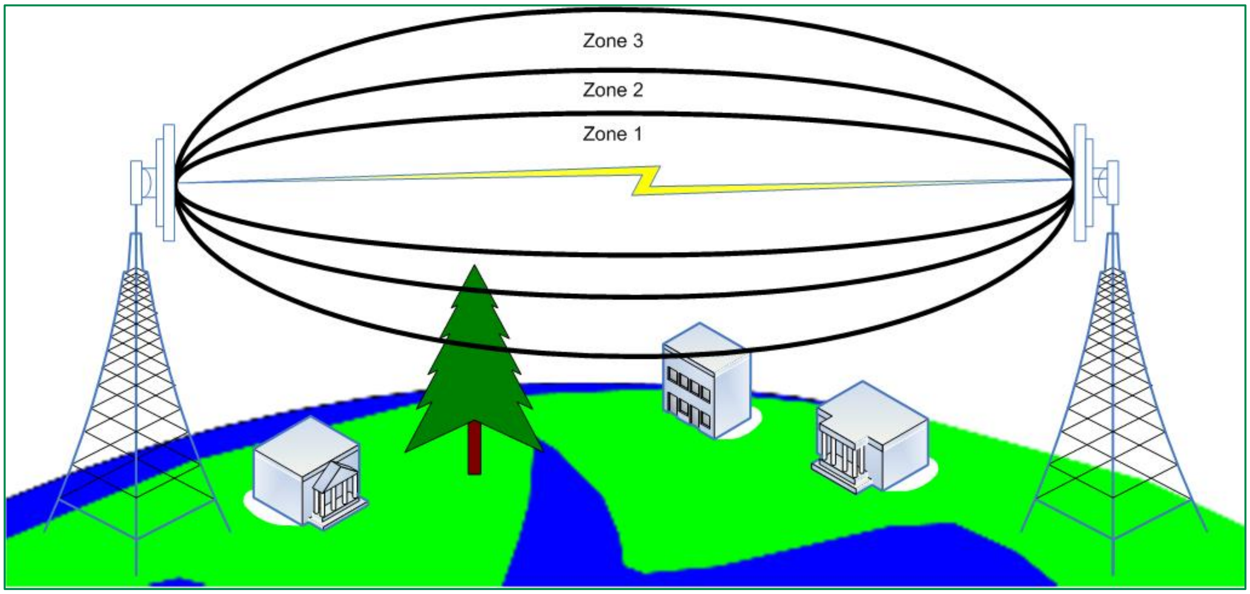


Figure 7-1: Fresnel Zone

Free Space Loss:

Free space loss, which is shown in the Equation below, results from signals spreading out from a wireless link as a function of distance and frequency. Calculating the free space loss gives a measure of the amount of loss that will occur over a given distance for a transmission frequency. The following equation indicates higher frequencies have greater losses at a given distance than lower frequencies.

$$\mathrm{FSL} = 36.6 + 20 \times \log(F) + 20 \times \log(D)$$

System Operating Margin:

System Operating Margin, sometimes called Fade Margin, is the difference between the level at which a wireless signal is received and the level required to decode a packet of information without error. High system operating margins increase the probability that a planned wireless link will work without error. Increased system operating margins help maintain a wireless link if noise is added to a system due to a transmitter or receiver being slightly misaligned, weather or atmospheric conditions, interference, or many other issues. Many engineers attempt to achieve 20 dB in a wireless link, but some links will run at a system operating margin of 10 dB or lower.

Vertical Assets:

Vertical assets refer to the structures on which communications links are mounted. These assets can include, but are not limited to, buildings, flagpoles, CCTV poles, light poles, or towers. Buildings can often be used as vertical assets in urban environments due to their proximity to each other. The length of the wireless communications link is often relatively short, which means the communications equipment does not require extremely high mounting. When data must travel long distances, however, communications towers are often built on mountains or other high points to increase the line of site distance and decrease the obstructions in the first Fresnel zone. Design considerations that are used when building a vertical asset include how high the tower must be to retain line of site and Fresnel zone considerations, footprint of the tower, and cost of the tower. Additionally, environmental issues such as wildlife concerns can affect the site locations of towers. Installing towers on existing buildings can alleviate environmental concerns as well as the footprint of the tower, because larger footprints are needed for taller towers.

There are three basic types of telecommunications towers. The three types include monopoles, self supporting towers, and guyed masts. Monopoles can be used in urban environments due to their small footprint. A 200-foot monopole has a footprint of only 36 feet. The biggest negative aspect of using monopoles is that they are expensive. Self-supporting towers have larger footprints than monopoles, but can often still be used in urban environments. Self-supporting towers are generally cheaper than monopoles. Guyed masts have the largest footprint of the three types of towers. Depending on the supporting load required, the footprint of a guyed mast tower can reach 2,000 feet[2].

7.2.4 Wireless Technology Conclusions

After considering the disadvantages that a broadband microwave option possesses, most agencies agree that this type of approach for an application that covers such a large geographical area with many up-link points is not practical. However, where the impact is less obtrusive and/or the cost of trenching a conduit system or leasing lines is impractical, a lower capacity microwave solution may be desirable. One issue to consider when specifying microwave equipment is the rapid development of technology.

The 5.7GHz band (Spread Spectrum C-Band) is preferred for CCTV field devices because most manufacturers of 5.7GHz equipment focus their products toward higher bandwidth applications such as T1 (1.544Mbps), multiple T1, or native Ethernet that are needed for video quality that is comparable to the fiber and leased alternatives presented.

The 2.4GHz band (Spread Spectrum S-Band) is preferred for low to medium speed data field devices as it has less loss and noise than 900MHz and can achieve greater distances. 2.4GHz equipment is generally less expensive and less susceptible to rain than 5.7GHz equipment. Furthermore, frequency hopping modulation is recommended due to the ability to maximize interference rejection, while allowing the most simultaneous frequency channels per site. This will allow for the most possible field device types to be deployed.

A system comprised completely of wireless components might prove expensive to setup, operate, and maintain, especially when high quality video distribution is involved. Wireless system equipment for such applications generally requires specialized system technicians to configure and maintain. Similar to municipally-owned fiber optic systems, municipally-owned wireless systems also incur less operational costs than leased line systems. Below are the advantages and disadvantages of wireless systems:

Advantages:

- Ability to carry full-motion video, high-speed data, and voice telecommunications
- Fault tolerance capabilities
- No monthly operational fees
- Rapid deployment

Disadvantages:

- Higher lifecycle cost to deploy
- Some jurisdictions may have difficulty gaining approval for new towers
- Requires line-of-sight for microwave backbone
- Susceptibility to security breaches
- Susceptibility to weather and EMI/RFI interference
- Backbone will not support regions entire bandwidth projection
- Backbone is not scalable without significant equipment replacement

7.3 Overview of Leased Line Technologies

Many telecommunications service providers in the area can provide a broad range of communications links. The desired connectivity level and bandwidth needed depends on the specific application of the communications link. The use of telecommunications service providers translates to lower up-front capital costs, but there is typically a substantial per-month charge for each service point that needs to be factored into the operating budget for the network. **Table 7-2** gives an approximation of how much data/video can be transported using the most common types of telecommunications services. A description of these types of services is provided in the following section.

Table 7-2: Leased Services Bandwidth Comparison

Lease Service (typical bandwidth)	D_L	V_L	D_L&V_L	D_L&2 V_L	D_H or V_H
3G Wireless	–	–	–	–	X
3G+ Wireless	_	_	_	_	X
POTS (56 Kbps)	X	–	–	–	–
ISDN (128 Kbps)	X	X	X	–	–
DSL (384 Kbps)	X	X	X	X	–
T1/DS-1 (1.544 Mbps)	X	X	X	X	X

Table Notes: D_L: Low speed data, data transfer at 19.2kbps
D_H: High speed data, data transfer at 1.544Mbps
V_L: Low quality video, digital video and CCTV control compressed to 128kbps
V_H: High quality video, digital video and CCTV control compressed to 1.544Mbps
Higher bandwidths for ISDN and DSL may be available depending on service provider offerings

7.3.1 Key Leased Line Technologies

There are a host of services available through service providers throughout Maricopa County. Some of these services available are described below.

3G Wireless Services:

International Mobile Telecommunications-2000 (IMT-2000), better known as 3G or 3rd Generation family of standards for wireless communications defined by the International Telecommunication Union which includes EDGE, CDMA2000, the UMTS family as well as DECT and WiMAX. Services include wide-area wireless voice telephone, video calls, and wireless data, all in a mobile environment. Compared to 2G and 2.5G services, 3G allows simultaneous use of speech and data services and higher data rates (up to 14.4 Mbit/s on the downlink and 5.8 Mbit/s on the uplink with HSPA+). Thus, 3G networks enable network operators to offer users a wider range of more advanced services while achieving greater network capacity through improved spectral efficiency.

3G can be an effective medium for semi-urban (or possibly rural) data communications distribution links. The data throughput for 3G is enough to support data communications for National Transportation Communications for ITS Protocol (NTCIP).

Plain Old Telephone Service:

Plain Old Telephone Service (POTS) has capabilities similar to twisted wire pair connections that are common in many ITS systems, except that the connections are provided by the telephone company instead of by the operating agency. In most cases, the type of modem that is deployed to interface the POTS is not directly compatible with private copper networks. POTS links are dial-up connections and the communications channel is normally off ("on hook," as with an in-home telephone) and requires time to dial and make a connection.

Bell-202 Standard Telephone Service:

Low-capacity 1200bps Bell-202 standard leased lines that are always connected can be used for the traffic signal systems, but cost considerably more than a dial-up connection because dedicated bandwidth for point-to-point connection must be continually maintained by the telephone company. The increase in price that is being realized for this type of service is most likely attributed to the increased maintenance burden on the service provider for continuing to offer this aging technology.

Integrated Services Digital Network:

Integrated Services Digital Network (ISDN) lines provide relatively low-cost voice and moderate-speed data pathways to the ITS market. ISDN combines phone service with some basic equipment to create three separate digital channels (two B channels at 56/64kbps and one D channel at 16kbps). Basic rate interface ISDN (ISDN BRI) out performs today's POTS technology by enabling simultaneous voice, data, video, and fax communications with data transmission speeds up to 128kbps, and throughput exceeding 500kbps using compression/aggregation techniques. With primary rate ISDN, speeds of 1.54Mbps can be achieved and are selectable in increments of 64kbps with the dialable wideband service feature.

ISDN is available in most metropolitan areas across North America, and is deployed in over 30 different countries. ISDN forms the foundation for an array of low-cost solutions, such as video conferencing, image processing, network-to-network connectivity, and private branch exchange connectivity to the public network.

Digital Subscriber Line:

Digital Subscriber Line (DSL) was developed for the telephone industry to deliver high-bandwidth digital communications to homes and businesses over the phone companies' existing copper networks. It is capable of speeds in excess of 1Mbps; however, the actual guaranteed data rate could be significantly lower depending on the service provider in the area. DSL technology is a transport technology like a variety of different network standards (such as Ethernet and Asynchronous Transfer Mode [ATM]) that can be transported between two or more points using DSL links from a communications service provider.

DSL is not available in all areas and the types of DSL available also might differ in each area. The following are just a few of many different types of DSL technologies that might be available from telecommunication service providers:

- *Asymmetric DSL (ADSL)*: The asymmetric naming convention stems from the fact that the bandwidth provided on an ADSL link differs between the upstream (transmit) path and the downstream (receive) path. This type of DSL line could be more cost-effective in point-to-point CCTV applications where the bandwidth intensive CCTV video goes in one direction and the non-intensive CCTV control data goes in the other direction; unfortunately, the higher bandwidth path is offered in the exact opposite direction in the public telephone networks. The amount of bandwidth provided for each direction also is dependent on how far the service drop is away from the telecommunication provider's central office building and the available capacity of the switching system at the provider's central office building;
- *Symmetric DSL (SDSL)*: SDSL provides symmetric (equal) bandwidth availability on both the upstream (transmit) and downstream (receive) paths. Most DSL technologies are symmetric between upstream and downstream paths, but differ in the maximum amount of bandwidth provided, the transmission medium used and the transmission distances that can be obtained; and
- *High Bit Rate DSL (HDSL)*: HDSL is one of the most common DSL technologies deployed within a telecommunication service providers' infrastructure; because it provides a fixed bandwidth of 1.544Mbps (T1 bandwidth equivalent) at distances greater than the standard T1 service.

North American Digital Signal Hierarchy (DS-#):

The North American DS-# is comprised of a series of circuits that are commonly referred to by the number of voice channels that they can support and the total bandwidth of the circuit. The circuit naming convention used is the Digital Signal Level (DS-#), where DS stands for Digital Signal and the value of the number identifies the type of circuit.

- *T-1/DS-1*: DS-1 (T1) is the most commonly used digital signal line in the United States, Canada, and Japan. A T1 circuit can provide 1.544Mbps of data communications bandwidth and is commonly used in the ITS world for carrying compressed video signals at a relatively high quality. T1 circuits work well over fiber or copper circuits. T1s can be constructed to deliver 24 voice channels, all data, or a mixture of the two between two or more locations. Unlike DSL, T-1s are not distance limited, but providers charge users for extended mileage (i.e. it costs more for a T1 from ADOT to New York than for one from ADOT to Avondale).
- *T-3/DS-3*: DS-3 (T3) provides the equivalent of 28 T1s on a single circuit. T3 circuits can provide up to 44.736Mbps of bandwidth and are generally cost-effective when eight or more T1s are needed at one location.

Frame Relay:

A packet technology designed specifically for delivering data services between multiple (geographically separate) locations over a common circuit. Frame Relay services generally use T1, T3, or fractions thereof, to provide Wide Area Network (WAN) connectivity between routers on a private corporate/government network. Frame Relay circuits are generally less expensive than conventional T1/T3 circuits.

ATM:

It is similar to Frame Relay in that it relies upon T1 and T3 circuits for physical transport. ATM uses much smaller packets called cells and has Quality of Service (QoS) standards that create a real-time environment for voice and video telecommunications. While data transmissions do not have the same real-time requirements as voice and video, QoS can also, for example, be applied to protect mission-critical applications from Internet traffic. ATM circuits are generally more expensive than Frame Relay and conventional T1/T3 circuits.

Internet Link:

Use of the Internet in lieu of agency-owned or leased lines for communications is more practical for distribution of FMS traveler information out to the public than for Field-to-Node and Node-to-TOC network distribution. Internet T1s may be considered as a secondary path to connect Node Buildings to the ATOC for redundancy. That way if the TOC fails, then the ATOC can still access the Node Buildings as long as the Node Buildings are equipped with direct Internet access.

7.3.2 Leased Line Technology Attributes

Leased-line technologies share the following attributes:

- *Scalability and Backward Compatibility*: This is an advantage of leased line networks because additional telephone lines can always be added. The public telephone network is designed for scalability from analog telephone lines (Digital Signal 0 (DS-0) to DS-1, DS-3, on up to and above Optical Carrier-192 (OC-192) channels.)
- *Interoperability*: Historically, this is an advantage of the public telephone network due to the fact that different carriers must work together.
- *Security*: The traditional T1, T3, and DS-0 line offerings are highly secure because they are dedicated to and only accessible by the leasing agency. However, other types of services like Frame Relay can potentially be intercepted/breached.
- *Cost*: Initial installation cost of leased lines is low to the consumer. As discussed above, the recurring operating costs are very high.

7.3.3 Leased Line Technology Conclusions

Two significant advantages of using leased communications lines are 1) a relatively low initial capital investment, and 2) most of the maintenance responsibilities are covered by the service provider. The converse though is that lease costs can present a significant long-term financial burden on the agencies operating budget that typically becomes a limiting factor on the systems growth potential of deploying field devices like CCTV that require more expensive leased services.

When using leased services, the agency has little impact of the service providers' responsiveness to maintenance calls. Source calls are typically an extra charge and can become expensive if there are a lot of problems with the service being provided.

Other field devices, like DMS, which have a relatively low speed data communications need and an infrequent polling cycle, would be better suited for a standard dial-up or wireless 3G service technologies.

It should be noted that leased services, especially wireless, are subject to change. When the user owns the equipment, such as with 3G, there is a risk of losing one's capital investment. For example, the failure of the Metricom service provider few years back left the California Department of Transportation in District 4 with useless equipment and loss of communications to their field devices.

For CCTV communications, a leased T1/DS-1 line is recommended to provide a video quality and frame rate that is reasonably comparable to what the other infrastructure options offer; however, other lower speed options like ISDN and DSL could be used to cut operating cost if a lower quality video signal was acceptable and field hardened termination equipment was available from the service provider's vender.

The lists below outline the advantages and disadvantages of leased lines.

Advantages:

- Low capital cost to deploy
- Limited obligation; use for temporary installations and disconnect when done
- Low maintenance because it is maintained by the telephone company
- Extensive trenching is not required
- Line-of-sight is not required

Disadvantages:

- Recurring monthly operating fees
- Available bandwidth usually limited
- Dependent on telephone company for maintaining service (longer time to repair than for agency-owned system)
- High-bandwidth services not available in all locations, particularly highways and rural areas.

8 STANDARD FMS NETWORK REQUIREMENTS AND GUIDELINES

This section details the FMS network standards and the required support of multiple communications media. These standards, requirements and guidelines need to be followed to create a network that is dependable, protected and reliable. If these industry standards are implemented properly, the network will have redundancy, minimizing down time and providing alternative data routing back to the TOC.

8.1 Recommended Standard Network Requirements

This section provides a high level summary of the recommended network requirements that are based on satisfying the network needs identified in Section 5 – FMS Needs Assessment.

8.1.1 FMS Network Reliability Requirements

In order to achieve the network reliability needs of the ADOT FMS program, the ADOT Field-to-Node network, Node-to-TOC network and node-to-ATOC network requires the following:

Field Cabinet Device Fault Tolerance:

- If power is lost to a single FMS field device (i.e., DMS, detector station, ramp meter, and CCTV) cabinet, then all other field devices are required to maintain communications with the TOC, via the Node Building. The loss of power at one field cabinet location should not impact the communications of the other FMS devices within the FMS network.
- If a communications device fails within a single FMS field device cabinet, then all other field devices are required to maintain communications with the TOC, via the Node Building. The loss of a communications device within one field cabinet location should not impact the communications of the other FMS devices within the FMS network.

Fiber Optic Conduit and Cable Fault Tolerance:

- If a fiber optic trunkline/backbone conduit/cable is severed/cut (planned or unplanned) in a single location, then all Node Building devices are required to maintain communications with the TOC and ATOC. A trunkline/backbone fiber optic conduit/cable break at a single point within the conduit/cable path should not impact FMS communications to any Node Building connected via the FMS fiber optic conduit/cable plant.
- If a fiber optic trunkline/backbone conduit/cable is severed/cut (planned or unplanned) in a single location, then all FMS field devices (i.e., DMS, detector station, ramp meter, and CCTV) are required to maintain communications with the TOC, via a Node Building. A trunkline/backbone fiber optic conduit/cable break at a single point within the conduit/cable path should not impact FMS communications to any FMS field device connected via the FMS fiber optic conduit/cable plant.
- If a fiber optic branch conduit/cable is severed/cut (planned or unplanned) then all other field devices are required to maintain communications with the TOC, via a Node Building. A fiber optic branch conduit/cable break should only impact communications to a single FMS field device location that is being connected by the branch conduit/cable and it should not impact the communications of the other FMS devices within the FMS network.

Node Building Device Fault Tolerance:

- If one or more communications devices are lost at a Node Building, then all other Node Buildings are required to maintain full communications with the TOC and ATOC. Communications device failure(s) at one Node Building location should only interrupt communications to that single Node Building location that has the device failure(s). All other Node Building shall maintain full communications with the TOC and ATOC.
- If one or more communications devices are lost at a Node Building, then all FMS field devices (i.e., DMS, detector station, ramp meter, and CCTV) connected to the Node Building location that has the device failure(s) are required to maintain communications with the TOC, via a redundant communications

path to a different Node Building location. (Note that this will require IP-based Ethernet out to the field device cabinets)

Node Building Power Fault Tolerance:

- If the primary power to a Node Building is lost at a Node Building, then the UPS back-up power is required to maintain all critical power loads within the Node Building for a minimum of four hours.
- If both the primary and back-up UPS power is lost at a Node Building, then all other Node Buildings are required to maintain full communications with the TOC and ATOC. A power failure at one Node Building location should only interrupt communications to that single Node Building location that has the power failure. All other Node Building shall maintain full communications with the TOC and ATOC.
- If both the primary and back-up UPS power is lost at a Node Building, then all ITS field devices (i.e., DMS, detector station, ramp meter, and CCTV) connected to the Node Building location that has the power failure are required to maintain communications with the TOC, via a redundant communications path to a different Node Building location. (Note that this will require IP-based Ethernet out to the field device cabinets)

8.1.2 Network Security Requirements

This section describes the basic levels of network separation that are required to achieve the tiered access need for connecting into the FMS communications infrastructure (conduit, fiber cable, field cabinets, Node Buildings, and communications devices). In order to achieve tiered access security approach the ADOT FMS communications infrastructure is required to provide the following security measures:

Physical FMS Facility Security:

- At the TOC, all equipment/communications/server rooms which contain FMS network switches connected to Node Buildings, FMS field devices, and FMS application servers are required to have access control, proximity card readers, that restrict access into the rooms.
- At the TOC, all equipment/communications/server rooms which contain FMS network switches connected to Node Buildings, FMS field devices, and FMS application servers are required to have security camera(s) within the room. The field of view of the security camera(s) are required to be positioned at the access door(s) for front view of personnel entering into the room.
- FMS Node Buildings are required to have access control, proximity card readers that restrict access into the building.
- FMS Node Buildings are required to have security camera(s) within the building. The field of view of the security camera(s) are required to be positioned at the access door(s) for front view of personnel entering into the building.
- FMS field device cabinets are required to have keyed access locks on all access doors.
- Transformer cabinets that support FMS field cabinets are required to have keyed access on all access doors.
- No. 9 FMS pull boxes are required to have a tamper proof bolting system.
- No. 7 FMS pull boxes are required to have a tamper proof bolting system.

Physical FMS Network Separation:

- The entire FMS WAN which is comprised of IP-based Ethernet network switches in the TOC and Node Buildings, as well as, any future network switches in FMS field device cabinets and the ATOC, are required be physical separated from other agency/department networks (i.e. the RCN, ADOT traffic signal system). Other agency/department networks are required to have physically separate fiber assignments that could potentially reside in the same fiber optic cable. Other agency/department networks can only be connected into the FMS WAN at controlled access points which provide an FMS network security appliance (i.e. firewall) between the networks.
- The FMS Node-to-TOC and node/TOC-to-ATOC networks are required be physical separated from the FMS Field-to-Node networks. The FMS Field-to-Node networks are required to have physically separate fiber assignments that could potentially reside in the same fiber optic cable. The FMS Field-to-Node

networks can only be connected into the FMS Node-to-TOC and node/TOC-to-ATOC networks at controlled access points (i.e., Node Buildings and TOC) and a security appliance (i.e., firewall) between the networks is not required.

Logical FMS Network Separation:

- All FMS WAN traffic is required to be logically separated. For example, CCTV video, CCTV control, detector and ramp meter stations, and DMS would all be separated logically onto different Virtual Local Area Networks (VLANs) but could potentially share the same physical fiber assignments.
- Any future network switches deployed within FMS field device cabinets are required to have Media Access Control (MAC) Address blocking security features deployed.

8.1.3 Inter-Jurisdictional Connectivity Requirements

A key component to the overall FMS program is information dissemination; as such, the freeway traffic information collected by the FMS needs to be shared with other departments, agencies, and ultimately the traveling public in order to achieve the maximum benefit of the FMS infrastructure assets. ADOT's 511 website and DMS are the primary tools within ADOT's FMS to share traffic congestion and incident data to the traveling public. With the development of the RCN program and other region-wide initiatives such as the AZTech™ C2C software integration initiatives, sharing FMS video and data between jurisdictions empowers these other jurisdictions to assist ADOT in disseminating freeway congestion and incident information to the traveling public. ADOT FMS operators also can benefit from receiving traffic video and data information about key arterial corridors that intersect the freeway system at the interchanges.

Inter-jurisdictional connectivity of the FMS network infrastructure is required as follows, without compromising the FMS Network Security Requirements described in Section 8.1.2:

- Spare conduit capacity is required to support the installation of other agency/department fiber optic cable(s) that are used for interconnecting into the FMS network at RCN node points and/or at FMS network firewall locations, as well as supporting other jurisdictions/department in achieving intra-connectivity of the traffic signal system and ITS system components owned and operated by these other jurisdictions/departments.
- Spare fiber capacity, within FMS fiber optic cables, is required to support other agencies/departments in achieving interconnects into the FMS network at RCN node points and/or at FMS network firewall locations as well as supporting other jurisdictions/department in achieving intra-connectivity of the traffic signal system and ITS system components owned and operated by these other jurisdictions/departments.
- Spare fiber capacity, within FMS fiber optic cables, is required to support ADOT in achieving communications to ADOT's traffic signal system.

8.1.4 FMS Bandwidth Requirements

Bandwidth is a term used to describe the maximum capacity of data that can be transmitted across a network at any given time. Bandwidth is primarily a function of two key parameters: the speed of transmission and the volume/density of data. Bandwidth can be defined literally as the width of a band of frequencies (i.e. subtracting the lowest frequency from the highest frequency). Typically, Information Technology staff refers to the "data rate" equivalent of bandwidth in bits per second. The number of bits that can be transmitted over a frequency band represents the volume/density of data. By multiplying the number of bits by the bandwidth (frequency), a representation of the data rate in bits/second is derived. For instance, a 1 Megahertz (MHz) bandwidth that is modulated to carry 64 bits per cycle would equate to a data rate of approximately 1,000,000 x 64 = 64 Mbps. From this point forward in the report, bandwidth will be equated to data rate and measured in bits per second.

It is important to note that any given communications link has a limited amount of bandwidth it can support. Factors that affect the available bandwidth of a network include:

- The amount of traffic on the network (packet density);
- The number of users (routing delay); and
- Collisions between sets of data (contention).

Different network services/uses require various amounts of bandwidth. Typical bandwidth requirements are shown in **Table 8-1**. Later sections of this communications plan further detail the impacts of network bandwidth on recommendations of the FMS communications network architecture.

Table 8-1: Typical Bandwidth Requirements

Interface Description	Bandwidth Requirement
Business Quality Voice (DS-0)	64 kbps
Field Data only (EIA-232/EIA-485)	19.2 kbps per channel
CCTV Video (full motion, one-way)	1.544 Mbps
CCTV Video (full motion, two-way)	3.088 Mbps
Videoconferencing (video and voice)	384 kbps
T-1/DS-1 (equivalent to 24 DS-0s + 8 kbps overhead)	1.544 Mbps
T-3/DS-3 (equivalent to 28 T-1s + 1.504 Mbps overhead)	44.736 Mbps

The number of devices on each fiber optic ring path back to the ADOT TOC and the bandwidth requirements of the total number of those devices determines the size of the Ethernet system needed to maintain communications to those devices. **Table 8-2** represents the summation of bandwidth requirements for the FMS devices in the current system. While it only reflects 70% of the capacity of a Gigabit Ethernet network, this leaves little room for expansion when factoring in overhead and network reliability/redundancy considerations. ADOT has deployed 10 Gigabit Ethernet network equipment for ADOT's WAN (Node-to-TOC) at five of the ten Node Buildings. The other five are soon to be online. The 10 Gigabit Ethernet communications capacity is several times what is needed for the current demand, provides ample room for expansion, and is the next logical step up from Gigabit Ethernet.

Table 8-2: Bandwidth Load Calculations for Current System in 2009

Bandwidth Load Calculations					
Application	**# of devices**	**Bandwidth Per device**		**Total Bandwidth of Supported Devices**	
ITS Components					
Ramp meter	200	19.2	kbps	3.84	Mbps
Detector loops	200	19.2	kbps	3.84	Mbps
CCTVs	120	3	Mbps	360	Mbps
DMS	71	19.2	kbps	1.32	Mbps
RCN Camera Sharing	120	3	Mbps	360	Mbps
Total Bandwidth of Supported Devices				**729**	**Mbps**

Table 8-3 calculates the increased bandwidth requirements to manage all devices in a full FMS build-out scenario along all existing highway within the Phoenix Metropolitan Area. **Figure 8-1** shows the anticipated future ADOT highway system within the Phoenix Metropolitan Area.

Table 8-3: Bandwidth Load Calculations for Full FMS Build-out of Current Highways

Bandwidth Load Calculations					
Application	**# of devices**	**Bandwidth Per Device**		**Total Bandwidth of Supported Devices**	
ITS Components					
Ramp meter data	400	19.2	kbps	7.68	Mbps
Detector Loops	400	19.2	kbps	7.68	Mbps
CCTVs	200	3	Mbps	600	Mbps
DMS	100	19.2	kbps	1.92	Mbps
RCN Camera Sharing	200	3	Mbps	600	Mbps
Total Bandwidth of Supported Devices				**1217.28**	**Mbps**

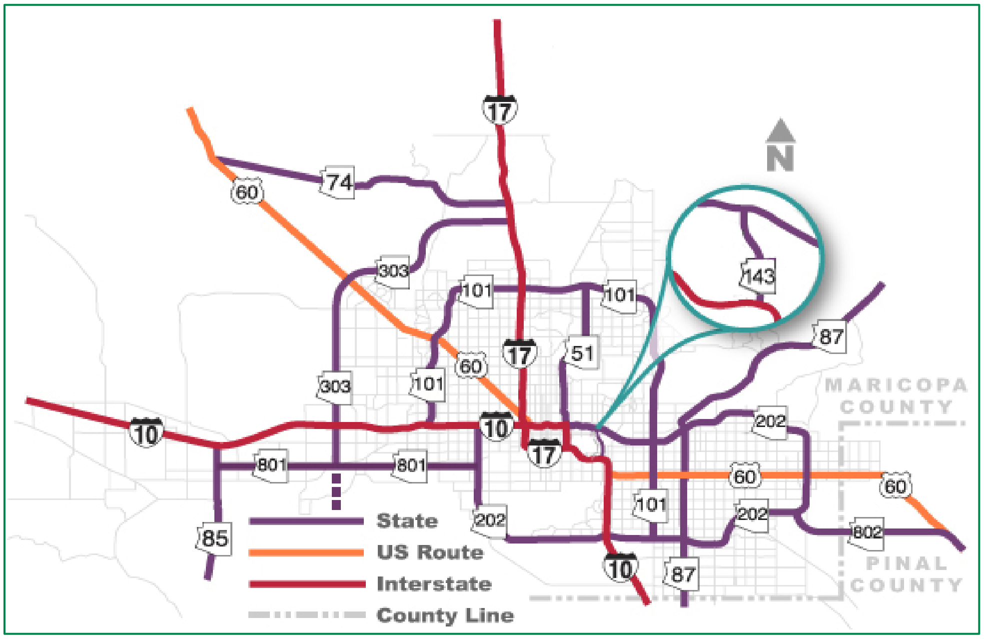


Figure 8-1: Future ADOT Highway Map

Table 8-4 calculates the increased bandwidth requirements for future highway build-out and future FMS deployment.

Table 8-4: Bandwidth Load Calculations for Full FMS Build-out of Future Highway System

Bandwidth Load Calculations					
Application	**# of devices**	**Bandwidth Per Device**		**Total Bandwidth of Supported Devices**	
ITS Components					
Ramp meter data	800	19.2	kbps	15.36	Mbps
Detector Loops	800	19.2	kbps	15.36	Mbps
CCTVs	400	3	Mbps	1200	Mbps
DMS	200	19.2	kbps	3.84	Mbps
RCN Camera Sharing	400	3	Mbps	1200	Mbps
Total Bandwidth of Supported Devices				**2434.56**	**Mbps**

In order to avoid network saturation that introduces network delay time, an Ethernet link is typically designed for 60%-80% of usable capacity; therefore; the 10 Gigabit link provides 6000Mbps – 8000Mbps of usable bandwidth. Based on the total number of devices, the 10 Gigabit Ethernet ring that has been established for the ADOT FMS WAN is adequate for current and future needs.

8.1.5 General FMS Communications Equipment Requirements

Availability:

The FMS communications infrastructure equipment is required to be evaluated with consideration as to the ease of which parts and support can be obtained. This will minimize the risk that ADOT acquires equipment that will not support its needs for future growth and continue maintenance needs of the system.

No Cutting Edge Technologies:

The FMS communications infrastructure equipment is required to be evaluated due to the availability of multiple vendors supporting the technology features and the strength of the vendor's support for current and pending industry standards/technologies. It is recommended that ADOT avoid using unproven cutting edge technologies by specifying equipment types with successful deployment histories and require adherence to adopted industry standards.

Interoperability:

The FMS communications infrastructure equipment is required to be evaluated based upon independent interoperability tests or standards that provide proof of vendor interoperability. Interoperability criteria will ultimately dictate the importance of using adopted industry standards for the technologies selected. If the vendor that is selected at one end of a communications link also has to be used at the other end of the communications link, then this is a technology that does not achieve ADOT's interoperability requirement. These technologies are commonly referred to as "proprietary technologies" because only one vendor can offer future expansion equipment without needing to replace equipment purchased in the initial investment. This severely limits the growth options and potential expansion of the FMS network.

Maintainability:

The FMS communications infrastructure equipment is required to be evaluated based upon the ability to obtain replacement parts, the level of staff training required to support the technology and the ease of replacing equipment with newer equipment. ADOT should not use equipment or services that cannot be readily maintained by ADOT technicians – this could lead to lengthy down times of critical infrastructure. ADOT should consider equipment and services that require minimal wait times for replacement parts and training for staff to operate/maintain the infrastructure is available if needed.

Scalability/Expandability:

The FMS communications infrastructure (conduit, fiber cables and equipment) are required to be designed with spare capacity to support the scalability/expandability need with minimal infrastructure replacement.

8.2 Recommended FMS Network Infrastructure Guidelines

This section provides a high level summary of the recommended FMS network infrastructure guidelines that are based on satisfying the network requirements identified in Section 8.1.

8.2.1 Inter-Jurisdictional Connectivity Guidelines

In order to achieve the inter-jurisdictional connections requirements of the FMS, while achieving the FMS network security requirements and the FMS network reliability requirements, this section provides some recommended guidelines for building new FMS communications infrastructure with inter-jurisdictional project partners.

Conduit Systems Interconnectivity:

The preferred way for ADOT to provide inter-jurisdictional connectivity is by having that agency install their own fiber optic cable within ADOT's FMS conduit infrastructure. In order to accomplish this, the conduit system of that agency needs to be interconnected with ADOT's FMS conduit system. **Figure 8-2** depicts ADOT's standard preferred approach for establishing conduit systems interconnectivity:

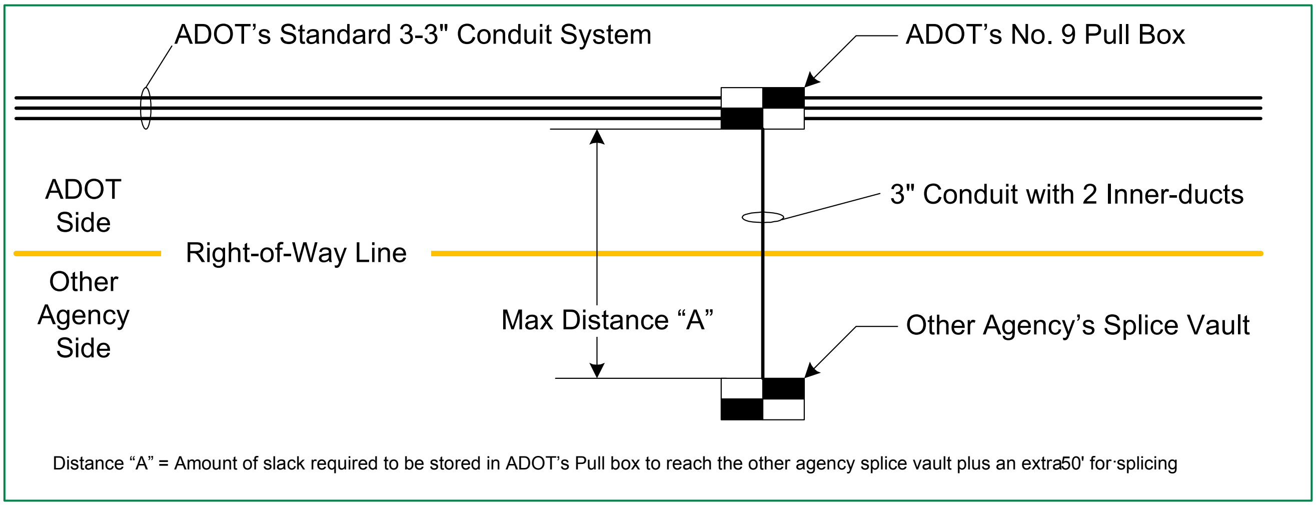


Figure 8-2: Inter-Jurisdictional Conduit Systems Interconnectivity

<u>Fiber Optic Cable Systems Interconnectivity:</u>

When installing a fiber optic cable for another agency to interconnect into ADOT's FMS fiber optic backbone or for another agency that is using ADOT's FMS conduit system to get from point A to point B (i.e. in-and-out of ADOT's right-of-way) it is important to keep in mind that only ADOT's contractor is allowed to pull cables within ADOT's right-of-way. As such, ADOT's contractor will be responsible for performing any fiber splices within ADOT's right-of-way. ADOT's contractor will coordinate with the inter-agency's contractor and pull the fiber optic cable from within ADOT's right-of-way to the other inter-agency splice vault as depicted on **Figure 8-2**.

<u>Interconnectivity within ADOT's Node Buildings:</u>

It is ADOT's standard practice to not allow other agencies to house non-ADOT equipment within a FMS Node Building. In order to maintain ADOT's FMS security requirements, ADOT is required to impose strict limits on who has access to FMS Node Buildings and when access is permitted. As such, it is not practical to allow other agencies to house their equipment in FMS Node Buildings, because it would impose an undue burden on ADOT staff to escort personnel from another agency every time they need to access the equipment within the FMS Node Buildings.

8.2.2 Network Security Guidelines

Various levels of network security are required for the FMS network. This section describes the basic levels of network separation that are required to achieve the tiered access need of the FMS communications infrastructure. Network traffic is defined as the total combination of the various separate networks (Field-to-Node, Node-to-TOC, node/TOC-to-ATOC, other TTG networks, and other department/agency networks) that is being sent over fiber, wireless, or leased line communications. Physical separation of network traffic is described first and represents the highest level of security that can be achieved through the network. Logical separation of network traffic is presented next and it is the least secure approach to sharing network links. Finally, implementing security policies and firewalls to provide security for shared links with no physical or logical separation of the network traffic is presented. All three basic security approaches should be considered for ADOT's FMS network infrastructure; however, only physical and logical separations of networks will have a direct impact on the FMS communications infrastructure.

<u>Physical Separation of Networks:</u>

Physical separation of network traffic will provide the highest level of security by making it physically impossible for someone connected to one distinct network to "hack" into another distinct network. For example, two networks would be physically separate if they were on separate fibers in separate conduits using separate end equipment where the end equipment is not physically connected to another network. This is the preferred case and is recommended to protect the integrity of FMS operations.

With current technology, physical separation can also be achieved over the same fiber using technologies such as Time Division Multiplexing (TDM) and Wave Division Multiplexing (WDM). Using these technologies, it is physically impossible for network traffic on one "time slice" or wavelength to "hack" into a different "time slice" or wavelength. The network equipment technology needed to provide physical separation has a reputation for being more reliable than just using devices that provide logical separation, but is typically more expensive to purchase. The fiber optic cable capacity (i.e., fiber count) being recommended for ADOT can achieve this level of separation without the need for TDM and WDM equipment for many years into the future.

Based on the security needs of ADOT, it is recommended that ADOT require completely physically separate fiber paths for all non-FMS network applications from other uses such as RCN or AZTech™ C2C communications with other agencies. Where physical separation cannot occur, logical separation with measures such as firewalls and permissions level access should be established as defined in the next section.

Logical Separation of Networks:

Logical separation is the most economical type of network separation because the concept allows the use of sharing fibers and equipment without disrupting each of the networks using that equipment. However, a "hacker" on a shared network that is logically separate can break into the network traffic path of other logically separate networks. The standards used to create logically separate networks, like VLAN and ATM, were developed to better manage the traffic on a shared network link, to improve data flows, contain the traffic of broadcast messages, and keep the common user from accessing files that do not pertain to their working group.

Logical separation is required to be the primary level of security for all Traffic/ITS components. For example, FMS field devices such as CCTVs, detectors and ramp meters, and DMS would all be separated logically onto different VLANs but could potentially share the same physical fibers, and associated network equipment. In order to do this, subnets and VLANs will be required to separate the ITS components on the network.

In typical networks, the IP addresses are designated as one of the "private" IP address subnets. The RFC 1918 Private Network Addresses are shown in **Table 8-5** below:

Table 8-5: Private Network IP Addressing

IP address range	number of IPs
10.0.0.0 – 10.255.255.255	16,777,216
172.16.0.0 – 172.31.255.255	1,048,576
192.168.0.0 – 192.168.255.255	65,536

Most large networks typically use the subnet 10.X.X.X. A router on that network would also have a private address such as 10.0.0.1. The use of subnets to separate network traffic is essential for maintenance and management of the network. Geographic addressing assignments also improve network efficiency by allowing for smaller routing tables by using route summarization.

Security Policies and Firewalls:

ADOT's main FMS network that is used to operate FMS Field-to-Node and Node-to-TOC/ATOC communications shall be physically separated from all non-FMS agencies/departments. For example, the ADOT FMS network will have its own fiber assignments providing physical separation requiring firewalls to protect access into the FMS network. Agencies external to ADOT shall not be able to access the FMS Field-to-Node and Node-to-TOC/ATOC networks. If these agencies were able to access the ADOT FMS Field-to-Node and Node-to-TOC/ATOC, they would potentially be able to operate/control ADOT field devices which would require an agreement with each connecting agency for use of their system. This type of access is not recommended for ADOT at this time.

The security policies are required to specify measures that will minimize intrusions from Internet links and from all data links interconnecting networks that are physically separated. IP data activity is comprised of both routing and gateway functions and can include access control restrictions for additional security. This provides the first line of defense by establishing a policy for permitting only hypertext transfer protocol (HTTP) packets (web page information), file transfer protocol (FTP) packets (file transfer outgoing), and e-mail to pass through the firewalls. A policy to restrict telnet, which allows remote users to login to a system, would be a recommended policy to enforce via a firewall. By excluding almost all content and then only including permissible applications, ADOT can create a network architecture that is much easier to operate, manage, and troubleshoot. It also reduces the likelihood of attacks generated from other systems or users from remote locations that do not possess the same level of security for ADOT's internal network.

If ADOT makes an exception and does not provide physical separation where it is typically required, it is recommended that they perform a thorough probe of the potential vulnerabilities that exist prior to connection and periodically conduct updates. The SANS Institute has a link to an automated network vulnerability scanner, which is available for download at http://oval.mitre.org/. This scanner is provided by Open Vulnerability Assessment Language (OVAL). The OVAL Board includes members from major operating systems vendors, commercial information security tool vendors, academia, government agencies, and research institutions.

Firewalls cannot protect against network traffic that does not go through the firewall. If internal users are given unrestricted access to the Internet, it would defeat the intent of the firewall. It is extremely important that all outside networks connecting to the FMS Field-to-Node and Node-to-TOC/ATOC be routed through a firewall.

Impacts of Network Security on Bandwidth:

If the FMS Field-to-Node and Node-to-TOC/ATOC were not required to support physical and logical separation of networks for security reasons, and if all users of the network could share the available bandwidth (similar to the way the Internet is being used), then there would be no additional bandwidth impacts to the network. This is not the case for the network recommendations and some level of separation between several of the networks will be required. The use of both logical and physical levels of network separation will ultimately result in network bandwidth (and fibers) that are reserved for specific links which cannot be shared by all users. These additional bandwidth/fiber impacts that the required levels of separation will have on the FMS network cannot be quantified to any degree of accuracy. The impact is largely dependent on specific links, the types of applications and quantity of devices utilizing network links.

8.2.3 Network Reliability Guidelines

One of the most important design techniques to building reliability into a communications network for ADOT is redundancy. This means that if one part of the system fails (i.e. one communications path); there is an alternate success path that can act as a backup communications path. Redundancy significantly increases system reliability through the use of multiple paths to critical devices or facilities such as the ADOT TOC.

Path diversity and equipment redundancy within the FMS network are required to meet the reliability needs of ADOT. Security policies and network equipment built to meet reliability standards can have a significant impact on improving network reliability. However, path diversity and equipment redundancy to protect from single points of failure will provide the greatest reduction in system down time. Network equipment is expected to be down from time to time due to system problems or planned outages for network upgrade activities. The only way to make these inevitable occurrences invisible to the users of the system is to have an alternate path for the network traffic to use while the outage is occurring.

The following subsections define and establish levels of diversity that will be used to interconnect field devices and facilities based on priority level. There are two methodologies that can be implemented to establish levels of diversity to create a more reliable and secure network. The first is path diversity and the second is physical separation of telecommunications infrastructure and these are described more in the following subsections. Both methodologies will play an integral part in the interconnection of facilities and field devices to the FMS network.

Fiber Path Diversity Levels:

Path diversity is defined as the types of path structures available to interconnect field devices and facilities to the fiber backbone network. Two paths are recommended when connecting all devices and facilities on the fiber network in order for each device to have redundant communications to ensure that communications to the device is not lost if one path has a failure. ADOT currently has a standard for a 96-fiber SMFO cable for its fiber optic backbone. This could mean that the path traveling to the device is utilizing one fiber of a 96-fiber SMFO cable and the second path is utilizing a separate fiber of the same 96-fiber SMFO cable, whereby each fiber is able to operate independent of the failure of the other. Or, this could also mean that the paths are traveling through separate 96-fiber SMFO cables entirely, which are then separated by some distance (such as either side of a freeway). Path diversity is the definition of a minimum of two separate paths for the information from each device or facility to travel back to the Node Building or TOC/ATOC.

Figure 8-3 shows a cross section of a conduit with two fiber optic cables inside. The physical size of the conduit and fiber optic cables is not drawn to scale. For presentation purposes, each SMFO cable does not show all eight buffer tubes or all twelve fiber strands in each buffer tube that would total 96 fibers.

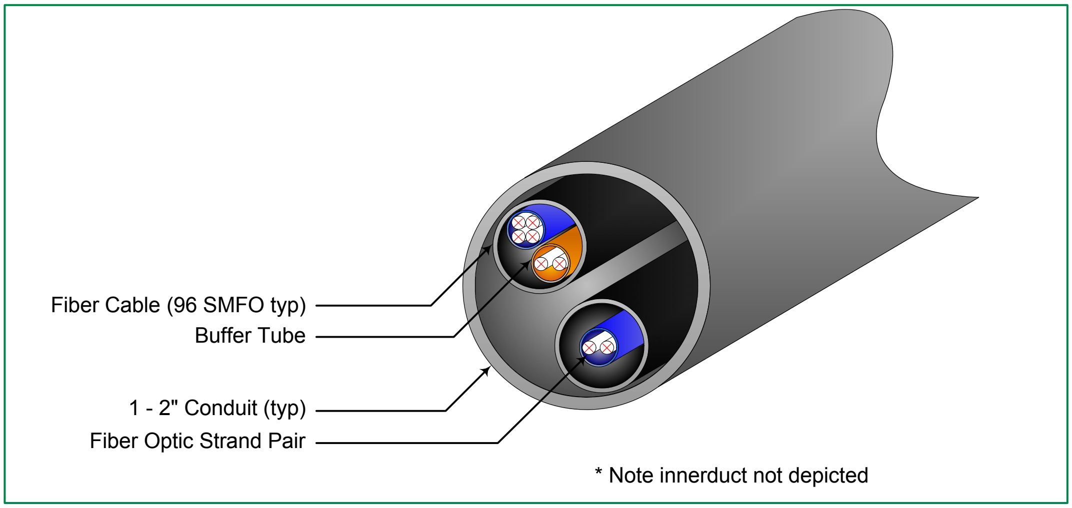
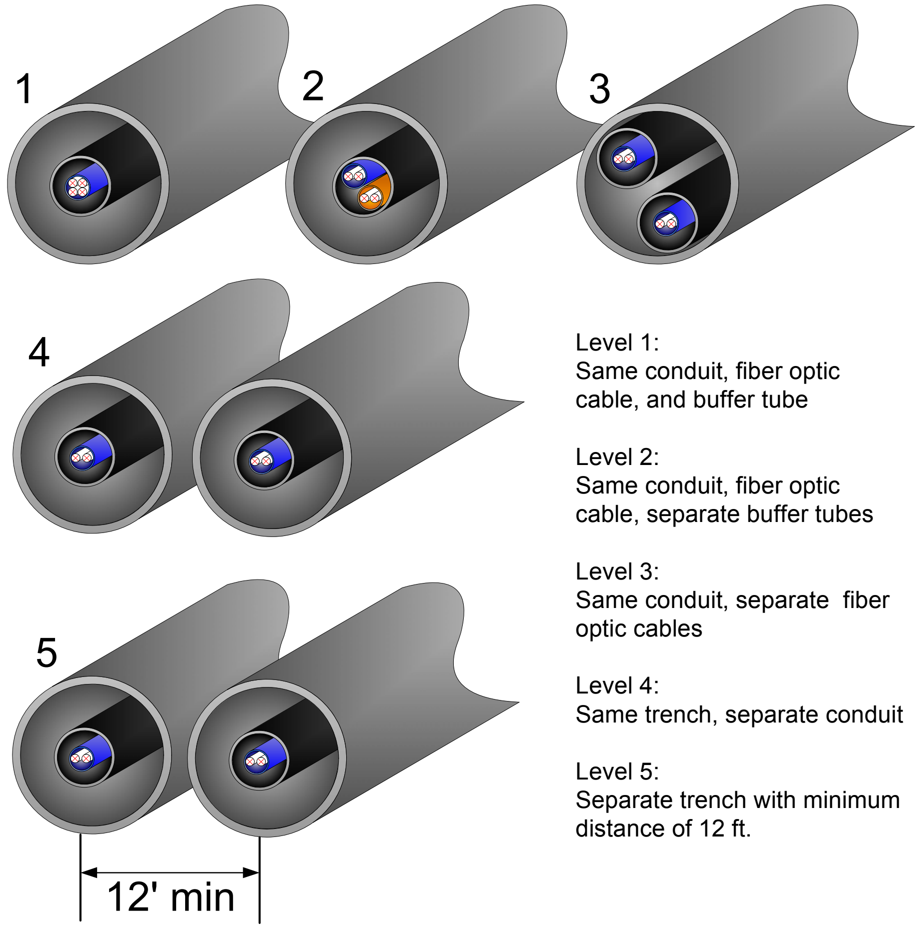


Figure 8-3: Communications Conduit and Fiber Optic Cable Cross Section

The path diversity options for fiber connectivity designate the required number of fiber strands, number of SMFO cables, and location of the distribution cables in conduit necessary to interconnect a given device or facility to the FMS network backbone SMFO cables. Each location throughout the ADOT FMS will need to be connected to the network using a fiber branch cable (of size 6, 12, 24, or other number of fibers) that will need to be spliced into the 96-fiber SMFO backbone cable.

The five path diversity levels for fiber connectivity that would be used to interconnect a given location (field device cabinet, Node Building, and TOC/ATOC facility) to the FMS fiber optic network are shown in **Figure 8-4**. A total of five levels of path diversity have been established within the telecommunications industry and the level required to connect a specific type of location is dependent on the operational function at that location and the impact to the overall network topology if that location is lost. Level 5 is recommended for the ADOT FMS fiber optic backbone paths connecting FMS Node Buildings and TOC/ATOC facilities.



Level 1:
Same conduit, fiber optic cable, and buffer tube

Level 2:
Same conduit, fiber optic cable, separate buffer tubes

Level 3:
Same conduit, separate fiber optic cables

Level 4:
Same trench, separate conduit

Level 5:
Separate trench with minimum distance of 12 ft.

Figure 8-4: Path Diversity Levels for Fiber Connectivity

Levels of Separation for Conduit Systems:

The levels of separation that have been established refer to the varying physical separation of the individual paths identified for redundancy to each device and facility. The level nomenclature correlates to the levels of fiber connectivity established in the previous section, where a location with Level 1 path diversity would have the corresponding Level 1 conduit separation.

Figure 8-5 illustrates the levels of conduit separation as it relates to the path diversity options. Even though Level 1 – 3 of the path diversity options show fiber in the same conduit, an additional conduit will be required as a spare for future use as shown in **Figure 8-5**. Levels 1 – 4 will share the same conduit configurations because the distribution conduit will share a common trench with less than 12' of separation. Levels 1-4 are therefore more susceptible to lose complete communications to devices/facilities upstream along the fiber cable if the trench that the conduit configuration is severed or disrupted for any reason. For field devices, (traffic signals, CCTV, DMS, traffic detection) Levels 1 – 4 are recommended as the importance of maintaining communications to each individual device is not as important as maintaining communications to essential facilities such as the ADOT Node Buildings and TOC/ATOC facilities, which requires Level 5 separation.

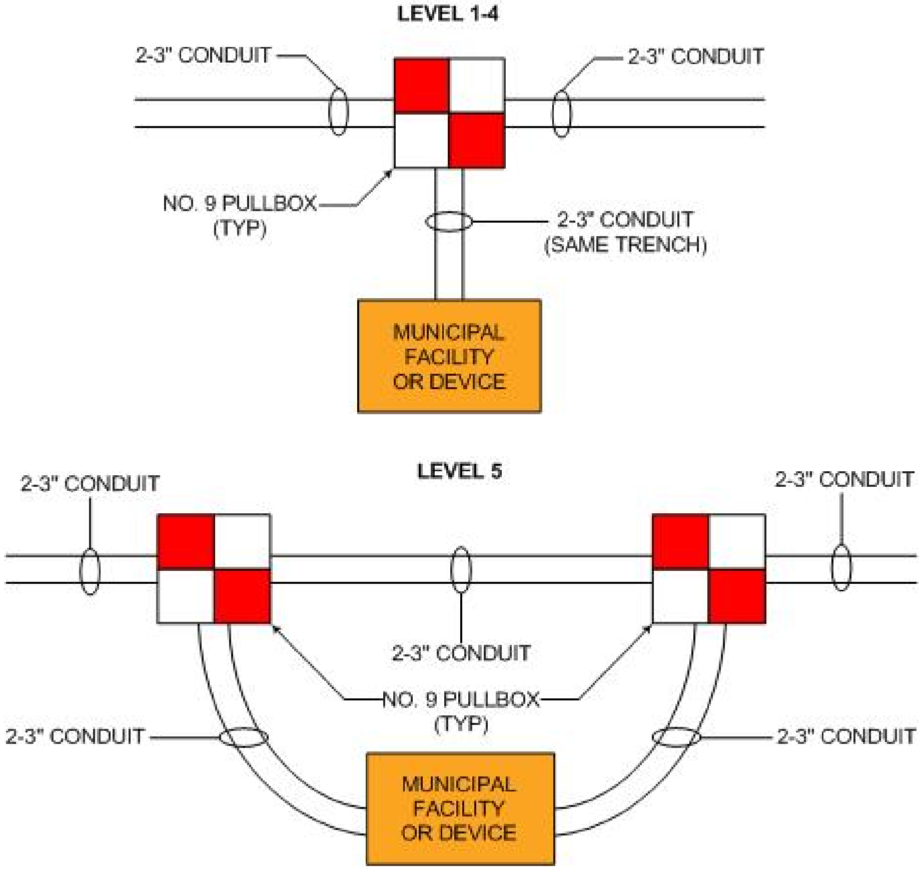


Figure 8-5: Levels of Separation for Conduit

A Level 5 configuration shows two distinct conduit paths entering a given location with a minimum of 12' of separation. Conduit should be placed between the two No. 9 pull boxes even if fiber does not pass through it. Level 5 has been established for critical locations/devices around the country to ensure alternate connectivity paths are available if one pathway is severed or disrupted. This configuration allows a contractor during construction or maintenance activity to take one pathway out for required construction tasks, but maintain the other connection for the duration of the construction until the first path is restored, at which time the second path may be taken out.

Level 5 separation of fiber entering the ADOT TOC/ATOC and FMS Node Buildings is recommended due to the added security of the fiber cable connections by establishing paths separated by a substantial distance to mitigate both paths being severed at the same time. This separation of fiber will give the ADOT TOC/ATOC and FMS Node Buildings added redundancy of the fiber backbone network. The RCN project has established a second conduit path entering the ADOT TOC – it is recommended that the existing ADOT fiber optic backbone cable segments entering into the TOC be re-routed to establish a secondary path for fiber connectivity into the ADOT TOC to support redundancy of the FMS system.

The main fiber backbone cable should also be configured in such a way that provides separation of the two paths that will bring communications from a single device or facility back to the ADOT TOC. Fiber backbone "rings" establish separation of two paths by providing a backbone cable for devices and facilities to connect to along priority corridors in a ring shape that then physically enters the ADOT TOC from two different directions. While it is general practice to establish a minimal number of rings to be able to connect a majority of the devices/facilities in the FMS network, it is recommended that the main fiber optic backbone cables be configured in a Level 5 separation to maximize the redundancy and security of the main communications for ADOT.

Communications Node Equipment Redundancy:

Communications node equipment redundancy is another type of network reliability requirement that the FMS network will have to support to minimize the potential for system down time. Redundancy is achieved through the connection of at least two separate sets of equipment in the ADOT TOC or Node Building that is connected to the fiber optic backbone network. If one set of equipment is not working, the other set of equipment is ready to accept the role of communications in its place. With redundant communications node equipment, the network can sustain planned or unplanned down time of the node equipment without ADOT losing connectivity. Currently the Field-to-Node communications topologies being used by ADOT and the associated equipment within the Node Buildings being used to achieve interconnectivity to the Node-to-TOC/ATOC network are susceptible to a single point of failure which would cause a large geographical area of the FMS to go down if a device within the node or the entire node was to experience a failure. However, until ADOT is ready to migrate to IP-based Ethernet out to the field cabinet level, using a Hybrid Flower topology, the Node Building will continue to be a point of vulnerability within the FMS network. The greatest point of vulnerability within the overall FMS network is the TOC and until such time that the ATOC is established the TOC will remain a point of vulnerability within the FMS network.

Impacts of Network Reliability on Bandwidth:

The reliability level that is planned for a network also can have an impact on the amount of bandwidth that is perceived to be available. For example, a communications link between two locations could have two diverse paths for network traffic to transverse, but the amount of available bandwidth is dependent on the link that offers the least amount of bandwidth. It is easy to confuse this issue and say that the amount of available bandwidth is the combined total bandwidth of the two links, which is the case when there is not a link failure. However, if there is a link failure, then the amount of available bandwidth is limited to the bandwidth of the other link providing the alternate path. If this limited bandwidth perception is kept in mind, then over allocating of the available bandwidth will not become a factor and the deployment of the FMS network will maintain the required reliability level.

9 EXISTING FMS NETWORK INFRASTRUCTURE EVALUATION

Each FMS deployment phase expands FMS coverage into new geographic areas and each of these deployment phases have resulted in ADOT having a mixture of varying types of communications network technologies in different geographic areas of the region. Although this mixture of different types of communications technologies has been limited through standard FMS communications approaches, the shear length of ADOT's FMS existence has resulted in a mixture of technologies as the standards have evolved over the years. It has been ADOT's policy to select communications technologies that can withstand the test of time. In addition, ADOT does not desire to replace existing infrastructure that is currently working, still practical to maintain, and achieving the basic needs of the FMS.

This evaluation provides answers to the following questions:

- Is it still practical to maintain some of the aging communications technologies deployed?
- Does the existing infrastructure achieve the current basic FMS communications needs?
- Is it time to change the standard FMS communications approach for new deployment areas?

The purpose in answering the above questions, for each type of communications technology approaches currently deployed, is to ultimately provide recommendations on:

- What existing technologies need to be phased out to achieve current day FMS communications needs?
- What is the new standard communications approach that will be used to replace these technologies?

This evaluation compares the various existing communications technologies/approaches to the Standard FMS Network Requirements and Guidelines in Section 8 to see if they achieve ADOT's current and future FMS network needs.

Figure 9-1 is a high-level depiction of the FMS Field-to-Node and Node-to-TOC communications architecture and central system processing platforms that were deployed as of July 2009. The Node-to-TOC communications backbone approaches are evaluated first within this section of the report, followed by Field-to-Node communications. Within each respective section a summary of evaluation conclusions and recommendation are also provided.

9.1 Node-to-TOC Existing Network Approach Evaluation

Currently ADOT is in the process of upgrading the FMS Node-to-TOC/ATOC communications backbone from the various types of multiplexing systems deployed in the past to a 10 Gigabit Ethernet backbone ring. Both the multiplexing systems approach and the 10 Gigabit Ethernet approach that ADOT had deployed have been evaluated to see if they achieve ADOT's current and future FMS network needs.

As depicted in **Figure 9-1**, Node Buildings 3/4, 6, 10, 11, and 13 on the left hand side of the diagram are using the multiplexed methods. The diagram shows how each type of multiplexer system from each Node Building requires its own dedicated fiber path to the TOC. The right hand side of the figure shows Node Buildings 7, 8, 9, 12, and 14. These five buildings have the 10 Gigabit Ethernet equipment installed and they share the same fiber pairs back to the TOC on the 10 Gigabit Ethernet ring.

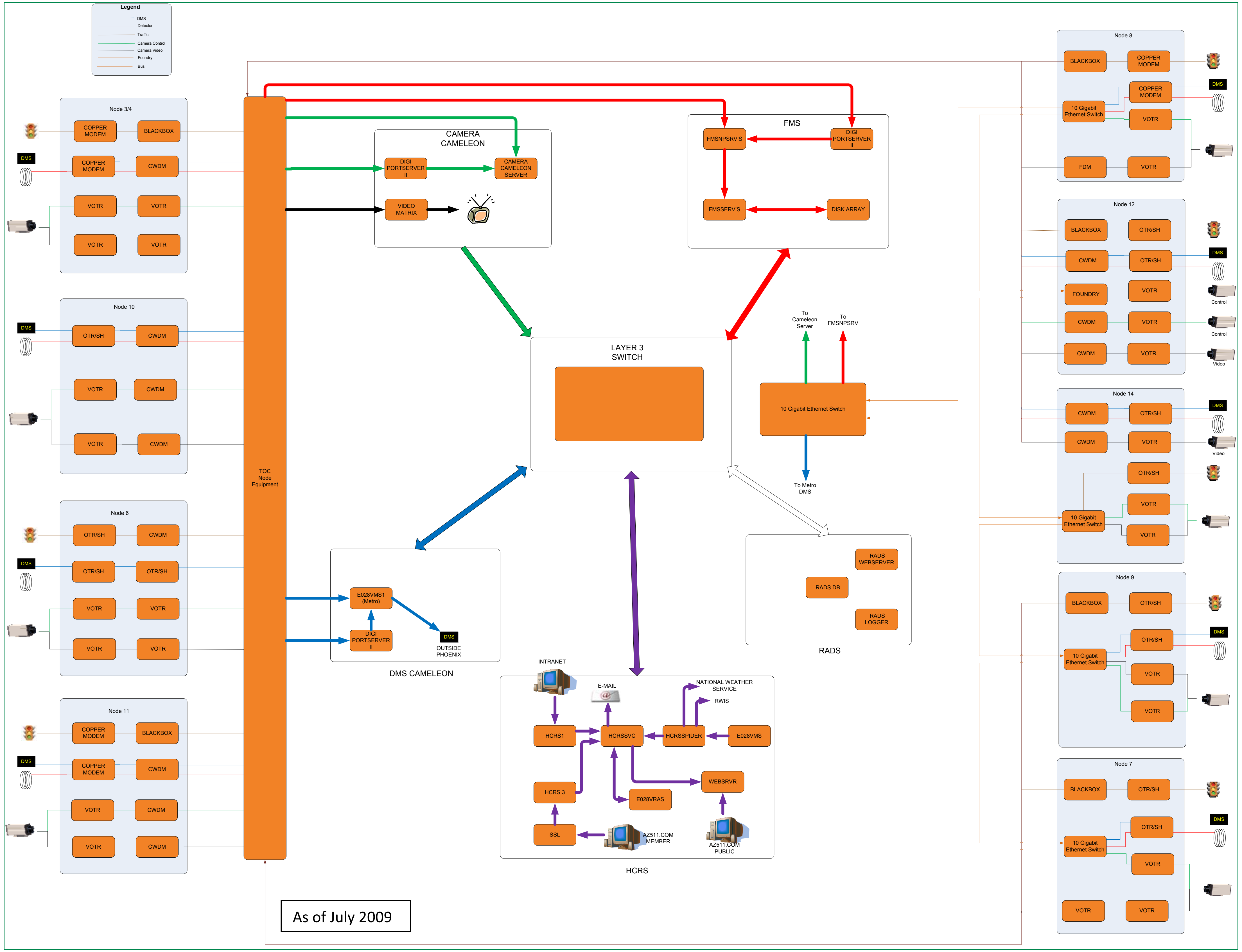


Figure 9-1: Node Building and TOC Interconnect diagram

9.1.1 Existing Multiplexed Systems Approach

Historically the ADOT FMS Node-to-TOC communications approach consisted of multiplexing multiple video and data signals from the field at the Node Building. These multiplexed signals are then transmitted independently from each Node Building to the TOC over dedicated fiber strands. In the early days of the FMS, a FDM system approach was deployed to achieve Node-to-TOC communications. Within the last decade, ADOT started to deploy a more sophisticated multiplexing platform called a CWDM system for all new FMS deployment projects. The main reason for moving away from the FDM and deploying the CWDM was due to the fact that FDM technology has reached the end of its lifecycle. Additionally, maintaining the FDM equipment has become very challenging because spare FDM parts are very limited within the industry.

As of July 2009, there were ten Node Buildings on the ADOT FMS network, five of which were still transmitting on these multiplexed systems (Node Buildings 3/4, 6, 10, 11, and 13). These existing multiplexing systems require dedicated fiber strands from the Node Buildings to the TOC as shown in **Figure 9-2**.

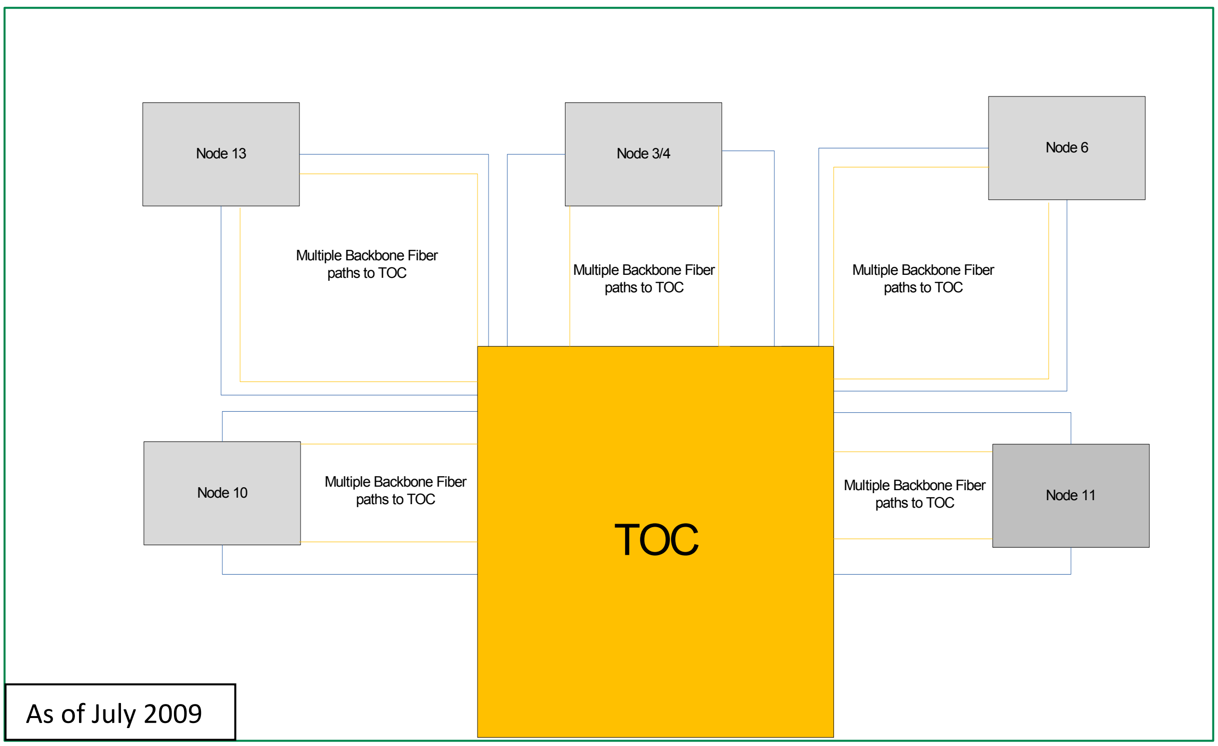


Figure 9-2: Existing Multiplexed C2C Communications from Node Building to TOC.

In the existing multiplexing system architecture, network bandwidth is more a function of available channels (frequency bands or wave lengths) than available bits per second bandwidth. The existing multiplexing system alternative relies heavily on fiber availability and the distance between the Node Building and the TOC. If ADOT was to continue deploy these types of multiplexing systems for future FMS deployments that are by their nature further and further away from the TOC, then ADOT would continue to need dark fibers and equipment mounting space within existing Node Buildings (i.e. for repeater equipment) within the TOC for the receiving end of the multiplexing equipment.

The following are the results of evaluating how this multiplexed systems approach (existing at Node Buildings 3/4, 6, 10, 11, and 13 as of July 2009) fits within ADOT's current Node-to-TOC communications requirements.

Fiber Optic Conduit and Cable Fault Tolerance:

If a fiber optic trunkline/backbone conduit/cable is severed/cut (planned or unplanned) in a single location, then the Node Building devices still maintain communications with the TOC as required. However, in areas where ADOT has only deployed fiber optic cable on one side of the freeway and that is shared for both primary and secondary Node-to-TOC communications paths. Using the existing multiplexing equipment in combination with fiber on one side of the road creates a situation where this basic FMS communications requirement is not achievable.

Node Building Device or Power Fault Tolerance:

- If one or more communications devices are lost at the Node Building or the Node Building loses power, then **all other Node Buildings** still maintain communications with the TOC as required. However, this requirement is not achieved for node-to-ATOC communications. All of the existing Node Buildings that are connected using multiplexing equipment are highly dependent on the TOC communications node for achieving communications to the ATOC. If there is a major failure at the TOC, then the ability for the ATOC to communicate directly with the Node Buildings is completely lost.
- If one or more communications devices are lost at a Node Building, then **all FMS field devices** (i.e., DMS, detector station, ramp meter, and CCTV) connected to the Node Building loose communications with the TOC. Using multiplexer equipment prevents ADOT from achieving field device path diversity between two different Node Building locations.

Physical FMS Network Separation:

The use of separate channels (frequency bands or wave lengths) within the multiplexing systems equipment can support physical network separation between FMS networks and other agency/department networks as required. However, the added cost needed for these additional channels and the resulting need to maintain these separate non-FMS channels from within an ADOT FMS Node Building makes using multiplexing equipment less desirable then the separate fiber path alternative to supporting other agency/department networks.

Logical FMS Network Separation:

Although logical FMS network separation and MAC addressing blocking are requirements for IP-based Ethernet network technologies and do not directly apply to multiplexing technologies, the multiplexing technologies do achieve network separation of FMS WAN traffic by having CCTV video, CCTV control, detector and ramp meter stations, and DMS traffic all separated into different channels.

Inter-Jurisdictional Connectivity Requirements:

ADOT's existing fiber infrastructure was purchased for current and future ADOT FMS network communications needs. ADOT is limited in its ability to allow other agencies to share fiber resources.

Bandwidth Requirements:

As previously discussed, bandwidth in multiplexing systems is more a function of available channels (frequency bands or wave lengths) than available bits per second bandwidth. In order to provide additional bandwidth capacity within the existing multiplexing systems, ADOT needs to purchase additional multiplexing system components In the case of the existing FDM equipment, purchasing new components may not even be an option because this technology has reached the end of its lifecycle. Purchasing new components for the existing CWDM equipment can become impractical from a cost perspective due to the complexity of the technology and the sole-source proprietary nature of the existing equipment.

Availability and Maintainability:

Obtaining parts and services for the relatively new CWDM equipment is also very limited as a direct result of the sole-source proprietary nature of the existing equipment currently deployed.

No Cutting Edge Technologies:

The proven multiplexing technologies that ADOT has deployed are no longer considered cutting edge technologies. In the past, cutting edge technologies like the FDM equipment were the only real platforms available in the market that could achieve the reliability/path diversity needs of the FMS program. The ability of the CWDM technology to grow within the market place with open platform standards that multiple vendors support in a single/common platform is far less than what was sold by the telecommunications industry as these technologies started to emerge. The existing CWDM equipment was cutting edge technology when ADOT began deployment and ADOT is now facing the costly realities of this sole-source proprietary equipment.

Interoperability, Scalability and Expandability:

Although the multiplexing technologies are proprietary equipment that require dependency on a single vendor for parts and service, these technologies do support a variety of industry standard interfaces for connecting other lower capacity network links (i.e., EIA-232, EIA-422, Ethernet, NTSC, etc.). The existing FDM equipment no longer meets this criterion because it is not practical to obtain the new parts that would be necessary to add new interface types and expand the capacity (i.e., channels) within the existing systems. CWDM technology achieves this requirement from a capacity perspective because new components are still available in the market to add channels and interfaces at the Node Building locations. However, the CWDM falls significantly short from a geographical expansion perspective. An entire new CWDM platform is needed every time the FMS grows geographically and adds a new Node Building location. This new CWDM platform requires new fiber paths back to the TOC and new equipment at the TOC.

9.1.2 Current 10 Gigabit Ethernet Ring Approach

ADOT has started to implement a 10 Gigabit Ethernet ring (at five of the ten Node Building locations, as of July 2009). In this alternative, conversion to Ethernet takes place at the Node Buildings, thus eliminating the multiplexing equipment and the fiber availability limitations at each Node Building.

By digitally encoding and compressing the signal at the Node Building level of the network architecture, the amount of backbone fiber cable required is reduced and a greater level of system flexibility is obtained. The 10 Gigabit Ethernet network signals then travel along the backbone to other Node Buildings along an ultimate path to the TOC, and the ATOC at some point in the future. **Figure 9-3** illustrates the existing 10 Gigabit Ethernet ring. It can be noted that only two backbone fibers are required along one side of the freeway in each freeway segment to complete the ring for these five Node Buildings.

The VLANs depicted in **Figure 9-3** demonstrate how the bandwidth located within the 10 Gigabit Ethernet backbone is logically separated into separate IP subnets.

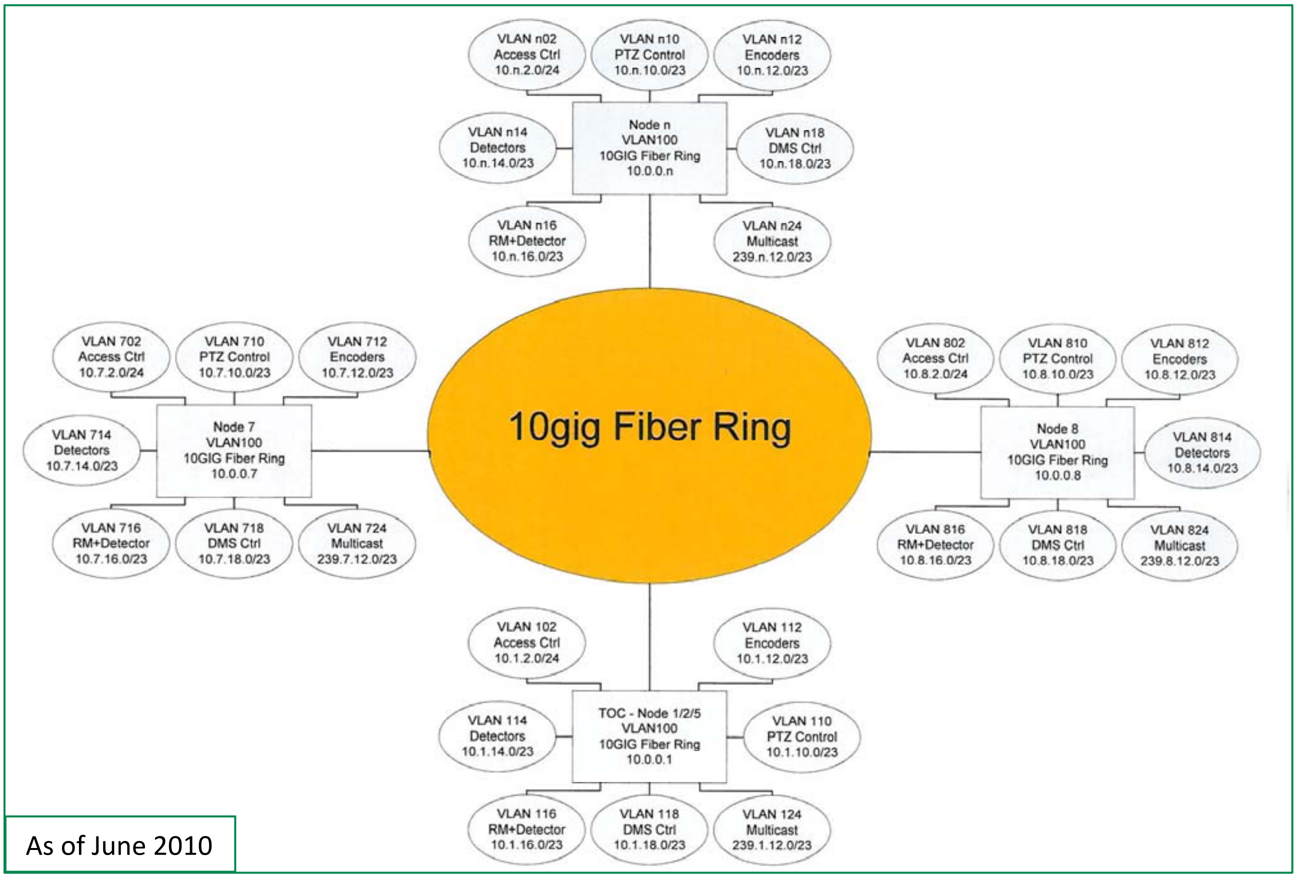


Figure 9-3: Current 10 Gigabit Ethernet Ring

The following are the results of evaluating how this 10 Gigabit Ethernet approach (deployed at Node Buildings 7, 8, 9, 12, and 14, as of July 2009) fits within ADOT's current Node-to-TOC communications requirements:

Fiber Optic Conduit and Cable Fault Tolerance:

If a fiber optic trunkline/backbone conduit/cable is severed/cut (planned or unplanned) in a single location, then the Node Building devices still maintain communications with the TOC as required. This is also true in areas where ADOT has only deployed fiber optic cable on one side of the freeway because the 10 Gigabit Ethernet ring spans multiple freeway segments to achieve its path diversity.

Node Building Device or Power Fault Tolerance:

- If one or more communications devices are lost at the Node Building or the Node Building loses power, then **all other Node Buildings** still maintain communications with the TOC as required. This is also true for future node-to-ATOC communications, since the 10 Gigabit Ethernet ring is not dependent on the node equipment at the TOC for achieving communications to the ATOC. If there is a major failure at the TOC, then the ability for the ATOC to communicate directly with the other Node Buildings remains intact.
- If one or more communications devices are lost at a Node Building, then **all FMS field devices** (i.e. DMS, detector station, ramp meter, and CCTV) connected to the Node Building lose communications with the TOC. Using 10 Gigabit Ethernet equipment provides ADOT with the ability to accomplish field device path diversity between two different Node Building locations. If ADOT plans to extend the Ethernet links out to the field device cabinet locations using the Hybrid Flower topology method, this 10 Gigabit Ethernet ring will support this type of topology.

Physical FMS Network Separation:

The use of VLAN logical separation between FMS networks and other agency/department networks is not recommended. However, switching from the multiplexer platforms to the 10 Gigabit Ethernet platform frees up fibers within the backbone cables that could be used to achieve physical fiber separation between the FMS networks and other agency/department networks.

Logical FMS Network Separation:

Logical FMS network separation FMS WAN traffic is supported and being accomplished by having separate VLANs for CCTV video, CCTV control, detector and ramp meter stations, and DMS traffic. MAC address blocking at the Node Building level is not required due to the existing physical security precautions already deployed at the Node Buildings. However, MAC address blocking is required at the field cabinet level if ADOT decides to extend the Ethernet links down to the field device cabinets.

Inter-Jurisdictional Connectivity Requirements:

Since the 10 Gigabit Ethernet approach does not require reserving fiber capacity for future Node Building locations and migrating to the 10 Gigabit Ethernet approach frees up more available fiber, there is less reluctance in allowing other agencies to use ADOT's remaining available fiber resources.

Bandwidth Requirements:

As previously discussed in Section 8.1.4 - FMS Bandwidth Requirements, 10 Gigabits of bandwidth provides sufficient capacity to serve all of ADOT's current and foreseeable future bandwidth needs.

Availability and Maintainability:

In the case of the existing 10 Gigabit Ethernet equipment, obtaining parts and support for the equipment is readily available from multiple vendors within the current market place. Because networks built using Ethernet standards represents the largest (on a per port basis) type of network technology currently deployed within the U.S. there are countless education programs available to train staff in maintaining this equipment.

No Cutting Edge Technologies:

The Ethernet technologies that ADOT has deployed are tried and true standards based technologies that are not considered cutting edge technologies. Proven independent interoperability tests of Ethernet standards across multiple vendor platforms provides ADOT assurances that these parts and services will continue to be available to maintain this equipment for the foreseeable future.

Interoperability, Scalability and Expandability:

As with all technologies, Ethernet based technologies do offer some feature sets that are not 100% compatible across multiple vendor platforms. However, what sets Ethernet apart from the other technologies is that the proprietary functionality is very limited and the vast majority of feature sets are based on openly adopted standards. Ethernet has been in the market place for decades and interfaces (also known as bridges) are widely available for many manufacturers that support interoperability with other industry standard interfaces such as: EIA-232, EIA-422, Ethernet, NTSC, etc. Ethernet technologies are also very scalable in terms of capacity and from a geographical expansion perspective. As the FMS grows geographically and adds new Node Building locations, there is no need to find available fiber paths back to the TOC and no need to add new equipment at the TOC or ATOC. ADOT only needs to tap into the same pair of fibers that the other nodes are connected to and extend this existing ring into the new geographical area.

9.1.3 Node-to-TOC Evaluation Conclusions and Recommendations

The results of the Node-to-TOC existing infrastructure evaluation are summarized below by answering the following questions:

Is it still practical to maintain some of the aging communications technologies deployed?

It is no longer practical for ADOT to continue maintaining the existing FDM equipment that has reached the end of its lifecycle. It is recommended that ADOT make it a priority to replace all the existing FDM equipment with newer technology.

Does the existing infrastructure achieve the current basic FMS communications needs?

Although not the ideal solution, the existing CWDM equipment does satisfy ADOT's immediate communications needs in some of the locations it is deployed. In areas where ADOT has chosen to deploy fiber backbone cable on one side of the freeway, and not both sides, the CWDM equipment no longer meets ADOT's reliability needs. It is recommended that ADOT make it a priority to replace all the existing CWDM equipment with newer technology in areas where fiber backbone cable is limited to one side of the freeway.

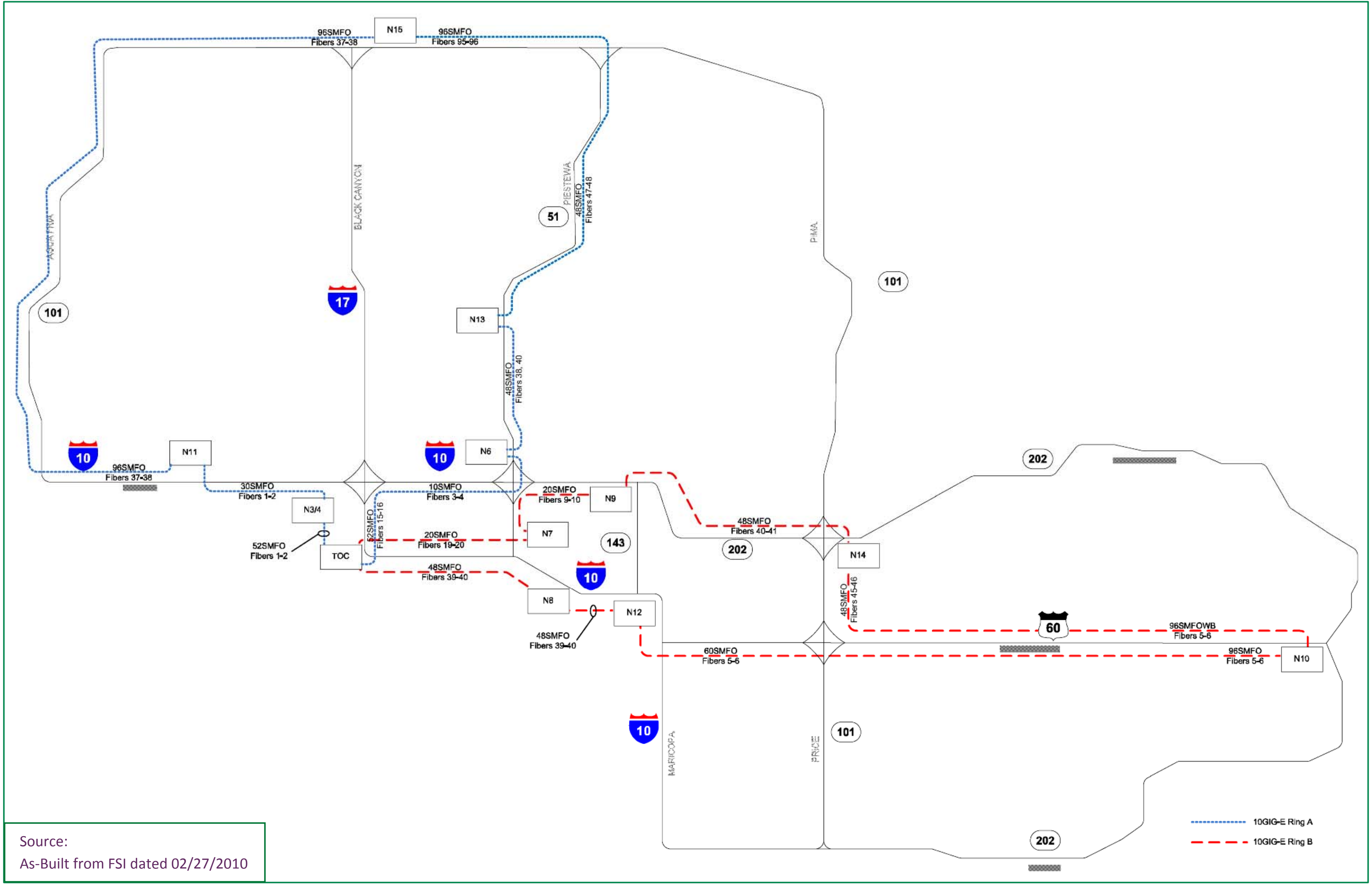
Is it time to change the standard FMS communications approach for new deployment areas?

ADOT should look to change their existing standard FMS communications approach for new deployment areas. The old multiplexing equipment standards (FDM and CWDM) for node-to-TOC no longer achieve ADOT's long term communications backbone needs. This is especially true in terms of making the ATOC an integral part of the overall FMS fiber backbone WAN architecture.

What is the new standard communications approach that will be used to replace these technologies?

The 10 Gigabit Ethernet fiber backbone communications approach is the communications approach that achieves all of near term FMS communications needs and requirements. **Figure 9-4** provides a visual illustration of the new Node-to-TOC standard communication approach that ADOT has started deploying.

This approach will need to be modified in the future to accommodate the long term FMS communications need of incorporating the ATOC into the FMS 10 Gigabit Ethernet fiber backbone. When ADOT is ready to connect the ATOC to this communications backbone, it is recommended that both 10 Gigabit Ethernet backbone rings (Rings A and B) are extended to the ATOC to avoid a single point of failure (of 10 Gigabit Ethernet Ring B) at the TOC node.



Source:
As-Built from FSI dated 02/27/2010

Figure 9-4: Standard Node-to-TOC Backbone Communications Approach

9.2 Field-to-Node Existing Network Approach Evaluation

The current ADOT FMS Field-to-Node communications distribution approach of field devices consists of analog optical or electrical transmission to communications Node Buildings in the field. CCTVs in the existing approach communicate with the closest communications Node Building using legacy point-to-point VOTR. During FMS Phase 1 and Phase 2 deployments, multi mode fiber was deployed as the communications media for Field-to-Node CCTV communications, and subsequent FMS Phases started using a single strand of fiber within the single mode fiber backbone cable for each CCTV field cabinet location.

Over the years, different Field-to-Node communications distribution approaches have been deployed for the detector, ramp meter, and DMS field device cabinet locations. Initially in FMS Phase 1 and Phase 2, shared multi-drop data distribution rings, over twisted-wire-pair (TWP) cables were utilized, for connecting both detector and ramp metering cabinets. A separate multi-drop data distribution ring, over TWPs, was used for the DMS communications circuits. After FMS Phase 1 and Phase 2 were completed, ADOT stopped deploying TWP cables and began to deploy multi-drop data distribution rings using the single mode fiber optic cable backbone. In the original designs, the TWP and single-mode fiber optic cable rings were deployed along both sides of the freeway to accomplish the added redundancy of having “physical rings,” as opposed to the limited redundancy of the folded ring topology.

In subsequent years ADOT started experiencing mechanical faults in the TWP distribution rings and made a maintenance decision to correct the problem by eliminating faulty self-healing ring components and continue with the non-redundant daisy-chain resulting topology. In recent FMS projects ADOT decided to only deploy the fiber optic backbone cable on one side of the freeway, as opposed to both sides, which has resulted in deploying a folded ring topology.

An evaluation of each of these Field-to-Node communications topologies currently deployed by ADOT, along with a new “Hybrid Flower” topology that ADOT should consider, is provided in Section 6 - Physical Network Topology Alternatives.

9.2.1 Field-to-Node Evaluation Conclusions and Recommendations

The results of the Field-to-Node existing infrastructure evaluation are summarized below by answering the following questions:

Is it still practical to maintain some of the aging communications technologies deployed?

It is no longer practical for ADOT to continue maintaining the existing TWP communications infrastructure and equipment that has reached the end of its lifecycle. It is recommended that ADOT make it a priority to replace all the existing TWP infrastructure and equipment with a newer technology using a single mode fiber optic backbone cable along both sides of the freeway where TWP cables exist today.

It is no longer practical for ADOT to continue maintaining the existing multi mode communications infrastructure and equipment. It is recommended that ADOT replace all the existing multi-mode fiber infrastructure and equipment with a newer technology using a single mode fiber optic backbone cable along both sides of the freeway where both multi mode fiber and TWP cables exist today.

Does the existing infrastructure achieve the current basic FMS communications needs?

The existing single mode point-to-point CCTV infrastructure between the CCTV field cabinets and the respective Node Building, does not accomplish ADOT’s basic needs because this approach does not protect against conduit/cable breaks.

The single mode fiber distribution rings for detector, ramp metering, and DMS circuits does satisfy ADOT’s immediate communications needs in some of the locations it is deployed. In areas where ADOT has chosen to deploy fiber backbone cable on one side of the freeway, and not both sides, the resulting folded distribution rings no longer meet ADOT’s reliability needs.

Is it time to change the standard FMS communications approach for new deployment areas?

It is time for ADOT to change the standard FMS communications approach for new deployment areas and areas where ADOT's basic FMS communications needs are not being met.

What is the new standard communications approach that will be used to replace these technologies?

The new "Hybrid Flower" topology approach (as described in Section 6.5 - Hybrid Flower Topology) is the Field-to-Node communications approach that achieves all of near term and long term FMS communications needs and requirements.

10 *ADOT FMS COMMUNICATIONS UPGRADE MIGRATION PLAN*

This section describes the necessary steps for ADOT to migrate from their existing communications approach to the new standard communications approach for Node-to-TOC and Field-to-Node communications as identified within this report and summarized within Section 10.1.

10.1 Standard FMS Communications Approach

All freeway segments requiring new FMS infrastructure (ITS devices and communications) or requiring significant impacts to the existing FMS infrastructure shall be designed using the standard FMS communications approach identified within this section, with the exception of design (requiring construction plans and special provisions) projects that have a Notice-to-Proceed (NTP) date before the date of this report.

10.1.1 Node-to-TOC Communications Standard

The current Node-to-TOC backbone communications standard approach is a 10 Gigabit Ethernet backbone configured in a two ring topology (Rings A and B) connected in the center by a layer 3 Ethernet switch in the TOC, as depicted logically in **Figure 10-1** and depicted geographically in **Figure 9-4**, shown in Section 9 of this report.

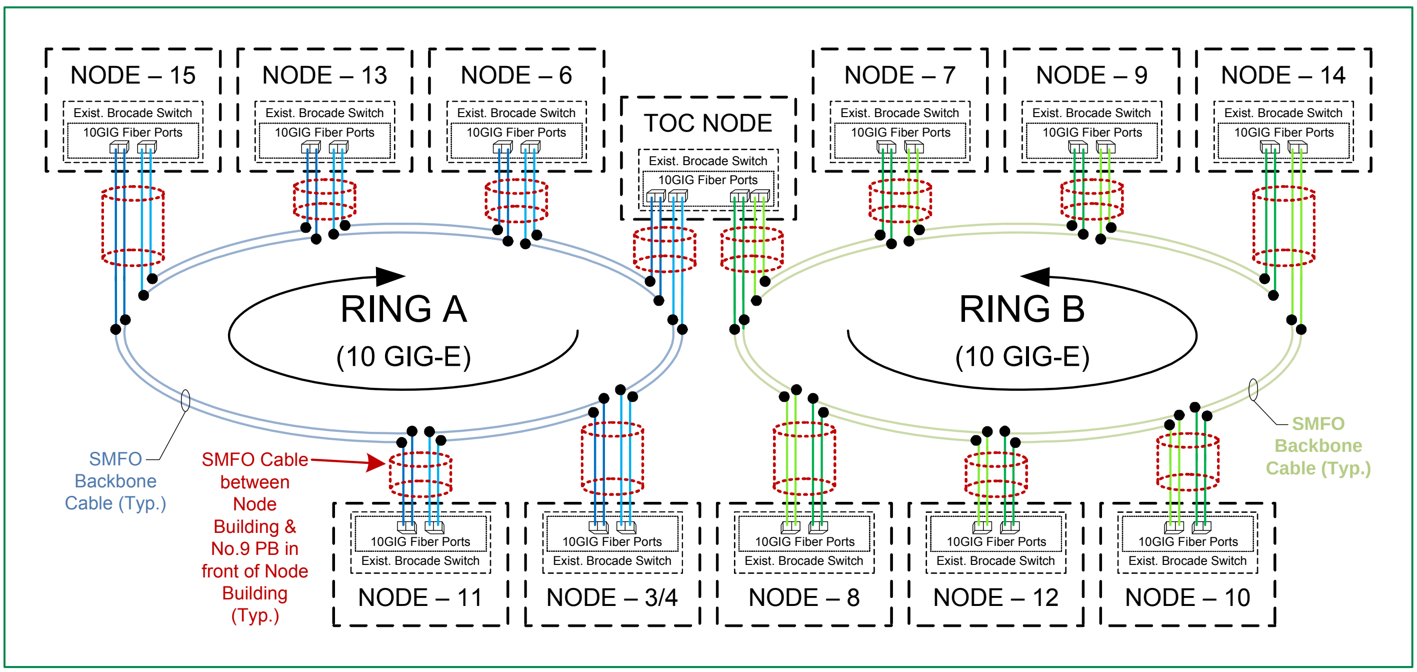


Figure 10-1: Standard Node-to-TOC Backbone Communications Approach

In order to satisfy ADOT's Node-to-TOC communications requirements, **no** two links (a link is the path between two nodes or between a node and the TOC) on the same ring can share the same fiber optic cable (except for the cable between the node building and the No.9 pull box immediately outside the node building) and **no** two links can share the same duct, conduit, and trench. For example, if a new Node Building was going to be installed along I-10 West of Loop 101 (Agua Fria) then a new fiber optic cable is required on both sides of the freeway [West of Loop 101 (Agua Fria)] to maintain the required link separation between the link connecting this new node to node 11 and the link between this new node and Node 15, as depicted in **Figure 10-2**.

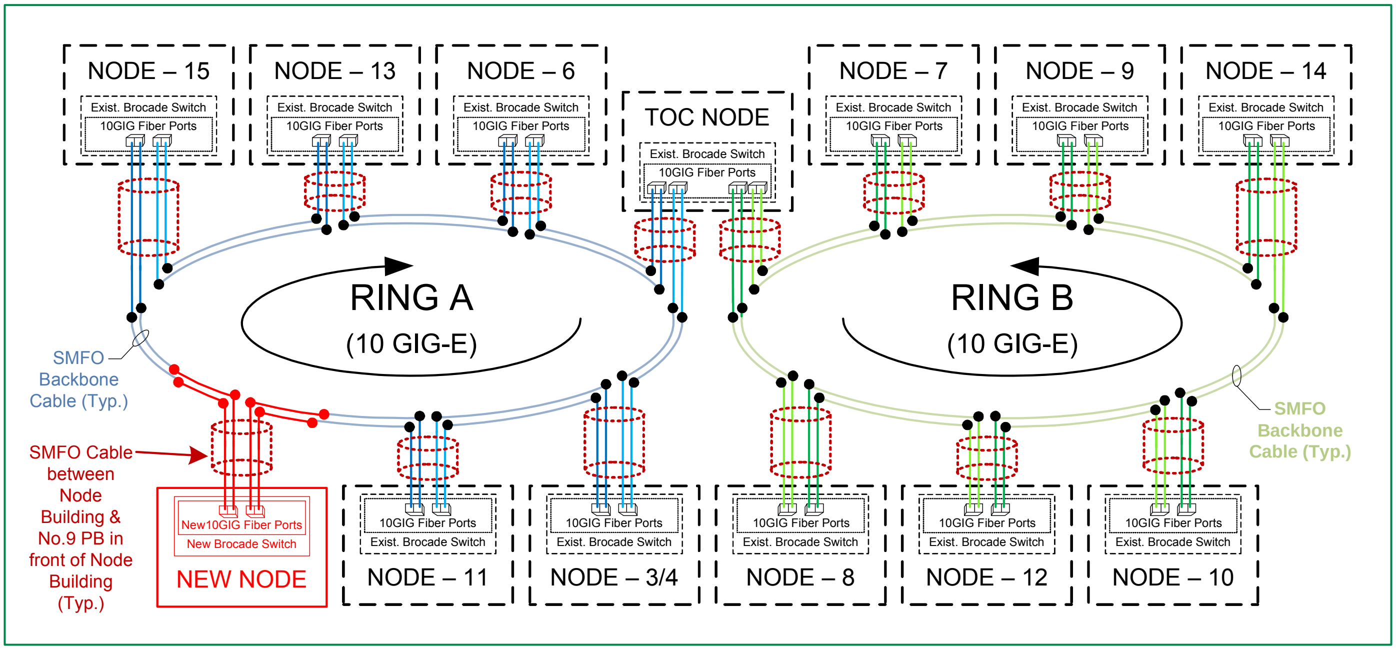


Figure 10-2: Example of Adding a New Node Building to 10 Gigabit Ring B

In addition to the general Node Building requirements, see Section 8, a new backbone Ethernet switch will be needed within the new Node Building. This new backbone Ethernet switch should be either furnished by ADOT TTG or specified in the project special provisions with the exact make and model number (which will require a finding in the public interest letter approved by FHWA on FHWA funded projects).

10.1.2 Field-to-Node Communications Standard

The field to node communications standard is the Hybrid Flower topology (see Section 6.5 for a general description and depiction of the Hybrid Flower topology) with the following requirements:

A. All Field-to-Node circuits must be two fiber Ethernet circuits which start at one Node Building and end at a different Node Building.

B. The Field-to-Node circuit path between two Node Buildings, or between a Node Building and the TOC/ATOC, **cannot** share the same fiber optic cable (i.e., upstream path and downstream path cannot be within the same fiber optic cable) and **cannot** share the same duct, conduit, and trench (i.e., upstream path and downstream path cannot be within the same duct, conduit, or trench), except for within the branch cable connecting a device cabinet to the backbone fiber cable.

C. Although technologically possible, different device types (CCTV, DMS, and detector/ramp meters) **cannot** coexist on the same Field-to-Node Ethernet circuit; however, they can share the same Ethernet switch within the device cabinet (i.e., in a shared CCTV and detector cabinet) and the same Ethernet switch within the Node Building or TOC/ATOC.

Figure 10-3 is an example of a Field-to-Node communications design that meets the standard requirements.

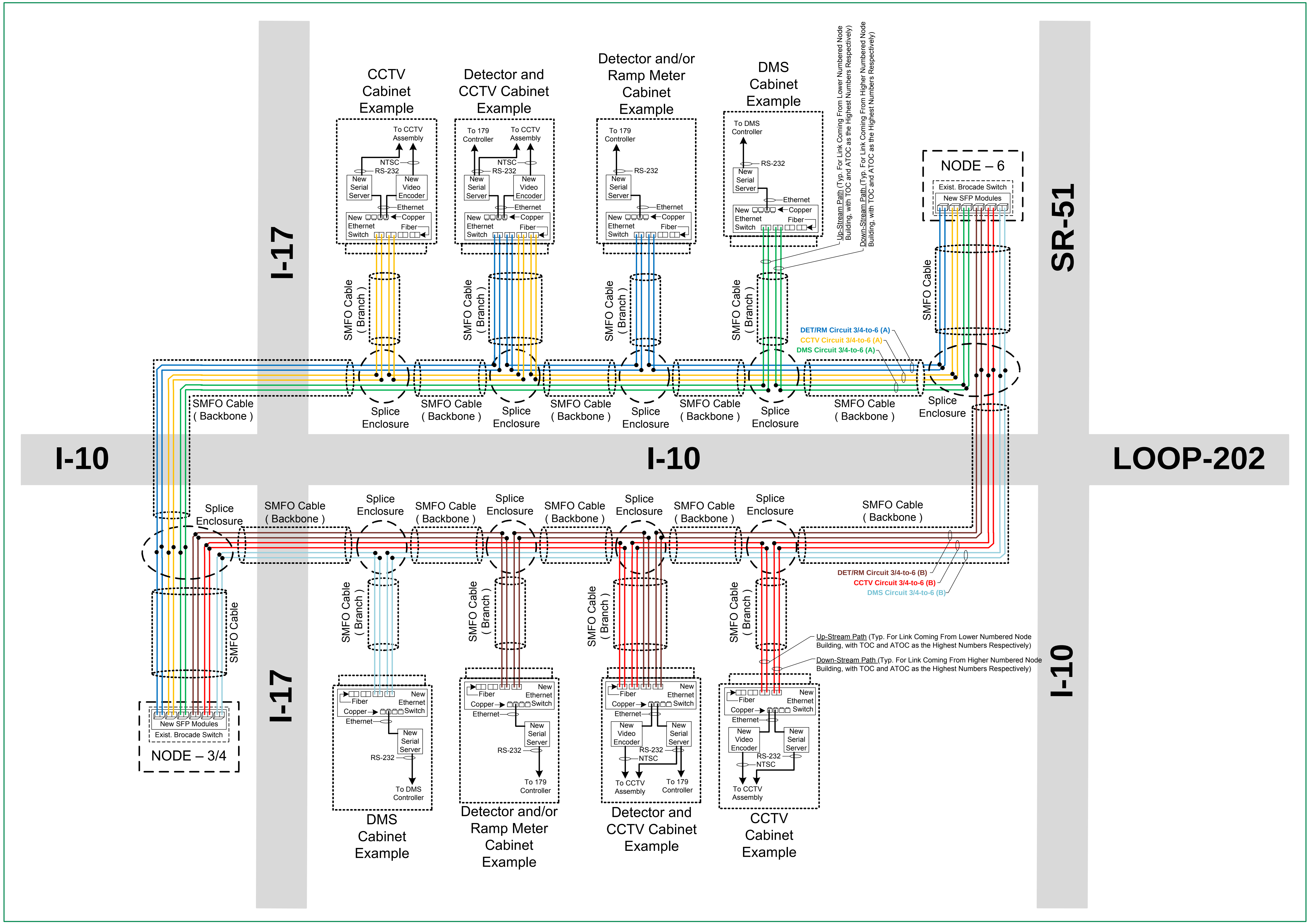


Figure 10-3: Examples of a Correct Field-to-Node Communications Design

10.1.3 Field Cabinet Communications Upgrade Considerations

When upgrading existing communications infrastructure to the new Field-to-Node communications standards, the designer needs to assess what the existing field device communications interfaces are for the existing field device assemblies that will remain in place. The following are a few examples of things to consider:

Existing and New CCTV Locations:

Although most video encoders on the market today support serial communications (i.e., CCTV PTZ control) and analog NTSC video signal, ADOT is currently not using the encoder serial communication capabilities when converting to IP-based Ethernet communication at the Node Buildings. ADOT's current communications standard approach is to have a serial server device handle the conversion between IP-based Ethernet and serial communications for CCTV PTZ control.

When replacing an existing VOTR, within a CCTV device cabinet, it is highly probable that the existing serial communications cable (i.e., CCTV PTZ control) connecting the existing VOTR to the existing CCTV assembly will also need to change to match the connector type (i.e., RJ-45, RJ-11, DB-25, etc.) of the new serial server. The serial communications standard (i.e., RS-232, RS-485, etc.) that the PTZ assembly is using will need to be confirmed and the new serial server must be configured accordingly.

Existing DMS Locations:

DMS controller manufacturers typically support the option to have an Ethernet Network Interface Card (NIC) installed within the DMS controller; however, most of the existing DMS field locations currently deployed by ADOT do not have this Ethernet NIC. ADOT's current communications standard approach is to have a separate serial server device handle the conversion between IP-based Ethernet and serial communications for interfacing existing DMS controls.

When replacing an existing OTR/SHC, TWP or wireless modem, within a DMS device cabinet, it is highly probable that the existing serial communications cable connecting the existing OTR/SHC, TWP or wireless modem to the existing DMS controller will also need to be modified to match the connector type (i.e., RJ-45, RJ-11, DB-25, etc.) of the new serial server. The serial communications standard (i.e., RS-232, RS-485, etc.) that the DMS controller is using will also need to be confirmed and the new serial server must be configured accordingly.

New DMS Locations:

At new DMS locations, ADOT may require DMS assembly be provided with a DMS controller that has both an Ethernet NIC and a Serial communications interface; however, ADOT's current communications standard approach (requiring a separate serial server device to handle the conversion between IP-based Ethernet and serial communications) will remain in place until ADOT has fully tested the Ethernet NIC approach (i.e., not requiring the serial server) for reliability and maintainability with the DMS central software at the TOC.

Existing Detector/Ramp-Meter Locations:

The existing 179 controllers that are currently deployed by ADOT do not have an Ethernet NIC. When interfacing and the existing 179 controllers, ADOT's current communications standard approach is to have a separate serial server device handle the conversion between IP-based Ethernet and the RS-232 serial communications needed by the 179 controller.

When replacing an existing OTR/SHC or TWP modem, within a detector/ramp-meter device cabinet, it is highly probable that the existing serial communications cable connecting the existing OTR/SHC or TWP modem to the 179 controller will need to be updated to match the connector type (i.e., RJ-45, RJ-11, DB-25, etc.) of the new serial server and the C2 connector of the existing 179 controllers.

New Detector/Ramp-Meter Locations:

At new detector/ramp-meter locations, ADOT currently requires the use of 179 controllers with an RS-232 serial communications interface using a C2 connector type. ADOT anticipates phasing out the use of the 179 controllers, with a new type of standard traffic signal controller and/or some other type of controller (i.e., in locations were standard traffic loops are not required and ramp meter signal heads are not required). When a decision is made on the new standard approach for replacing the 179 controllers, the communications interface requirements for this approach will also be defined.

10.2 Proposed FMS Rehabilitation Projects to Phase-Out Old Communications Infrastructure

This section identifies a series of projects needed to migrate to the current FMS Communications standards, identified in Section 10.1, and phase-out the existing communications infrastructure of various types. The order in which these projects are presented within this section represents a logical progression of phasing-out the oldest field communications technologies first; followed by existing communications topologies which are the most problematic/vulnerable, and then reconfiguring the remaining existing communications infrastructure segments to the current FMS communications standards.

In order to establish a base line for estimating the cost of upgrading each of the existing communications infrastructure segments, the budgetary cost projections for each upgrade segment assumes that various existing/on-going projects have been completed. **Figure 10-4** summarizes the existing communications cabling infrastructure and field device type and quantity assumed for developing the budgetary cost projections.

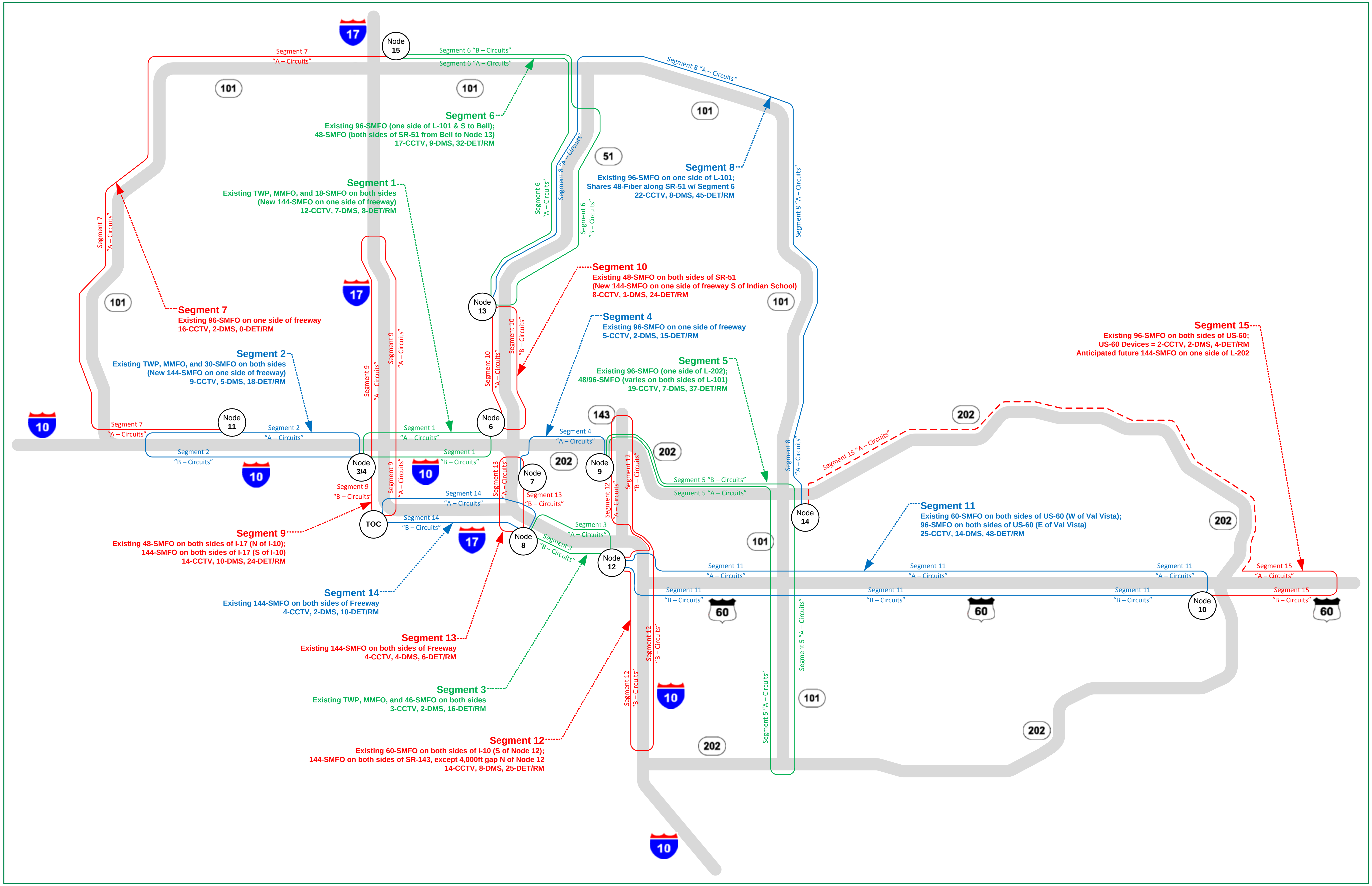


Figure 10-4: Field-to-Node Upgrade Segments with Existing Device Types/Quantities and General Existing Cabling Types

Figure 10-4 and the budgetary cost projections, identified in the following sections, assume that ADOT continues to move forward with the following existing FMS projects, as they are currently being designed and/or upgraded:

Node-to-TOC Backbone Communications Upgrade:

Over the past several months, ADOT has made significant progress upgrading their Node-to-TOC communications backbone. Currently all 10 Gigabit Ethernet, Layer-3, Ethernet node switches have been installed and the two 10 Gigabit Ethernet rings (Rings A and B as shown in **Figure 9-4**) are operational. ADOT has also made significant progress converting the serial communications for DMS and detector/ramp-meter circuits over to Ethernet based IP communications at the Node Buildings (not the field cabinets). Progress has also been made converting the analog CCTV video and serial PTZ controls over to IP based Ethernet communications, by adding video encoders in the Node Buildings and video decoders at the TOC. It is assumed that ADOT will continue with these upgrades until all communications between the nodes and the TOC have been fully upgraded to IP communications over the 10 Gigabit Ethernet backbone network. As such, the cost of the Node Building upgrades and associated TOC upgrades have not been included in the cost to upgrade the freeway segments identified in subsequent sections of this report.

FMS Rehabilitation (Node 3/4 to TOC to Node 8 to Node 7):

ADOT is in the process of completing an FMS rehabilitation design that replaces the existing Field-to-Node communications media (i.e., TWP cable) over to a new 144-SMFO fiber optic backbone cable along both sides of the I-17 freeway (South of Node 3/4 to the I-10 eastern limits) and along both sides of the I-10 freeway [South of Loop 202 (Red Mountain) to I-17]. It is assumed that ADOT will continue to move forward constructing this project. As such, the cost of these cable infrastructure upgrades, to the 144-SMFO media, have not been included into the upgrade cost of the freeway segments identified in subsequent sections of this report.

City of Phoenix 144-SMFO Fiber Project along I-10 and SR 51 (Between 83rd Avenue and Indian School Road):

ADOT and the City of Phoenix have completed the design of a joint venture project that installs an ADOT owned 144-SMFO cable along one side of the I-10 freeway (83rd Avenue to SR 51) and along SR 51 (I-10 to Indian School Road). It is assumed that the City of Phoenix and ADOT will continue to move forward constructing this project. As such, the cost of adding a 144-SMFO cable within this project area has not been included into the upgrade cost of the freeway segments identified in subsequent sections of this report.

Loop 202 (Red Mountain) Design Build Project [Between 24th Street and Loop 101 (Pima)]:

ADOT is nearing completion of a design build project that removes the FMS communications infrastructure along both sides of the freeway and replaces it with a single 96-SMFO cable, along one side of the freeway, between Node 7 and Node 14. As such, the cost of adding a new SMFO cable within the project area has not been included into the upgrade cost of the freeway segments identified in subsequent sections of this report.

FMS Phases 12A, 12B and 6B [Loop 101 (Pima) between SR 51 and Loop 202 (Red Mountain)]:

FMS Phases 12A, 12B and 6B, which is nearing completion, creates a new 96-SMFO cable path along Loop 101 (Pima) [SR 51 to Loop 202 (Red Mountain)]. As such, the cost of adding a new SMFO cable within this project area has not been included into the upgrade cost of the freeway segments identified in subsequent sections of this report.

FMS Cable Replacement along SR 143/Sky Harbor TI:

ADOT is in the process of completing a design project that replaces the existing Field-to-Node communications media (i.e., TWP cable) over to a new 144-SMFO fiber optic backbone cable along both sides of SR 143 (Tempe drainage Ditch No.2 to the northern most SR 143 on/off ramp limits). It is assumed that ADOT will continue to move forward constructing this project. As such, the cost of these cable infrastructure upgrades, to the 144-SMFO media, have not been included into the upgrade cost of the freeway segments identified in subsequent sections of this report. However, a SMFO cable gap (between Node 12 and Tempe drainage Ditch No.2) will still exist along this corridor. The installation cost of closing the SMFO gap has been included in the upgrade cost of the freeway segments identified in subsequent sections of this report.

10.2.1 Segment 1 – Field-to-Node Communications Between Node 3/4 and Node 6

Project Area:

Segment 1 project limits are along I-10 between I-17 and SR 51.

Project Description:

The Segment 1 communications upgrade project will remove and replace the existing copper TWP communications medium and MMFO communications medium deployed along both sides of the freeway. The existing 18-SMFO backbone cable deployed along both sides of the freeway and the soon to be installed 144-SMFO backbone cable on one side of the freeway will remain in place.

New 12-SMFO branch cables will be installed, between each field device cabinet and the nearest existing No.9 pull box that contains a backbone cable with sufficient slack for splicing. At some locations, it may be necessary (or cost effective) to install a new No.9 pull box that provides a better location for the new branch cable to be spliced to the SMFO backbone cable. Conduit proofing and SMFO backbone cable slack verification will be required by the contractor during construction. As such, a force account will be needed for repairing existing damaged conduit and adding sufficient SMFO backbone cable slack to the new splice points, if necessary. A force account will also need to be established for repairing existing pull boxes and lids, as necessary.

Using the SMFO cables, described above, the following two sets of three communications circuits will be established by splicing these fiber optic cables together to create a Hybrid Flower topology between Node 3/4 and Node 6, as depicted in **Figure 10-3**:

A. The "A" circuits [DET/RM Circuit 3/4-6 (A), CCTV Circuit 3/4-6 (A) and DMS Circuit 3/4-6 (A)] will each consist of a two fiber path starting at Node Building 3/4 and ending at Node Building 6, picking up the respective device cabinets along the way, following the Segment 1 "A – Circuits" path depicted in **Figure 10-4**.

B. The "B" circuits [DET/RM Circuit 3/4-6 (B), CCTV Circuit 3/4-6 (B) and DMS Circuit 3/4-6 (B)] will each consist of a two fiber path starting at Node Building 3/4 and ending at Node Building 6, picking up the respective device cabinets along the way, following the Segment 1 "B – Circuits" path depicted in **Figure 10-4**.

Table 10-1 provides a summary of the work items and cost associated with upgrading Segment 1 to the current communications standard for Node-to-Field communications.

Table 10-1: Segment 1 Upgrade Cost Summary, as of 2010

Item Description	Unit	Quantity	Unit Cost	Work Type Cost
REMOVE (EXISTING 25 TWP CABLE)	L.FT.	59,180	$ 1.50	$ 88,770.00
REMOVE (EXISTING MMFO CABLE)	L.FT.	25,060	$ 1.50	$ 37,590.00
PULL BOX (NO. 9)	EACH	13	$ 2,500.00	$ 32,500.00
SINGLE MODE FIBER OPTIC CABLE (144 FIBERS)	L.FT.	30,070	$ 3.50	$ 105,245.00
SINGLE MODE FIBER OPTIC CABLE (12 FIBERS)	L.FT.	5,850	$ 2.00	$ 11,700.00
***FIBER OPTIC SPLICE CLOSURE (SPLICE CLOSURE W/ SPLICING)(INCLUDING AT NODE)	EACH	29	$ 3,000.00	$ 87,000.00
FORCE ACCOUNT WORK (PULL BOX RECONDITIONING)	L.SUM	1	$ 10,000.00	$ 10,000.00
FORCE ACCOUNT WORK (CONDUIT RECONDITIONING)	L.SUM	1	$ 20,000.00	$ 20,000.00
MISCELLANEOUS WORK (REMOVE EXISTING SMFO 10 CABLE)	L.FT.	53,110	$ 1.50	$ 79,665.00
FIBER TO TUNNEL CONTROL ROOM (1 SPLICE CLOSURE & 140 FT OF SMFO 12)	L.SUM	1	$ 3,280.00	$ 3,280.00
*VIDEO ENCODERS	EACH	12	$ 3,000.00	$ 36,000.00
***SERIAL SERVERS (4-PORT)	EACH	15	$ 1,000.00	$ 15,000.00
**24 SFP PORT EXPANSION MODULE FOR 10-GIG SWITCH AT NODE	EACH	2	$ 6,000.00	$ 12,000.00
100 Mbps ETHERNET SFP (OPTICS) FOR 10-GIG SWITCH AT NODE	EACH	12	$ 500.00	$ 6,000.00
***ETHERNET SWITCH AT FIELD CABINET	EACH	27	$ 3,000.00	$ 81,000.00
			Subtotal =	$ 625,750.00
CONTINGENCY		10%		$ 62,575.00
TRAFFIC CONTROL		10%		$ 62,575.00
MOBILIZATION		8%		$ 50,060.00
SYSTEM INTEGRATION		5%		$ 31,287.50
CONSTRUCTION ADMINISTRATION		15%		$ 93,862.50
			Subtotal =	$ 926,110.00
DESIGN ENGINEERING		12%		$ 111,133.20
			SEGMENT TOTAL =	**$ 1,037,243.20**

NOTES: * ASSUMES VIDEO ENCODERS AT NODE CAN'T BE RELOCATED TO FIELD CABINETS

** ASSUMES THIS EXPANSION MODULE HAS NOT BEEN ADDED BY A PREVIOUS SEGMENT UPGRADE PHASE

*** ASSUMES NO EXISTING SHARED CABINETS (I.E., NO COMBINED DETECTOR & CCTV CABINETS)

10.2.2 Segment 2 – Field-to-Node Communications Between Node 3/4 and Node 11

Project Area:

Segment 2 project limits are along I-10 between Loop 101 (Agua Fria) and I-17.

Project Description:

The Segment 2 communications upgrade project will remove and replace the existing copper TWP communications medium and MMFO communications medium deployed along both sides of the freeway. The existing 30-SMFO backbone cable deployed along both sides of the freeway and the soon to be installed 144-SMFO backbone cable on one side of the freeway will remain in place.

New 12-SMFO branch cables will be installed, between each field device cabinet and the nearest existing No.9 pull box that contains a backbone cable with sufficient slack for splicing. At some locations, it may be necessary (or cost effective) to install a new No.9 pull box that provides a better location for the new branch cable to be spliced to the SMFO backbone cable. Conduit proofing and SMFO backbone cable slack verification will be required by the contractor during constructing. As such, a force account will be needed for repairing existing damaged conduit and adding sufficient SMFO backbone cable slack to the new splice points, if necessary. A force account will also need to be established for repairing existing pull boxes and lids, as necessary.

Using the SMFO cables, described above, the following two sets of three communications circuits will be established by splicing these fiber optic cables together to create a Hybrid Flower topology between Node 3/4 and Node 11:

A. The “A” circuits [DET/RM Circuit 3/4-11 (A), CCTV Circuit 3/4-11 (A) and DMS Circuit 3/4-11 (A)] will each consist of a two fiber path starting at Node Building 3/4 and ending at Node Building 11, picking up the respective device cabinets along the way, following the Segment 2 “A – Circuits” path depicted in **Figure 10-4**.

B. The "B" circuits [DET/RM Circuit 3/4-11 (B), CCTV Circuit 3/4-11 (B) and DMS Circuit 3/4-11 (B)] will each consist of a two fiber path starting at Node Building 3/4 and ending at Node Building 11, picking up the respective device cabinets along the way, following the Segment 2 "B – Circuits" path depicted in **Figure 10-4**.

Table 10-2 provides a summary of the work items and cost associated with upgrading Segment 2 to the current communications standard for Node-to-Field communications.

Table 10-2: Segment 2 Upgrade Cost Summary, as of 2010

Item Description	Unit	Quantity	Unit Cost	Work Type Cost
REMOVE (EXISTING 25 TWP CABLE)	L.FT.	90,205	$ 1.50	$ 135,307.50
REMOVE (EXISTING MMFO CABLE)	L.FT.	28,980	$ 1.50	$ 43,470.00
PULL BOX (NO. 9)	EACH	27	$ 2,500.00	$ 67,500.00
SINGLE MODE FIBER OPTIC CABLE (144 FIBERS)	L.FT.	37,948	$ 3.50	$ 132,818.00
SINGLE MODE FIBER OPTIC CABLE (12 FIBERS)	L.FT.	5,335	$ 2.00	$ 10,670.00
***FIBER OPTIC SPLICE CLOSURE (SPLICE CLOSURE W/ SPLICING)(INCLUDING AT NODE)	EACH	34	$ 3,000.00	$ 102,000.00
FORCE ACCOUNT WORK (PULL BOX RECONDITIONING)	L.SUM	1	$ 15,000.00	$ 15,000.00
FORCE ACCOUNT WORK (CONDUIT RECONDITIONING)	L.SUM	1	$ 30,000.00	$ 30,000.00
*VIDEO ENCODERS	EACH	9	$ 3,000.00	$ 27,000.00
***SERIAL SERVERS (4-PORT)	EACH	32	$ 1,000.00	$ 32,000.00
**24 SFP PORT EXPANSION MODULE FOR 10-GIG SWITCH AT NODE	EACH	2	$ 6,000.00	$ 12,000.00
100 Mbps ETHERNET SFP (OPTICS) FOR 10-GIG SWITCH AT NODE	EACH	12	$ 500.00	$ 6,000.00
***ETHERNET SWITCH AT FIELD CABINET	EACH	32	$ 3,000.00	$ 96,000.00
			Subtotal =	$ 709,765.50
CONTINGENCY	10%			$ 70,976.55
TRAFFIC CONTROL	10%			$ 70,976.55
MOBILIZATION	8%			$ 56,781.24
SYSTEM INTEGRATION	5%			$ 35,488.28
CONSTRUCTION ADMINISTRATION	15%			$ 106,464.83
			Subtotal =	$ 1,050,452.94
DESIGN ENGINEERING	12%			$ 126,054.35
			SEGMENT TOTAL =	**$ 1,176,507.29**

NOTES: * ASSUMES VIDEO ENCODERS AT NODE CAN'T BE RELOCATED TO FIELD CABINETS
** ASSUMES THIS EXPANSION MODULE HAS NOT BEEN ADDED BY A PREVIOUS SEGMENT UPGRADE PHASE
*** ASSUMES NO EXISTING SHARED CABINETS (I.E., NO COMBINED DETECTOR & CCTV CABINETS)

10.2.3 Segment 3 – Field-to-Node Communications Between Node 8 and Node 12

Project Area:

Segment 3 project limits are along I-10 between I-17 and SR 143.

Project Description:

The Segment 3 communications upgrade project will remove and replace the existing copper TWP communications medium and MMFO communications medium deployed along both sides of the freeway. The existing 46-SMFO backbone cable deployed along both sides of the freeway will remain in place.

New 12-SMFO branch cables will be installed, between each field device cabinet and the nearest existing No.9 pull box that contains a backbone cable with sufficient slack for splicing. At some locations, it may be necessary (or cost effective) to install a new No.9 pull box that provides a better location for the new branch cable to be spliced to the SMFO backbone cable. Conduit proofing and SMFO backbone cable slack verification will be required by the contractor during constructing. As such, a force account will be needed for repairing existing damaged conduit and adding sufficient SMFO backbone cable slack to the new splice points, if necessary. A force account will also need to be established for repairing existing pull boxes and lids, as necessary.

Using the SMFO cables, described above, the following two sets of three communications circuits will be established by splicing these fiber optic cables together to create a Hybrid Flower topology between Node 8 and Node 12:

A. The "A" circuits [DET/RM Circuit 8-12 (A), CCTV Circuit 8-12 (A) and DMS Circuit 8-12 (A)] will each consist of a two fiber path starting at Node Building 8 and ending at Node Building 12, picking up the respective device cabinets along the way, following the Segment 3 "A – Circuits" path depicted in **Figure 10-4**.

B. The "B" circuits [DET/RM Circuit 8-12 (B), CCTV Circuit 8-12 (B) and DMS Circuit 8-12 (B)] will each consist of a two fiber path starting at Node Building 8 and ending at Node Building 12, picking up the respective device cabinets along the way, following the Segment 3 "B – Circuits" path depicted in **Figure 10-4**.

Table 10-3 provides a summary of the work items and cost associated with upgrading Segment 3 to the current communications standard for Node-to-Field communications.

Table 10-3: Segment 3 Upgrade Cost Summary, as of 2010

Item Description	Unit	Quantity	Unit Cost	Work Type Cost
REMOVE (EXISTING 25 TWP CABLE)	L.FT.	53,960	$ 1.50	$ 80,940.00
REMOVE (EXISTING MMFO CABLE)	L.FT.	50,810	$ 1.50	$ 76,215.00
PULL BOX (NO. 9)	EACH	10	$ 2,500.00	$ 25,000.00
****SINGLE MODE FIBER OPTIC CABLE (144 FIBERS)	L.FT.	50,810	$ 3.50	$ 177,835.00
SINGLE MODE FIBER OPTIC CABLE (12 FIBERS)	L.FT.	3,150	$ 2.00	$ 6,300.00
***FIBER OPTIC SPLICE CLOSURE (SPLICE CLOSURE W/ SPLICING)(INCLUDING AT NODE)	EACH	18	$ 3,000.00	$ 54,000.00
FORCE ACCOUNT WORK (PULL BOX RECONDITIONING)	L.SUM	1	$ 5,000.00	$ 5,000.00
FORCE ACCOUNT WORK (CONDUIT RECONDITIONING)	L.SUM	1	$ 10,000.00	$ 10,000.00
*VIDEO ENCODERS	EACH	4	$ 3,000.00	$ 12,000.00
***SERIAL SERVERS (4-PORT)	EACH	16	$ 1,000.00	$ 16,000.00
**24 SFP PORT EXPANSION MODULE FOR 10-GIG SWITCH AT NODE	EACH	2	$ 6,000.00	$ 12,000.00
100 Mbps ETHERNET SFP (OPTICS) FOR 10-GIG SWITCH AT NODE	EACH	12	$ 500.00	$ 6,000.00
***ETHERNET SWITCH AT FIELD CABINET	EACH	16	$ 3,000.00	$ 48,000.00
			Subtotal =	$ 529,290.00
CONTINGENCY		10%		$ 52,929.00
TRAFFIC CONTROL		10%		$ 52,929.00
MOBILIZATION		8%		$ 42,343.20
SYSTEM INTEGRATION		5%		$ 26,464.50
CONSTRUCTION ADMINISTRATION		15%		$ 79,393.50
			Subtotal =	$ 783,349.20
DESIGN ENGINEERING		12%		$ 94,001.90
			SEGMENT TOTAL =	**$ 877,351.10**

NOTES: * ASSUMES VIDEO ENCODERS AT NODE CAN'T BE RELOCATED TO FIELD CABINETS
** ASSUMES THIS EXPANSION MODULE HAS NOT BEEN ADDED BY A PREVIOUS SEGMENT UPGRADE PHASE
*** ASSUMES NO EXISTING SHARED CABINETS (I.E., NO COMBINED DETECTOR & CCTV CABINETS)
**** ASSUMES THE EXISTING 48-SMFO WILL NOT BE USED, BUT CHANCES ARE THAT IT COULD BE

10.2.4 Segment 4 – Field-to-Node Communications Between Node 7 and Node 9

Project Area:

Segment 4 project limits are along I-10 between Node 7 and Loop 202 (Red Mountain); and along Loop 202 (Red Mountain) between SR 51 and SR 143.

Project Description:

The Segment 4 communications upgrade project will utilize the existing 96-SMFO backbone cable deployed along one side of the freeway and the existing SMFO branch cables between the device cabinets and the 96-SMFO backbone cables. A force account will need to be established for repairing existing pull boxes and lids, as necessary.

Using the SMFO cables, described above, the following set of three communications circuits will be established by splicing these fiber optic cables together to create a Hybrid Flower topology between Node 7 and Node 9:

A. The “A” circuits [DET/RM Circuit 7-9 (A), CCTV Circuit 7-9 (A) and DMS Circuit 7-9 (A)] will each consist of a two fiber path starting at Node Building 7 and ending at Node Building 9, picking up the respective device cabinets along the way, following the Segment 4 “A – Circuits” path depicted in **Figure 10-4**.

Table 10-4 provides a summary of the work items and cost associated with upgrading Segment 4 to the current communications standard for Node-to-Field communications.

Table 10-4: Segment 4 Upgrade Cost Summary, as of 2010

Item Description	Unit	Quantity	Unit Cost	Work Type Cost
FORCE ACCOUNT WORK (FIBER OPTIC SPLICE CLOSURE RECONDITIONING)	L.SUM	1	$ 10,000.00	$ 10,000.00
FORCE ACCOUNT WORK (PULL BOX RECONDITIONING)	L.SUM	1	$ 5,000.00	$ 5,000.00
FORCE ACCOUNT WORK (CONDUIT RECONDITIONING)	L.SUM	1	$ 10,000.00	$ 10,000.00
*VIDEO ENCODERS	EACH	5	$ 3,000.00	$ 15,000.00
***SERIAL SERVERS (4-PORT)	EACH	22	$ 1,000.00	$ 22,000.00
**24 SFP PORT EXPANSION MODULE FOR 10-GIG SWITCH AT NODE	EACH	2	$ 6,000.00	$ 12,000.00
100 Mbps ETHERNET SFP (OPTICS) FOR 10-GIG SWITCH AT NODE	EACH	6	$ 500.00	$ 3,000.00
***ETHERNET SWITCH AT FIELD CABINET	EACH	22	$ 3,000.00	$ 66,000.00
***FIBER SPLICE RECONFIGURATION PER CABINET/NODE	EACH	24	$ 1,200.00	$ 28,800.00
			Subtotal =	$ 171,800.00
CONTINGENCY		10%		$ 17,180.00
TRAFFIC CONTROL		0%		$ -
MOBILIZATION		8%		$ 13,744.00
SYSTEM INTEGRATION		5%		$ 8,590.00
CONSTRUCTION ADMINISTRATION		15%		$ 25,770.00
			Subtotal =	$ 237,084.00
DESIGN ENGINEERING		12%		$ 28,450.08
			SEGMENT TOTAL =	**$ 265,534.08**

NOTES: * ASSUMES VIDEO ENCODERS AT NODE CAN'T BE RELOCATED TO FIELD CABINETS
** ASSUMES THIS EXPANSION MODULE HAS NOT BEEN ADDED BY A PREVIOUS SEGMENT UPGRADE PHASE
*** ASSUMES NO EXISTING SHARED CABINETS (I.E., NO COMBINED DETECTOR & CCTV CABINETS)

10.2.5 Segment 5 – Field-to-Node Communications Between Node 9 and Node 14

Project Area:

Segment 5 project limits are along Loop 202 (Red Mountain) between SR 143 and Loop 101 (Pima); and along Loop 101 (Price).

Project Description:

The Segment 5 communications upgrade project will utilize the existing 96-SMFO backbone cable (and/or 48-SMFO) deployed along both sides of the Loop 101 (Price) and the existing 96-SMFO cable on one side of the freeway along Loop 202 (Red Mountain) in the project area.

Existing 12-SMFO branch cables will be utilized, between each field device cabinet and the SMFO backbone cable splices with existing splice enclosures will be reconfigured to the new Field-to-Node topology standard.

Using the SMFO cables, described above, the following two sets of three communications circuits will be established by splicing these fiber optic cables together to create a Hybrid Flower topology between Node 9 and Node 14:

A. The “A” circuits [DET/RM Circuit 9-14 (A), CCTV Circuit 9-14 (A) and DMS Circuit 9-14 (A)] will each consist of a two fiber path starting at Node Building 9 and ending at Node Building 14, picking up the respective device cabinets along the way, following the Segment 5 “A – Circuits” path depicted in **Figure 10-4**.

B. The "B" circuits [DET/RM Circuit 9-14 (B), CCTV Circuit 9-14 (B) and DMS Circuit 9-14 (B)] will each consist of a two fiber path starting at Node Building 9 and ending at Node Building 14, picking up the respective device cabinets along the way, following the Segment 5 "B – Circuits" path depicted in **Figure 10-4**.

Table 10-5 provides a summary of the work items and cost associated with upgrading Segment 5 to the current communications standard for Node-to-Field communications.

Table 10-5: Segment 5 Upgrade Cost Summary, as of 2010

Item Description	Unit	Quantity	Unit Cost	Work Type Cost
FORCE ACCOUNT WORK (FIBER OPTIC SPLICE CLOSURE RECONDITIONING)	L.SUM	1	$ 20,000.00	$ 20,000.00
FORCE ACCOUNT WORK (PULL BOX RECONDITIONING)	L.SUM	1	$ 10,000.00	$ 10,000.00
FORCE ACCOUNT WORK (CONDUIT RECONDITIONING)	L.SUM	1	$ 10,000.00	$ 10,000.00
*VIDEO ENCODERS	EACH	19	$ 3,000.00	$ 57,000.00
***SERIAL SERVERS (4-PORT)	EACH	63	$ 1,000.00	$ 63,000.00
**24 SFP PORT EXPANSION MODULE FOR 10-GIG SWITCH AT NODE	EACH	2	$ 6,000.00	$ 12,000.00
100 Mbps ETHERNET SFP (OPTICS) FOR 10-GIG SWITCH AT NODE	EACH	12	$ 500.00	$ 6,000.00
***ETHERNET SWITCH AT FIELD CABINET	EACH	63	$ 3,000.00	$ 189,000.00
***FIBER SPLICE RECONFIGURATION PER CABINET/NODE	EACH	65	$ 1,200.00	$ 78,000.00
			Subtotal =	$ 445,000.00
CONTINGENCY		10%		$ 44,500.00
TRAFFIC CONTROL		0%		$ -
MOBILIZATION		8%		$ 35,600.00
SYSTEM INTEGRATION		5%		$ 22,250.00
CONSTRUCTION ADMINISTRATION		15%		$ 66,750.00
			Subtotal =	$ 614,100.00
DESIGN ENGINEERING		12%		$ 73,692.00
			SEGMENT TOTAL =	$ 687,792.00

NOTES: * ASSUMES VIDEO ENCODERS AT NODE CAN'T BE RELOCATED TO FIELD CABINETS
** ASSUMES THIS EXPANSION MODULE HAS NOT BEEN ADDED BY A PREVIOUS SEGMENT UPGRADE PHASE
*** ASSUMES NO EXISTING SHARED CABINETS (I.E., NO COMBINED DETECTOR & CCTV CABINETS)

10.2.6 *Segment 6 – Field-to-Node Communications Between Node 13 and Node 15*

Segment 6 project limits are along Loop 101 (Pima) between I-17 and SR 51; and along SR 51 between Loop 101 (Pima) and Glendale Avenue.

Project Description:

The Segment 6 communications upgrade project will utilize the existing 96-SMFO backbone cable deployed along both sides of the freeway along SR 51 from Bell Road to Node 13, and the existing 96-SMFO backbone cable on one side of the Loop 101 (Pima) within the project limits.

Existing 12-SMFO branch cables will be utilized, between each field device cabinet and the backbone cable. Splices within existing splice enclosures will be reconfigured to the new Field-to-Node topology standard.

Using the SMFO cables, described above, the following two sets of three communications circuits will be established by splicing these fiber optic cables together to create a Hybrid Flower topology between Node 13 and Node 15:

A. The "A" circuits [DET/RM Circuit 13-15 (A), CCTV Circuit 13-15 (A) and DMS Circuit 13-15 (A)] will each consist of a two fiber path starting at Node Building 13 and ending at Node Building 15, picking up the respective device cabinets along the way, following the Segment 6 "A – Circuits" path depicted in **Figure 10-4**.

B. The "B" circuits [DET/RM Circuit 13-15 (B), CCTV Circuit 13-15 (B) and DMS Circuit 13-15 (B)] will each consist of a two fiber path starting at Node Building 13 and ending at Node Building 15, picking up the respective device cabinets along the way, following the Segment 6 "B – Circuits" path depicted in **Figure 10-4**.

Table 10-6 provides a summary of the work items and cost associated with upgrading Segment 6 to the current communications standard for Node-to-Field communications.

Table 10-6: Segment 6 Upgrade Cost Summary, as of 2010

Item Description	Unit	Quantity	Unit Cost	Work Type Cost
FORCE ACCOUNT WORK (FIBER OPTIC SPLICE CLOSURE RECONDITIONING)	L.SUM	1	$ 20,000.00	$ 20,000.00
FORCE ACCOUNT WORK (PULL BOX RECONDITIONING)	L.SUM	1	$ 10,000.00	$ 10,000.00
FORCE ACCOUNT WORK (CONDUIT RECONDITIONING)	L.SUM	1	$ 10,000.00	$ 10,000.00
*VIDEO ENCODERS	EACH	17	$ 3,000.00	$ 51,000.00
***SERIAL SERVERS (4-PORT)	EACH	58	$ 1,000.00	$ 58,000.00
**24 SFP PORT EXPANSION MODULE FOR 10-GIG SWITCH AT NODE	EACH	2	$ 6,000.00	$ 12,000.00
100 Mbps ETHERNET SFP (OPTICS) FOR 10-GIG SWITCH AT NODE	EACH	12	$ 500.00	$ 6,000.00
***ETHERNET SWITCH AT FIELD CABINET	EACH	58	$ 3,000.00	$ 174,000.00
***FIBER SPLICE RECONFIGURATION PER CABINET/NODE	EACH	60	$ 1,200.00	$ 72,000.00
			Subtotal =	$ 413,000.00
CONTINGENCY		10%		$ 41,300.00
TRAFFIC CONTROL		0%		$ -
MOBILIZATION		8%		$ 33,040.00
SYSTEM INTEGRATION		5%		$ 20,650.00
CONSTRUCTION ADMINISTRATION		15%		$ 61,950.00
			Subtotal =	$ 569,940.00
DESIGN ENGINEERING		12%		$ 68,392.80
			SEGMENT TOTAL =	$ 638,332.80

NOTES: * ASSUMES VIDEO ENCODERS AT NODE CAN'T BE RELOCATED TO FIELD CABINETS
** ASSUMES THIS EXPANSION MODULE HAS NOT BEEN ADDED BY A PREVIOUS SEGMENT UPGRADE PHASE
*** ASSUMES NO EXISTING SHARED CABINETS (I.E., NO COMBINED DETECTOR & CCTV CABINETS)

10.2.7 Segment 7 – Field-to-Node Communications Between Node 11 and Node 15

Project Area:

Segment 7 project limits are along Loop 101 (Agua Fria) between I-10 and I-17, and along I-10 from Loop 101 (Agua Fria) to 59th Avenue.

Project Description:

The Segment 7 communications upgrade project will utilize the existing 96-SMFO backbone cable deployed along one side of the freeway.

Existing 12-SMFO branch cables will be utilized, between each field device cabinet and the backbone cable. Splices within existing splice enclosures will be reconfigured to the new Field-to-Node topology standard.

Using the SMFO cables, described above, the following one set of three communications circuits will be established by splicing these fiber optic cables together to create a Hybrid Flower topology between Node 11 and Node 15:

A. The "A" circuits [DET/RM Circuit 11-15 (A), CCTV Circuit 11-15 (A) and DMS Circuit 11-15 (A)] will each consist of a two fiber path starting at Node Building 11 and ending at Node Building 15, picking up the respective device cabinets along the way, following the Segment 7 "A – Circuits" path depicted in **Figure 10-4**.

Table 10-7 provides a summary of the work items and cost associated with upgrading Segment 7 to the current communications standard for Node-to-Field communications.

Table 10-7: Segment 7 Upgrade Cost Summary, as of 2010

Item Description	Unit	Quantity	Unit Cost	Work Type Cost
FORCE ACCOUNT WORK (FIBER OPTIC SPLICE CLOSURE RECONDITIONING)	L.SUM	1	$ 10,000.00	$ 10,000.00
FORCE ACCOUNT WORK (PULL BOX RECONDITIONING)	L.SUM	1	$ 5,000.00	$ 5,000.00
FORCE ACCOUNT WORK (CONDUIT RECONDITIONING)	L.SUM	1	$ 5,000.00	$ 5,000.00
*VIDEO ENCODERS	EACH	16	$ 3,000.00	$ 48,000.00
***SERIAL SERVERS (4-PORT)	EACH	18	$ 1,000.00	$ 18,000.00
**24 SFP PORT EXPANSION MODULE FOR 10-GIG SWITCH AT NODE	EACH	2	$ 6,000.00	$ 12,000.00
100 Mbps ETHERNET SFP (OPTICS) FOR 10-GIG SWITCH AT NODE	EACH	6	$ 500.00	$ 3,000.00
***ETHERNET SWITCH AT FIELD CABINET	EACH	18	$ 3,000.00	$ 54,000.00
***FIBER SPLICE RECONFIGURATION PER CABINET/NODE	EACH	20	$ 1,200.00	$ 24,000.00
			Subtotal =	$ 179,000.00
CONTINGENCY		10%		$ 17,900.00
TRAFFIC CONTROL		0%		$ -
MOBILIZATION		8%		$ 14,320.00
SYSTEM INTEGRATION		5%		$ 8,950.00
CONSTRUCTION ADMINISTRATION		15%		$ 26,850.00
			Subtotal =	$ 247,020.00
DESIGN ENGINEERING		12%		$ 29,642.40
			SEGMENT TOTAL =	**$ 276,662.40**

NOTES: * ASSUMES VIDEO ENCODERS AT NODE CAN'T BE RELOCATED TO FIELD CABINETS

** ASSUMES THIS EXPANSION MODULE HAS NOT BEEN ADDED BY A PREVIOUS SEGMENT UPGRADE PHASE

*** ASSUMES NO EXISTING SHARED CABINETS (I.E., NO COMBINED DETECTOR & CCTV CABINETS)

10.2.8 Segment 8 – Field-to-Node Communications Between Node 13 and Node 14

Project Area:

Segment 8 project limits are along Loop 101 (Pima) between SR 51 and Loop 202 (Red Mountain).

Project Description:

The Segment 8 communications upgrade project will utilize the existing 96-SMFO backbone cable deployed along one side of the Loop 101 (Pima) freeway and SR 51 south to Bell Road; as well as, share one of the existing 48-SMFO backbone with segment 6 along SR 51.

Existing 12-SMFO branch cables will be utilized, between each field device cabinet and the backbone cable. Splices within the existing splice enclosures will be reconfigured to the new Field-to-Node topology standard.

Using the SMFO cables, described above, the following one set of three communications circuits will be established by splicing these fiber optic cables together to create a Hybrid Flower topology between Node 13 and Node 14:

A. The “A” circuits [DET/RM Circuit 13-14 (A), CCTV Circuit 13-14 (A) and DMS Circuit 13-14 (A)] will each consist of a two fiber path starting at Node Building 13 and ending at Node Building 14, picking up the respective device cabinets along the way, following the Segment 8 “A – Circuits” path depicted in **Figure 10-4**.

Table 10-8 provides a summary of the work items and cost associated with upgrading Segment 8 to the current communications standard for Node-to-Field communications.

Table 10-8: Segment 8 Upgrade Cost Summary, as of 2010

Item Description	Unit	Quantity	Unit Cost	Work Type Cost
FORCE ACCOUNT WORK (FIBER OPTIC SPLICE CLOSURE RECONDITIONING)	L.SUM	1	$ 10,000.00	$ 10,000.00
FORCE ACCOUNT WORK (PULL BOX RECONDITIONING)	L.SUM	1	$ 5,000.00	$ 5,000.00
FORCE ACCOUNT WORK (CONDUIT RECONDITIONING)	L.SUM	1	$ 5,000.00	$ 5,000.00
*VIDEO ENCODERS	EACH	22	$ 3,000.00	$ 66,000.00
***SERIAL SERVERS (4-PORT)	EACH	75	$ 1,000.00	$ 75,000.00
**24 SFP PORT EXPANSION MODULE FOR 10-GIG SWITCH AT NODE	EACH	2	$ 6,000.00	$ 12,000.00
100 Mbps ETHERNET SFP (OPTICS) FOR 10-GIG SWITCH AT NODE	EACH	6	$ 500.00	$ 3,000.00
***ETHERNET SWITCH AT FIELD CABINET	EACH	75	$ 3,000.00	$ 225,000.00
***FIBER SPLICE RECONFIGURATION PER CABINET/NODE	EACH	77	$ 1,200.00	$ 92,400.00
			Subtotal =	$ 493,400.00
CONTINGENCY		10%		$ 49,340.00
TRAFFIC CONTROL		0%		$ -
MOBILIZATION		8%		$ 39,472.00
SYSTEM INTEGRATION		5%		$ 24,670.00
CONSTRUCTION ADMINISTRATION		15%		$ 74,010.00
			Subtotal =	$ 680,892.00
DESIGN ENGINEERING		12%		$ 81,707.04
			SEGMENT TOTAL =	**$ 762,599.04**

NOTES: * ASSUMES VIDEO ENCODERS AT NODE CAN'T BE RELOCATED TO FIELD CABINETS
** ASSUMES THIS EXPANSION MODULE HAS NOT BEEN ADDED BY A PREVIOUS SEGMENT UPGRADE PHASE
*** ASSUMES NO EXISTING SHARED CABINETS (I.E., NO COMBINED DETECTOR & CCTV CABINETS)

10.2.9 Segment 9 – Field-to-Node Communications Between Node 3/4 and TOC

Project Area:

Segment 9 project limits are along I-17 between Peoria Avenue and Durango Street.

Project Description:

The Segment 9 communications upgrade project will utilize the existing 48-SMFO backbone cable deployed along both sides of the I-17 freeway north of Thomas Road and will utilize the 144-SMFO cable south of Thomas Road which is being installed as part of the FMS Rehabilitation Project.

Existing 12-SMFO branch cables will be utilized, between each field device cabinet and the backbone cable. Splices within the existing splice enclosures will be reconfigured to accept the new Field-to-Node topology standard.

Using the SMFO cables, described above, the following two sets of three communications circuits will be established by splicing these fiber optic cables together to create a Hybrid Flower topology between Node 3/4 and the TOC:

A. The “A” circuits [DET/RM Circuit TOC-3/4 (A), CCTV Circuit TOC-3/4 (A) and DMS Circuit TOC-3/4 (A)] will each consist of a two fiber path starting at the TOC and ending at Node Building 3/4, picking up the respective device cabinets along the way, following the Segment 9 “A – Circuits” path depicted in **Figure 10-4**.

B. The “B” circuits [DET/RM Circuit TOC-3/4 (B), CCTV Circuit TOC-3/4 (B) and DMS Circuit TOC-3/4 (B)] will each consist of a two fiber path starting at the TOC and ending at Node Building 3/4, picking up the respective device cabinets along the way, following the Segment 9 “B – Circuits” path depicted in **Figure 10-4**.

Table 10-9 provides a summary of the work items and cost associated with upgrading Segment 9 to the current communications standard for Node-to-Field communications.

Table 10-9: Segment 9 Upgrade Cost Summary, as of 2010

Item Description	Unit	Quantity	Unit Cost	Work Type Cost
FORCE ACCOUNT WORK (FIBER OPTIC SPLICE CLOSURE RECONDITIONING)	L.SUM	1	$ 20,000.00	$ 20,000.00
FORCE ACCOUNT WORK (PULL BOX RECONDITIONING)	L.SUM	1	$ 10,000.00	$ 10,000.00
FORCE ACCOUNT WORK (CONDUIT RECONDITIONING)	L.SUM	1	$ 10,000.00	$ 10,000.00
*VIDEO ENCODERS	EACH	14	$ 3,000.00	$ 42,000.00
***SERIAL SERVERS (4-PORT)	EACH	44	$ 1,000.00	$ 44,000.00
**24 SFP PORT EXPANSION MODULE FOR 10-GIG SWITCH AT NODE	EACH	2	$ 6,000.00	$ 12,000.00
100 Mbps ETHERNET SFP (OPTICS) FOR 10-GIG SWITCH AT NODE	EACH	12	$ 500.00	$ 6,000.00
***ETHERNET SWITCH AT FIELD CABINET	EACH	44	$ 3,000.00	$ 132,000.00
***FIBER SPLICE RECONFIGURATION PER CABINET/NODE	EACH	46	$ 1,200.00	$ 55,200.00
			Subtotal =	$ 331,200.00
CONTINGENCY		10%		$ 33,120.00
TRAFFIC CONTROL		0%		$ -
MOBILIZATION		8%		$ 26,496.00
SYSTEM INTEGRATION		5%		$ 16,560.00
CONSTRUCTION ADMINISTRATION		15%		$ 49,680.00
			Subtotal =	$ 457,056.00
DESIGN ENGINEERING		12%		$ 54,846.72
			SEGMENT TOTAL =	**$ 511,902.72**

NOTES: * ASSUMES VIDEO ENCODERS AT NODE CAN'T BE RELOCATED TO FIELD CABINETS

** ASSUMES THIS EXPANSION MODULE HAS NOT BEEN ADDED BY A PREVIOUS SEGMENT UPGRADE PHASE

*** ASSUMES NO EXISTING SHARED CABINETS (I.E., NO COMBINED DETECTOR & CCTV CABINETS)

10.2.10 Segment 10 – Field-to-Node Communications Between Node 6 and Node 13

Project Area:

Segment 10 project limits are along SR 51 between Glendale Avenue and I-10.

Project Description:

The Segment 10 communications upgrade project will utilize the existing 48-SMFO backbone cable deployed along both sides of the SR 51 freeway.

Existing 12-SMFO branch cables will be utilized, between each field device cabinet and the backbone cable. Splices within the existing splice enclosures will be reconfigured to accept the new Field-to-Node topology standard.

Using the SMFO cables, described above, the following two sets of three communications circuits will be established by splicing these fiber optic cables together to create a Hybrid Flower topology between the Node 6 and Node 13:

A. The “A” circuits [DET/RM Circuit 6-13 (A), CCTV Circuit 6-13 (A), and DMS Circuit 6-13 (A)] will each consist of a two fiber path starting at Node Building 6 and ending at Node Building 13, picking up the respective device cabinets along the way, following the Segment 10 “A – Circuits” path depicted in **Figure 10-4**.

B. The “B” circuits [DET/RM Circuit 6-13 (B), CCTV Circuit 6-13 (B), and DMS Circuit 6-13 (B)] will each consist of a two fiber path starting at Node Building 6 and ending at Node Building 13, picking up the respective device cabinets along the way, following the Segment 10 “B – Circuits” path depicted in **Figure 10-4**.

Table 10-10 provides a summary of the work items and cost associated with upgrading Segment 10 to the current communications standard for Node-to-Field communications.

Table 10-10: Segment 10 Upgrade Cost Summary, as of 2010

Item Description	Unit	Quantity	Unit Cost	Work Type Cost
FORCE ACCOUNT WORK (FIBER OPTIC SPLICE CLOSURE RECONDITIONING)	L.SUM	1	$ 10,000.00	$ 10,000.00
FORCE ACCOUNT WORK (PULL BOX RECONDITIONING)	L.SUM	1	$ 5,000.00	$ 5,000.00
FORCE ACCOUNT WORK (CONDUIT RECONDITIONING)	L.SUM	1	$ 5,000.00	$ 5,000.00
*VIDEO ENCODERS	EACH	8	$ 3,000.00	$ 24,000.00
***SERIAL SERVERS (4-PORT)	EACH	33	$ 1,000.00	$ 33,000.00
**24 SFP PORT EXPANSION MODULE FOR 10-GIG SWITCH AT NODE	EACH	2	$ 6,000.00	$ 12,000.00
100 Mbps ETHERNET SFP (OPTICS) FOR 10-GIG SWITCH AT NODE	EACH	12	$ 500.00	$ 6,000.00
***ETHERNET SWITCH AT FIELD CABINET	EACH	33	$ 3,000.00	$ 99,000.00
***FIBER SPLICE RECONFIGURATION PER CABINET/NODE	EACH	35	$ 1,200.00	$ 42,000.00
			Subtotal =	$ 236,000.00
CONTINGENCY		10%		$ 23,600.00
TRAFFIC CONTROL		0%		$ -
MOBILIZATION		8%		$ 18,880.00
SYSTEM INTEGRATION		5%		$ 11,800.00
CONSTRUCTION ADMINISTRATION		15%		$ 35,400.00
			Subtotal =	$ 325,680.00
DESIGN ENGINEERING		12%		$ 39,081.60
			SEGMENT TOTAL =	**$ 364,761.60**

NOTES: * ASSUMES VIDEO ENCODERS AT NODE CAN'T BE RELOCATED TO FIELD CABINETS
** ASSUMES THIS EXPANSION MODULE HAS NOT BEEN ADDED BY A PREVIOUS SEGMENT UPGRADE PHASE
*** ASSUMES NO EXISTING SHARED CABINETS (I.E., NO COMBINED DETECTOR & CCTV CABINETS)

10.2.11 Segment 11 – Field-to-Node Communications Between Node 10 and Node 12

Project Area:

Segment 11 project limits are along US 60 between Loop 202 (Red Mountain) and I-10.

Project Description:

The Segment 11 communications upgrade project will utilize the existing 60-SMFO backbone cable deployed along both sides of the US 60 freeway between Val Vista Drive and the Loop 202 (Red Mountain) and the existing 96-SMFO backbone on both sides of US-60 from Val Vista Drive to I-10.

Existing 12-SMFO branch cables will be utilized, between each field device cabinet and the backbone cable. Splices within the existing splice enclosures will be reconfigured to accept the new Field-to-Node topology standard.

Using the SMFO cables, described above, the following two sets of three communications circuits will be established by splicing these fiber optic cables together to create a Hybrid Flower topology between the Node 10 and Node 12:

A. The “A” circuits [DET/RM Circuit 10-12 (A), CCTV Circuit 10-12 (A) and DMS Circuit 10-12 (A)] will each consist of a two fiber path starting at Node Building 10 and ending at Node Building 12, picking up the respective device cabinets along the way, following the Segment 11 “A – Circuits” path depicted in **Figure 10-4**.

B. The “B” circuits [DET/RM Circuit 10-12 (B), CCTV Circuit 10-12 (B) and DMS Circuit 10-12 (B)] will each consist of a two fiber path starting at Node Building 10 and ending at Node Building 12, picking up the respective device cabinets along the way, following the Segment 11 “B – Circuits” path depicted in **Figure 10-4**.

Table 10-11 provides a summary of the work items and cost associated with upgrading Segment 11 to the current communications standard for Node-to-Field communications.

Table 10-11: Segment 11 Upgrade Cost Summary, as of 2010

Item Description	Unit	Quantity	Unit Cost	Work Type Cost
FORCE ACCOUNT WORK (FIBER OPTIC SPLICE CLOSURE RECONDITIONING)	L.SUM	1	$ 10,000.00	$ 10,000.00
FORCE ACCOUNT WORK (PULL BOX RECONDITIONING)	L.SUM	1	$ 5,000.00	$ 5,000.00
FORCE ACCOUNT WORK (CONDUIT RECONDITIONING)	L.SUM	1	$ 5,000.00	$ 5,000.00
*VIDEO ENCODERS	EACH	25	$ 3,000.00	$ 75,000.00
***SERIAL SERVERS (4-PORT)	EACH	87	$ 1,000.00	$ 87,000.00
**24 SFP PORT EXPANSION MODULE FOR 10-GIG SWITCH AT NODE	EACH	2	$ 6,000.00	$ 12,000.00
100 Mbps ETHERNET SFP (OPTICS) FOR 10-GIG SWITCH AT NODE	EACH	12	$ 500.00	$ 6,000.00
***ETHERNET SWITCH AT FIELD CABINET	EACH	87	$ 3,000.00	$ 261,000.00
***FIBER SPLICE RECONFIGURATION PER CABINET/NODE	EACH	89	$ 1,200.00	$ 106,800.00
			Subtotal =	$ 567,800.00
CONTINGENCY		10%		$ 56,780.00
TRAFFIC CONTROL		0%		$ -
MOBILIZATION		8%		$ 45,424.00
SYSTEM INTEGRATION		5%		$ 28,390.00
CONSTRUCTION ADMINISTRATION		15%		$ 85,170.00
			Subtotal =	$ 783,564.00
DESIGN ENGINEERING		12%		$ 94,027.68
			SEGMENT TOTAL =	**$ 877,591.68**

NOTES: * ASSUMES VIDEO ENCODERS AT NODE CAN'T BE RELOCATED TO FIELD CABINETS
** ASSUMES THIS EXPANSION MODULE HAS NOT BEEN ADDED BY A PREVIOUS SEGMENT UPGRADE PHASE
*** ASSUMES NO EXISTING SHARED CABINETS (I.E., NO COMBINED DETECTOR & CCTV CABINETS)

10.2.12 Segment 12 – Field-to-Node Communications Between Node 9 and Node 12

Project Area:

Segment 12 project limits are along I-10 between US 60 and Loop 202 (Santan); and along SR 143 between Mcdowell Road and I-10.

Project Description:

The Segment 12 communications upgrade project will utilize the existing 60-SMFO backbone cable deployed along both sides of the I-10 freeway, and the existing 144-SMFO on both sides of SR 143 from Mcdowell Road to 4,000 feet north of Node 12.

Existing 12-SMFO branch cables will be utilized, between each field device cabinet and the backbone cable. Splices within the existing splice enclosures will be reconfigured to accept the new Field-to-Node topology standard.

Using the SMFO cables, described above, the following two sets of three communications circuits will be established by splicing these fiber optic cables together to create a Hybrid Flower topology between the Node 9 and Node 12:

A. The "A" circuits [DET/RM Circuit 9-12 (A), CCTV Circuit 9-12 (A) and DMS Circuit 9-12 (A)] will each consist of a two fiber path starting at Node Building 9 and ending at Node Building 12, picking up the respective device cabinets along the way, following the Segment 12 "A – Circuits" path depicted in **Figure 10-4**.

B. The "B" circuits [DET/RM Circuit 9-12 (B), CCTV Circuit 9-12 (B) and DMS Circuit 9-12 (B)] will each consist of a two fiber path starting at Node Building 9 and ending at Node Building 12, picking up the respective device cabinets along the way, following the Segment 12 "B – Circuits" path depicted in **Figure 10-4**.

Table 10-12 provides a summary of the work items and cost associated with upgrading Segment 12 to the current communications standard for Node-to-Field communications.

Table 10-12: Segment 12 Upgrade Cost Summary, as of 2010

Item Description	Unit	Quantity	Unit Cost	Work Type Cost
FORCE ACCOUNT WORK (FIBER OPTIC SPLICE CLOSURE RECONDITIONING)	L.SUM	1	$ 10,000.00	$ 10,000.00
FORCE ACCOUNT WORK (PULL BOX RECONDITIONING)	L.SUM	1	$ 5,000.00	$ 5,000.00
FORCE ACCOUNT WORK (CONDUIT RECONDITIONING)	L.SUM	1	$ 5,000.00	$ 5,000.00
*VIDEO ENCODERS	EACH	14	$ 3,000.00	$ 42,000.00
***SERIAL SERVERS (4-PORT)	EACH	47	$ 1,000.00	$ 47,000.00
**24 SFP PORT EXPANSION MODULE FOR 10-GIG SWITCH AT NODE	EACH	2	$ 6,000.00	$ 12,000.00
100 Mbps ETHERNET SFP (OPTICS) FOR 10-GIG SWITCH AT NODE	EACH	12	$ 500.00	$ 6,000.00
***ETHERNET SWITCH AT FIELD CABINET	EACH	47	$ 3,000.00	$ 141,000.00
***FIBER SPLICE RECONFIGURATION PER CABINET/NODE	EACH	49	$ 1,200.00	$ 58,800.00
			Subtotal =	$ 326,800.00
CONTINGENCY		10%		$ 32,680.00
TRAFFIC CONTROL		0%		$ -
MOBILIZATION		8%		$ 26,144.00
SYSTEM INTEGRATION		5%		$ 16,340.00
CONSTRUCTION ADMINISTRATION		15%		$ 49,020.00
			Subtotal =	$ 450,984.00
DESIGN ENGINEERING		12%		$ 54,118.08
			SEGMENT TOTAL =	**$ 505,102.08**

NOTES: * ASSUMES VIDEO ENCODERS AT NODE CAN'T BE RELOCATED TO FIELD CABINETS

** ASSUMES THIS EXPANSION MODULE HAS NOT BEEN ADDED BY A PREVIOUS SEGMENT UPGRADE PHASE

*** ASSUMES NO EXISTING SHARED CABINETS (I.E., NO COMBINED DETECTOR & CCTV CABINETS)

10.2.13 Segment 13 – Field-to-Node Communications Between Node 7 and Node 8

Project Area:

Segment 13 project limits are along I-10 between I-17 and Loop 202 (Red Mountain).

Project Description:

The Segment 13 communications upgrade project will utilize the existing 144-SMFO backbone cable deployed along both sides of the I-10 freeway, as part of the FMS Rehabilitation Project.

Existing 12-SMFO branch cables will be utilized, between each field device cabinet and the backbone cable. Splices within the existing splice enclosures will be reconfigured to accept the new Field-to-Node topology standard.

Using the SMFO cables, described above, the following two sets of three communications circuits will be established by splicing these fiber optic cables together to create a Hybrid Flower topology between the Node 7 and Node 8:

A. The "A" circuits [DET/RM Circuit 7-8 (A), CCTV Circuit 7-8 (A) and DMS Circuit 7-8 (A)] will each consist of a two fiber path starting at Node Building 7 and ending at Node Building 8, picking up the respective device cabinets along the way, following the Segment 13 "A – Circuits" path depicted in **Figure 10-4**.

B. The "B" circuits [DET/RM Circuit 7-8 (B), CCTV Circuit 7-8 (B) and DMS Circuit 7-8 (B)] will each consist of a two fiber path starting at Node Building 7 and ending at Node Building 8, picking up the respective device cabinets along the way, following the Segment 13 "B – Circuits" path depicted in **Figure 10-4**.

Table 10-13 provides a summary of the work items and cost associated with upgrading Segment 13 to the current communications standard for Node-to-Field communications.

Table 10-13: Segment 13 Upgrade Cost Summary, as of 2010

Item Description	Unit	Quantity	Unit Cost	Work Type Cost
FORCE ACCOUNT WORK (FIBER OPTIC SPLICE CLOSURE RECONDITIONING)	L.SUM	1	$ 10,000.00	$ 10,000.00
FORCE ACCOUNT WORK (PULL BOX RECONDITIONING)	L.SUM	1	$ 5,000.00	$ 5,000.00
FORCE ACCOUNT WORK (CONDUIT RECONDITIONING)	L.SUM	1	$ 5,000.00	$ 5,000.00
*VIDEO ENCODERS	EACH	4	$ 3,000.00	$ 12,000.00
***SERIAL SERVERS (4-PORT)	EACH	14	$ 1,000.00	$ 14,000.00
**24 SFP PORT EXPANSION MODULE FOR 10-GIG SWITCH AT NODE	EACH	2	$ 6,000.00	$ 12,000.00
100 Mbps ETHERNET SFP (OPTICS) FOR 10-GIG SWITCH AT NODE	EACH	12	$ 500.00	$ 6,000.00
***ETHERNET SWITCH AT FIELD CABINET	EACH	14	$ 3,000.00	$ 42,000.00
***FIBER SPLICE RECONFIGURATION PER CABINET/NODE	EACH	16	$ 1,200.00	$ 19,200.00
			Subtotal =	$ 125,200.00
CONTINGENCY		10%		$ 12,520.00
TRAFFIC CONTROL		0%		$ -
MOBILIZATION		8%		$ 10,016.00
SYSTEM INTEGRATION		5%		$ 6,260.00
CONSTRUCTION ADMINISTRATION		15%		$ 18,780.00
			Subtotal =	$ 172,776.00
DESIGN ENGINEERING		12%		$ 20,733.12
			SEGMENT TOTAL =	**$ 193,509.12**

NOTES: * ASSUMES VIDEO ENCODERS AT NODE CAN'T BE RELOCATED TO FIELD CABINETS
** ASSUMES THIS EXPANSION MODULE HAS NOT BEEN ADDED BY A PREVIOUS SEGMENT UPGRADE PHASE
*** ASSUMES NO EXISTING SHARED CABINETS (I.E., NO COMBINED DETECTOR & CCTV CABINETS)

10.2.14 Segment 14 – Field-to-Node Communications Between TOC and Node 8

Project Area:

Segment 14 project limits are along I-17 between SR 51 and Durango Street.

Project Description:

The Segment 14 communications upgrade project will utilize the existing 144-SMFO backbone cable deployed along both sides of the I-17 freeway, as part of the FMS Rehab Project.

Existing 144-SMFO branch cables will be utilized, between each field device cabinet and the backbone cable. Splices within the existing splice enclosures will be reconfigured to accept the new Field-to-Node topology standard.

Using the SMFO cables, described above, the following two sets of three communications circuits will be established by splicing these fiber optic cables together to create a Hybrid Flower topology between the TOC and Node 8:

A. The "A" circuits [DET/RM Circuit TOC-8 (A), CCTV Circuit TOC-8 (A) and DMS Circuit TOC-8 (A)] will each consist of a two fiber path starting at the TOC and ending at Node Building 8, picking up the respective device cabinets along the way, following the Segment 14 "A – Circuits" path depicted in **Figure 10-4**.

B. The "B" circuits [DET/RM Circuit TOC-8 (B), CCTV Circuit TOC-8 (B) and DMS Circuit TOC-8 (B)] will each consist of a two fiber path starting at the TOC and ending at Node Building 8, picking up the respective device cabinets along the way, following the Segment 14 "B – Circuits" path depicted in **Figure 10-4**.

Table 10-14 provides a summary of the work items and cost associated with upgrading Segment 14 to the current communications standard for Node-to-Field communications.

Table 10-14: Segment 14 Upgrade Cost Summary, as of 2010

Item Description	Unit	Quantity	Unit Cost	Work Type Cost
FORCE ACCOUNT WORK (FIBER OPTIC SPLICE CLOSURE RECONDITIONING)	L.SUM	1	$ 10,000.00	$ 10,000.00
FORCE ACCOUNT WORK (PULL BOX RECONDITIONING)	L.SUM	1	$ 5,000.00	$ 5,000.00
FORCE ACCOUNT WORK (CONDUIT RECONDITIONING)	L.SUM	1	$ 5,000.00	$ 5,000.00
*VIDEO ENCODERS	EACH	4	$ 3,000.00	$ 12,000.00
***SERIAL SERVERS (4-PORT)	EACH	16	$ 1,000.00	$ 16,000.00
**24 SFP PORT EXPANSION MODULE FOR 10-GIG SWITCH AT NODE	EACH	2	$ 6,000.00	$ 12,000.00
100 Mbps ETHERNET SFP (OPTICS) FOR 10-GIG SWITCH AT NODE	EACH	12	$ 500.00	$ 6,000.00
***ETHERNET SWITCH AT FIELD CABINET	EACH	16	$ 3,000.00	$ 48,000.00
***FIBER SPLICE RECONFIGURATION PER CABINET/NODE	EACH	18	$ 1,200.00	$ 21,600.00
			Subtotal =	$ 135,600.00
CONTINGENCY		10%		$ 13,560.00
TRAFFIC CONTROL		0%		$ -
MOBILIZATION		8%		$ 10,848.00
SYSTEM INTEGRATION		5%		$ 6,780.00
CONSTRUCTION ADMINISTRATION		15%		$ 20,340.00
			Subtotal =	$ 187,128.00
DESIGN ENGINEERING		12%		$ 22,455.36
			SEGMENT TOTAL =	$ 209,583.36

NOTES: * ASSUMES VIDEO ENCODERS AT NODE CAN'T BE RELOCATED TO FIELD CABINETS
** ASSUMES THIS EXPANSION MODULE HAS NOT BEEN ADDED BY A PREVIOUS SEGMENT UPGRADE PHASE
*** ASSUMES NO EXISTING SHARED CABINETS (I.E., NO COMBINED DETECTOR & CCTV CABINETS)

10.2.15 Segment 15 – Field-to-Node Communications Between Node 10 and Node 14

Project Area:

Segment 15 project limits are along Loop 202 (Red Mountain) between Loop 101 (Pima) and US 60; and along US 60 from Loop 202 (Red Mountain) to Crismon Road.

Project Description:

The Segment 15 communications upgrade project will utilize the existing 96-SMFO backbone cable deployed along both sides of the US-60 freeway, and an anticipated 144-SMFO cable on one side of Loop 202 (Red Mountain).

Existing 12-SMFO branch cables will be utilized, between each field device cabinet and the backbone cable. Splices within the existing splice enclosures will be reconfigured to accept the new Field-to-Node topology standard.

Using the SMFO cables, described above, the following two sets of three communications circuits will be established by splicing these fiber optic cables together to create a Hybrid Flower topology between the Node 10 and Node 14:

A. The "A" circuits [DET/RM Circuit 10-14 (A), CCTV Circuit 10-14 (A) and DMS Circuit 10-14 (A)] will each consist of a two fiber path starting at Node Building 10 and ending at Node Building 14, picking up the respective device cabinets along the way, following the Segment 15 "A – Circuits" path depicted in **Figure 10-4**.

B. The "B" circuits [DET/RM Circuit 10-14 (B), CCTV Circuit 10-14 (B) and DMS Circuit 10-14 (B)] will each consist of a two fiber path starting at Node Building 10 and ending at Node Building 14, picking up the respective device cabinets along the way, following the Segment 15 "B – Circuits" path depicted in **Figure 10-4**.

Table 10-15 provides a summary of the work items and cost associated with upgrading Segment 15 to the current communications standard for Node-to-Field communications.

Table 10-15: Segment 15 Upgrade Cost Summary, as of 2010

Item Description ***EXISTING US 60 DEVICE LOCATIONS ONLY***	Unit	Quantity	Unit Cost	Work Type Cost
FORCE ACCOUNT WORK (FIBER OPTIC SPLICE CLOSURE RECONDITIONING)	L.SUM	1	$ 10,000.00	$ 10,000.00
FORCE ACCOUNT WORK (PULL BOX RECONDITIONING)	L.SUM	1	$ 5,000.00	$ 5,000.00
FORCE ACCOUNT WORK (CONDUIT RECONDITIONING)	L.SUM	1	$ 5,000.00	$ 5,000.00
*VIDEO ENCODERS	EACH	2	$ 3,000.00	$ 6,000.00
***SERIAL SERVERS (4-PORT)	EACH	8	$ 1,000.00	$ 8,000.00
**24 SFP PORT EXPANSION MODULE FOR 10-GIG SWITCH AT NODE	EACH	2	$ 6,000.00	$ 12,000.00
100 Mbps ETHERNET SFP (OPTICS) FOR 10-GIG SWITCH AT NODE	EACH	12	$ 500.00	$ 6,000.00
***ETHERNET SWITCH AT FIELD CABINET	EACH	8	$ 3,000.00	$ 24,000.00
***FIBER SPLICE RECONFIGURATION PER CABINET/NODE	EACH	10	$ 1,200.00	$ 12,000.00
			Subtotal =	$ 88,000.00
CONTINGENCY		10%		$ 8,800.00
TRAFFIC CONTROL		0%		$ -
MOBILIZATION		8%		$ 7,040.00
SYSTEM INTEGRATION		5%		$ 4,400.00
CONSTRUCTION ADMINISTRATION		15%		$ 13,200.00
			Subtotal =	$ 121,440.00
DESIGN ENGINEERING		12%		$ 14,572.80
			SEGMENT TOTAL =	**$ 136,012.80**

NOTES: * ASSUMES VIDEO ENCODERS AT NODE CAN'T BE RELOCATED TO FIELD CABINETS
** ASSUMES THIS EXPANSION MODULE HAS NOT BEEN ADDED BY A PREVIOUS SEGMENT UPGRADE PHASE
*** ASSUMES NO EXISTING SHARED CABINETS (I.E., NO COMBINED DETECTOR & CCTV CABINETS)

10.2.16 TOC IP Video Distribution Upgrade and ATOC Full Deployment

Although the TOC IP Video Distribution Upgrade and ATOC Full Deployment migration step is listed last, it does not mean these two communications migration steps are the least important. In fact, these two critical migration steps can in many ways be viewed as most important; however, the cost-to-benefits ratio associated with these two upgrades increases as the other migration steps are achieved.

APPENDIX A – ETHERNET TECHNOLOGY STANDARDS

Ethernet technology has evolved over the last 40 years to accommodate the continuous demand for higher and higher data transfer rates. The two transmission mediums that are predominant in today's landline networks are copper cabling and fiber optic cabling. The following breaks down the current Ethernet standards along with a comparison of overall cost versus transmission distance.

Traditionally, leased lines were utilized to connect devices and facilities over large distances. Other municipalities have experienced high operations and management cost due to subscription to services utilizing CWDM or SONET standards offered by service providers. Ethernet technologies are widely available today and offer municipal agencies a long term cost effective alternative for long distance data transmission.

Most networks deployed today, no matter the size, use a combination of copper and fiber cabling. The deployment of a Node-to-TOC/ATOC and Field-to-Node networks will be no different and will require the use of various Ethernet technologies in order to connect these buildings/cabinets using short haul transmissions as well as remote sites that demand long haul transmission. 10/100Megabit Ethernet devices are being reduced in large network deployment percentages as gigabit and 10 Gigabit Ethernet devices become more affordable in the market. **Table A-1** through **Table A-3** show a comparison of the existing cabling standards and their maximum transmission distances.

Table A-1: 10/100Mb Ethernet LAN Standards

10/100 Mbps Ethernet				
Cabling Standard	**IEEE Standard**	**Cabling Type**	**Description**	**Maximum Distances**
10Base-2	IEEE 802.3	RG-58 Coaxial cabling	Medium Haul Copper	up to 185m
10Base-5	IEEE 802.3	RG-8 Coaxial cabling	Long Haul Copper	up to 500m
10Base-T	IEEE 802.3i	RJ-45 CAT 3	Medium Haul Copper	up to 150m*
10Base-FL	IEEE 802.3i	50μ Multi-mode Fiber 62.5μ Multi-mode Fiber	Medium Haul Fiber	up to 1km
100Base-T	IEEE 802.3u	RJ-45 CAT 3 and CAT 5	Medium Haul Copper	up to 100m
100Base-SX	IEEE 802.3u	50μ Multi-mode Fiber 62.5μ Multi-mode Fiber	Short Haul Fiber	up to 300m
100Base-FX	IEEE 802.3u	50μ Multi-mode Fiber 62.5μ Multi-mode Fiber	Long Haul Fiber	up to 2km
100Base-LX10	IEEE 802.3u	9μ Single-mode Fiber	Long Haul Fiber	up to 10km
100Base-BX10	IEEE 802.3u	9μ Single-mode Fiber	Long Haul Fiber	up to 2km

*10BASE-T does not specify the exact type of wiring to be used or a maximum length but instead specifies certain "characteristics" which a cable must meet. With high quality cabling that is available, cable runs of 150 meters or longer are often obtained and are considered viable by most technicians familiar with the 10baseT specification. There are several standards of Ethernet over twisted-pair that is collectively grouped as 10Base-T. This standard includes 10Base-TX, 10Base-T2, and 10Base-T4.

Table A-2: Gigabit Ethernet LAN Standards

Gigabit Ethernet				
Cabling Standard	**IEEE Standard**	**Cabling Type**	**Description**	**Maximum Distances**
1000Base-T	IEEE 802.3ab	RJ-45 CAT 5, 5E, 6	Medium Haul Copper	up to 100m
1000Base-CX	IEEE 802.3z	Copper Cabling	Short Haul Copper	up to 25m
1000Base-SX	IEEE 802.3z	50μ Multi-mode Fiber 62.5μ Multi-mode Fiber	Short Haul Fiber	up to 550m up to 275m
1000Base-LX	IEEE 802.3z	9μ Single-mode Fiber 50μ Multi-mode Fiber 62.5μ Multi-mode Fiber	Long Haul Fiber	up to 5km up to 550m up to 275m

*Note 1000Base-Z is a non-standard, but industry accepted Gigabit Ethernet platform for distances up to 70km using single mode fiber.

Table A-3: 10 Gigabit Ethernet LAN Standards

10 Gigabit Ethernet				
Type	**IEEE Standard**	**Transmission Medium**	**Description**	**Maximum Distances**
10GBase-SR	IEEE 802.3ae	50μ Multi-mode Fiber 62.5μ Multi-mode Fiber	Short Haul Fiber	up to 85m up to 35m
10GBase-LR	IEEE 802.3ae	9μ Single-mode Fiber	Long Haul Fiber	up to 10km
10GBase-ER	IEEE 802.3ae	9μ Single-mode Fiber	Long Haul Fiber	up to 30km
10GBase-LX4	IEEE 802.3ae	9μ Single-mode Fiber 50μ Multi-mode Fiber 62.5μ Multi-mode Fiber	Long Haul Fiber	up to 10km up to 550m up to 275m
10GBase-CX4	IEEE 802.3ak	8 pair, 100Ω twin axial cable	Short Haul Copper	up to 15m*

*Optical Media Converters using multi-mode fiber (MMF) can extend range to 300m

The 10 Gigabit Ethernet standards listed below show the relative cost comparison of each standard and the cabling technologies each uses for data transmission:

- 10GBASE-SR – lowest cost optics (850nm)
- 10GBASE-LR – second lowest cost optics (1310nm)
- 10GBASE-LX4 – more expensive than both SR and LR because it requires four times the optical and electrical circuitry in addition to optical multiplexers
- 10GBASE-ER – most expensive optics (1550nm)
- 10GBASE-CX4 – low-cost copper cabling with short distance connectivity, the longer the length used the thicker the cable

As shown in the three tables above, short haul optics exceed the distance of long haul copper. Short haul optics can be used to interconnect a hub in a building or campus, while long haul optics can be used to transmit data over large distances. The main goal of long haul optics is to eliminate and/or reduce the use of repeaters that are necessary at intervals to maintain signal quality, not allowing the signal to deteriorate to the point where it is unusable.

The maximum distances for all transmission medium can be extended with additional equipment. Repeaters are used to re-amplify signals at specific intervals along the length of the transmission. The use of repeaters is very costly and the maintenance can be an additional burden. Optical media converters can also be used to convert Ethernet LAN copper transmissions to fiber optic transmissions in order to extend the transmission distance beyond 100 meters. This is also a method that can reduce the costs of a fully fiber optic solution. Media converters can extend a 100Mb transmission up to 100km and a 1000Mb transmission up to 70km.

At the Node Buildings it is recommended that individual IP video encoders be installed. This will give the future flexibility to reinstall these encoders at the camera cabinet locations when needed.

APPENDIX B – NODE BUILDINGS COMMUNICATIONS CONFIGURATIONS

During the preliminary stages of preparing this Communications Master Plan, an inventory was taken at each Node Building so an accurate analysis of the system could be performed. The following text should be included in the special provisions for future construction projects that change Node Building(s) communications configuration:

"The Node Building communications configuration diagram(s), within The FMS Communications Master Plan, will be updated by the Contractor. The Contractor will request the most current version of the diagram(s) from the ADOT TTG Project Manager. The diagrams are currently drawn in Microsoft Visio software format. The Contractor will update the diagram(s) to accurately depict the entire Node Building(s) communications configuration at the completion of the project."

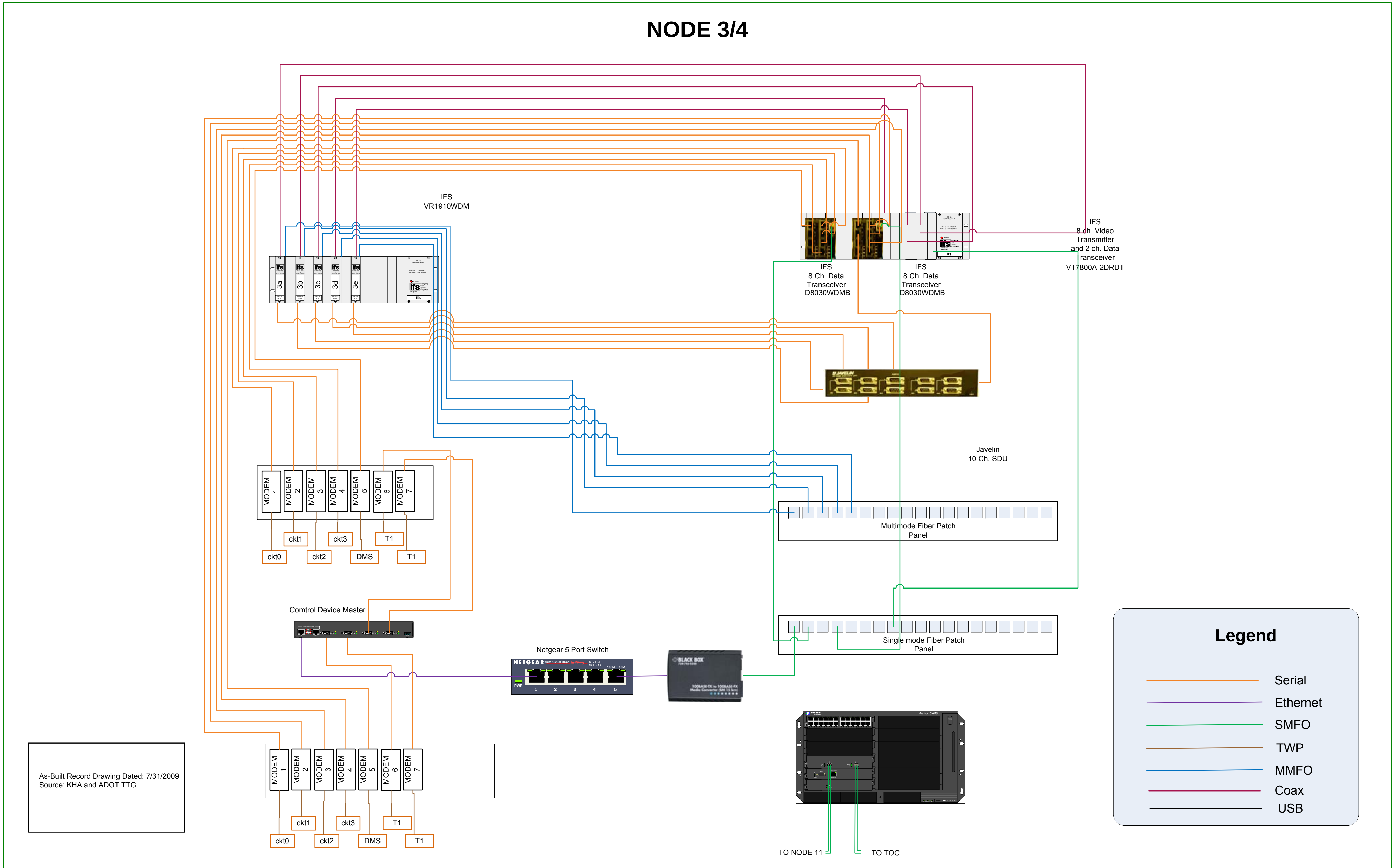


Figure B-1: Node 3/4 Layout

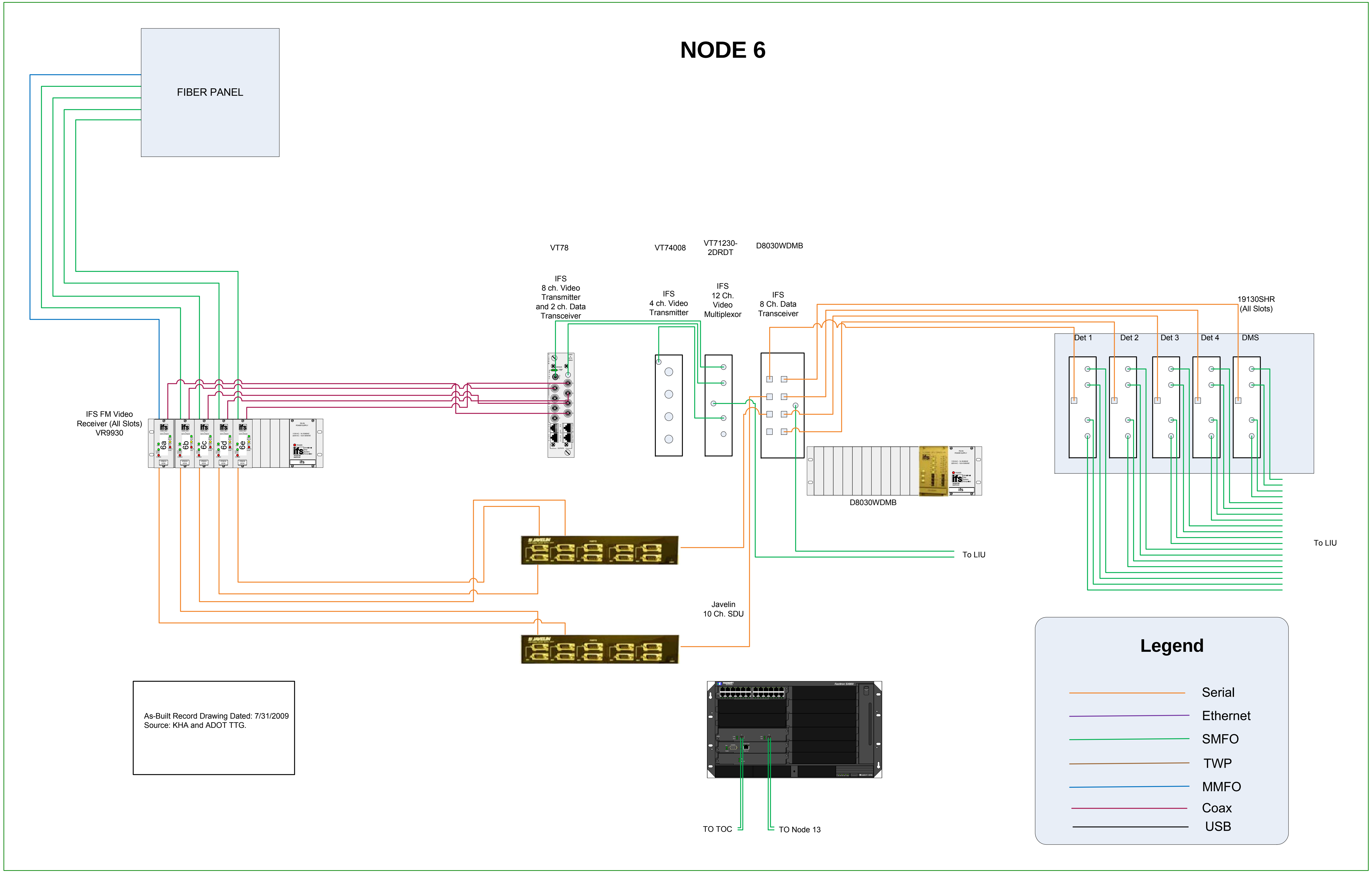


Figure B-2: Node 6 Layout

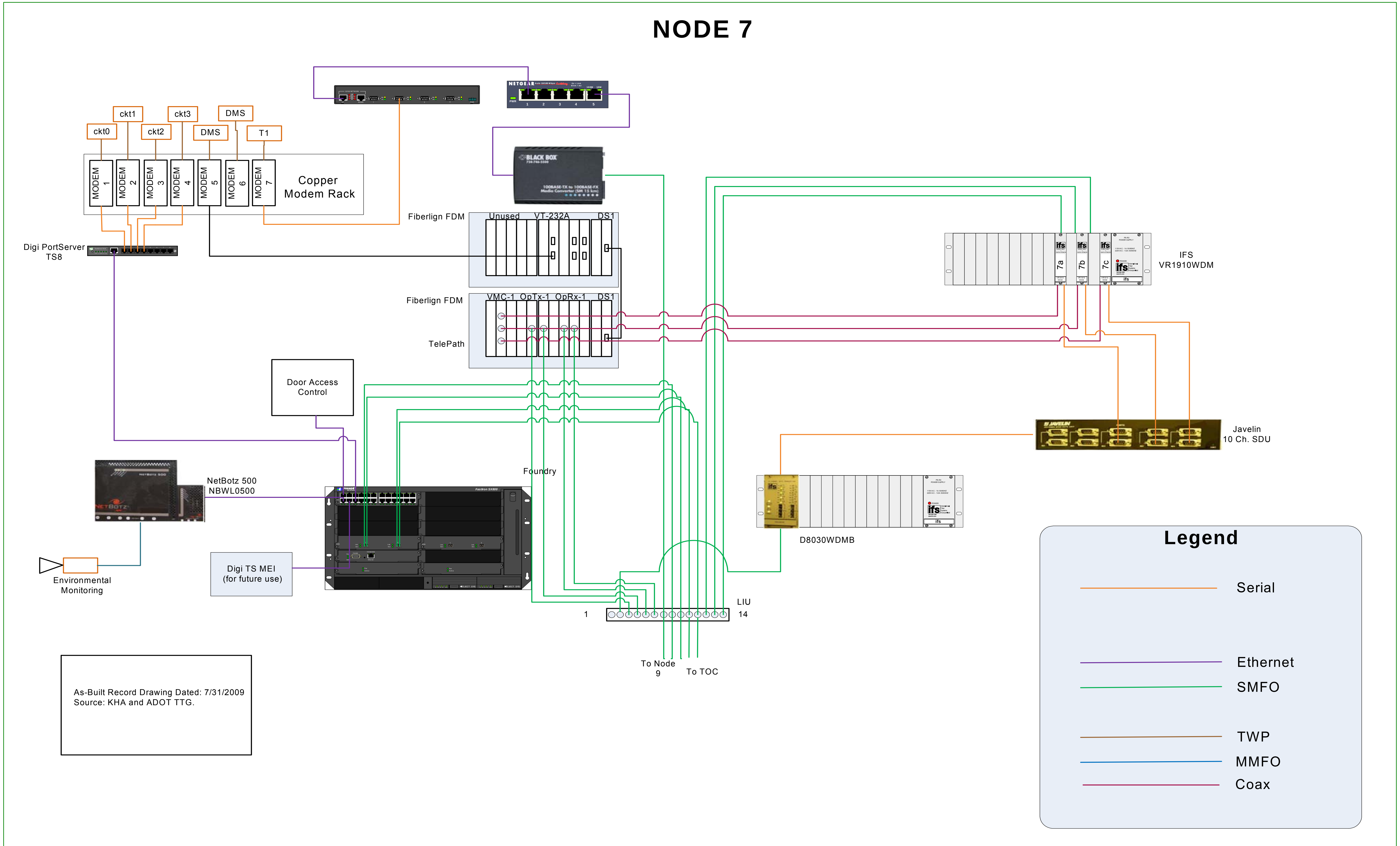


Figure B-3: Node 7 Layout

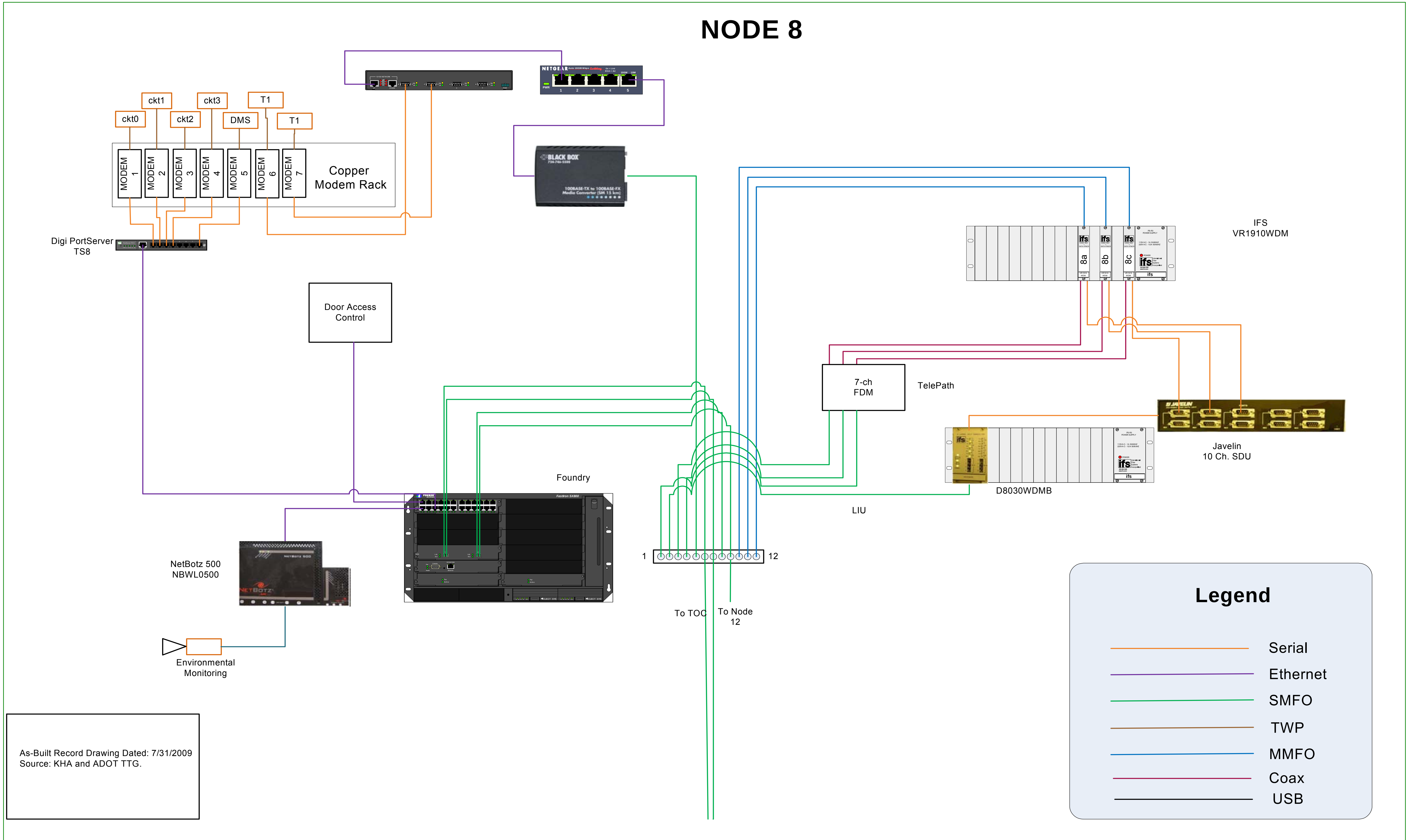
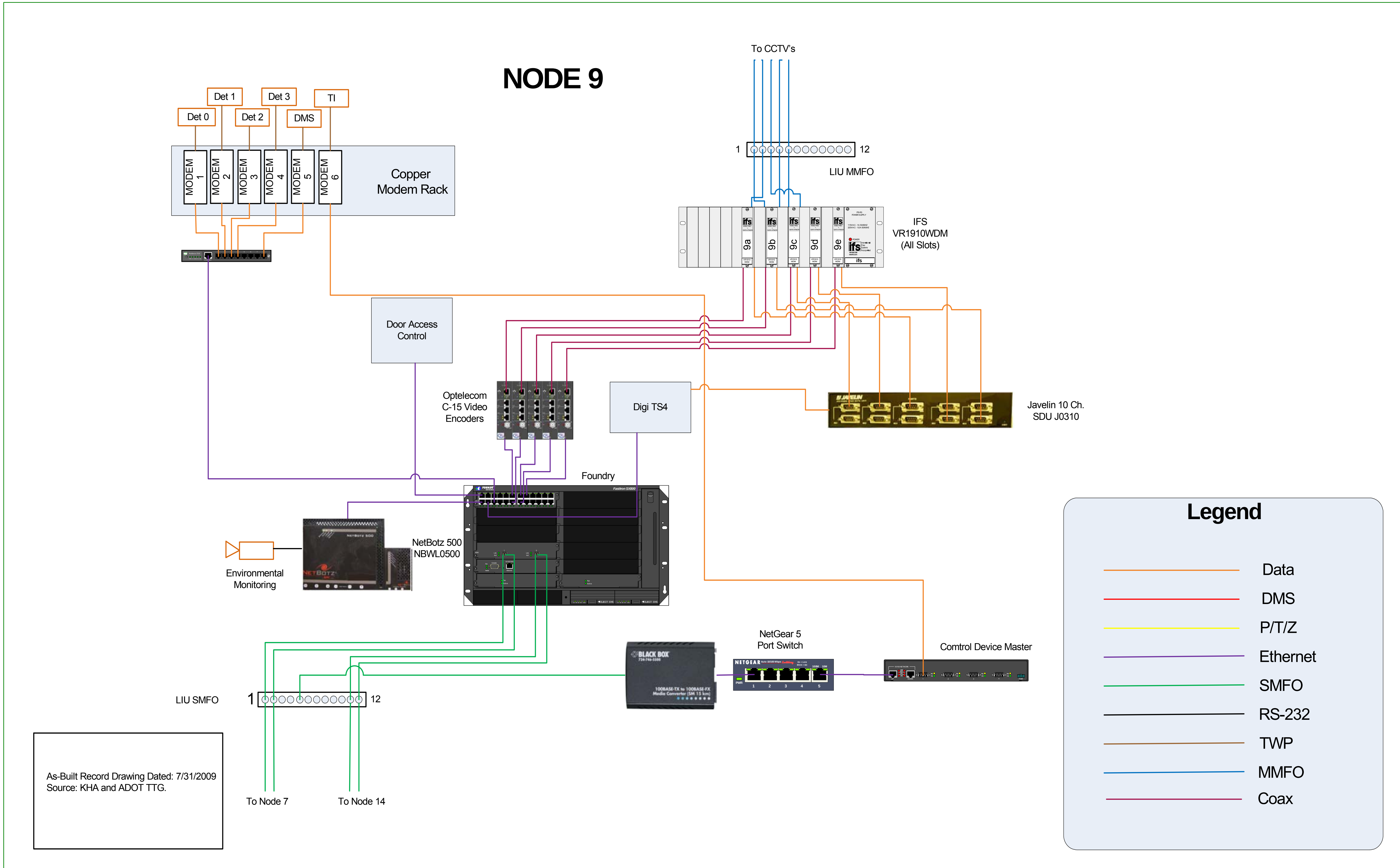


Figure B-4: Node 8 Layout



As-Built Record Drawing Dated: 7/31/2009
Source: KHA and ADOT TTG.

Figure B-5: Node 9 Layout

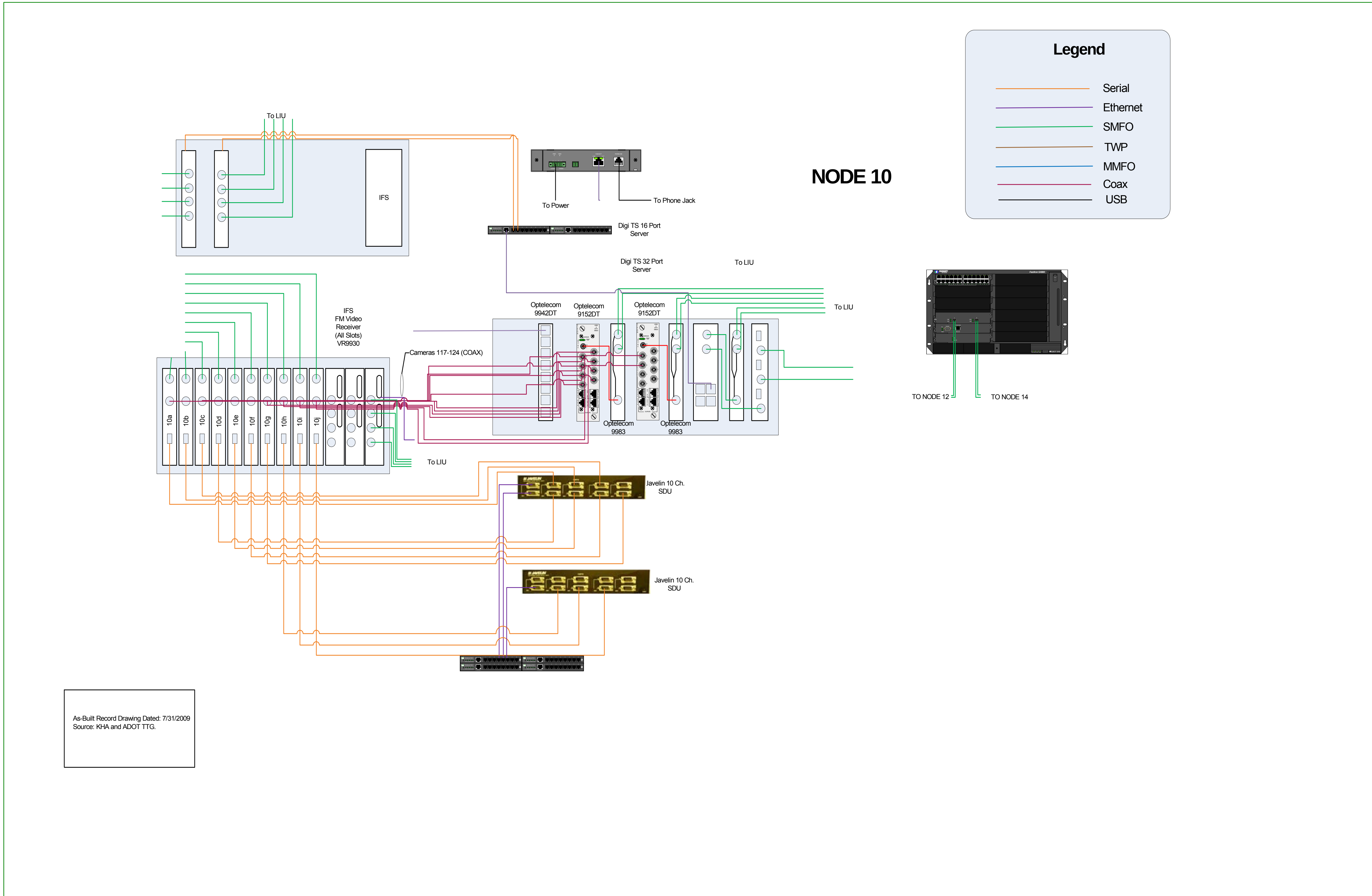


Figure B-6: Node 10 Layout

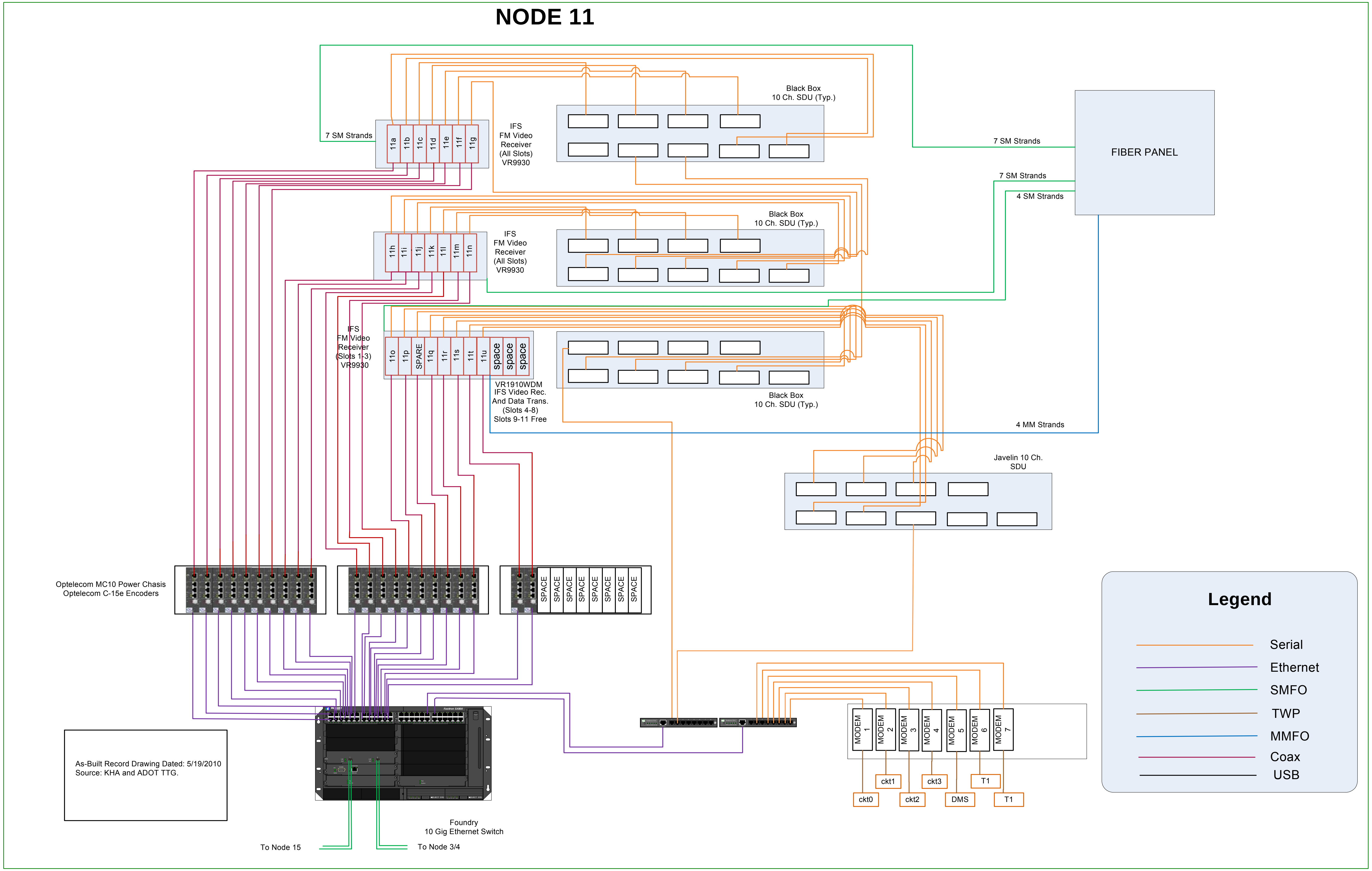


Figure B-7: Node 11 Layout

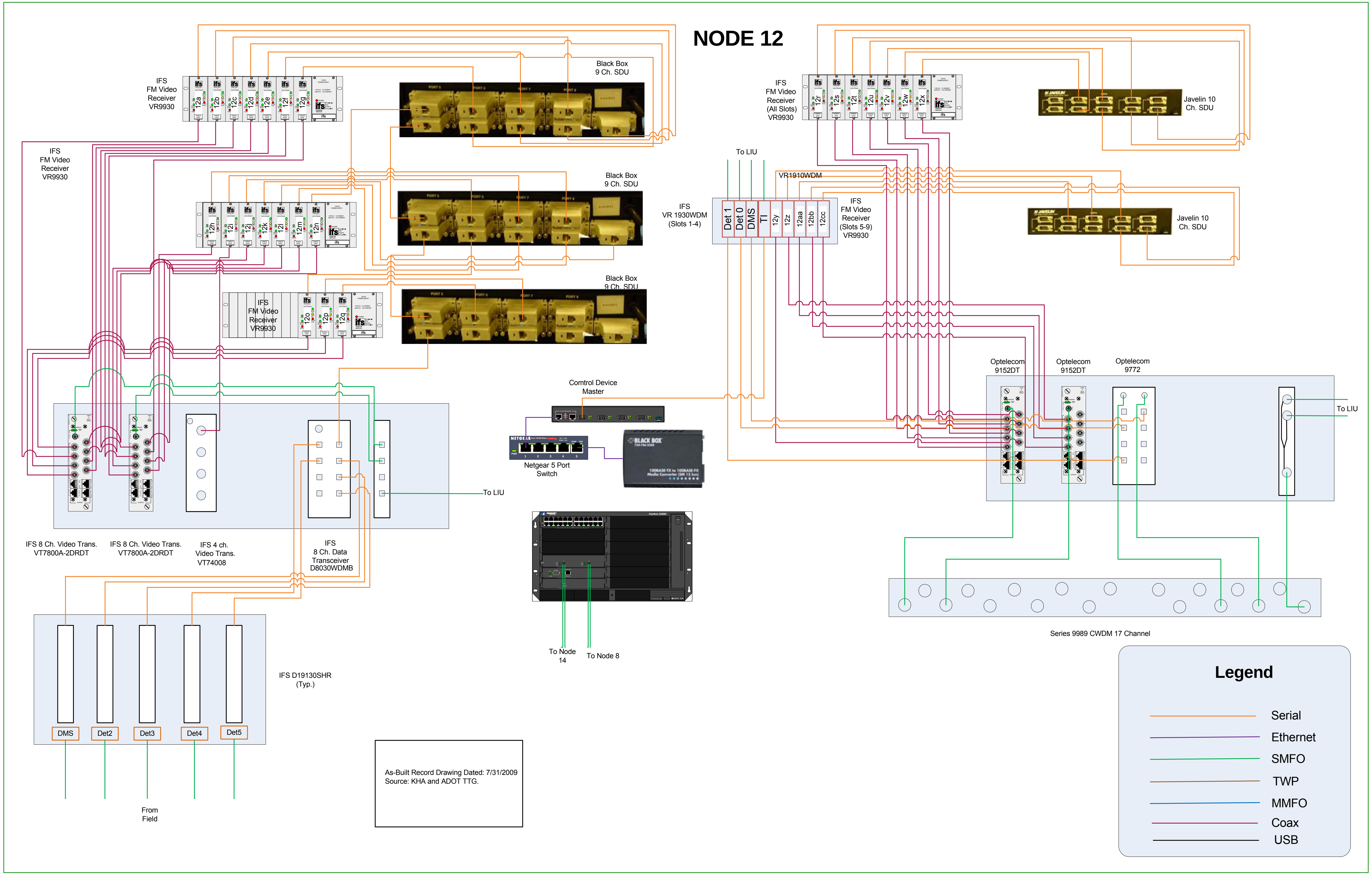


Figure B-8: Node 12 Layout

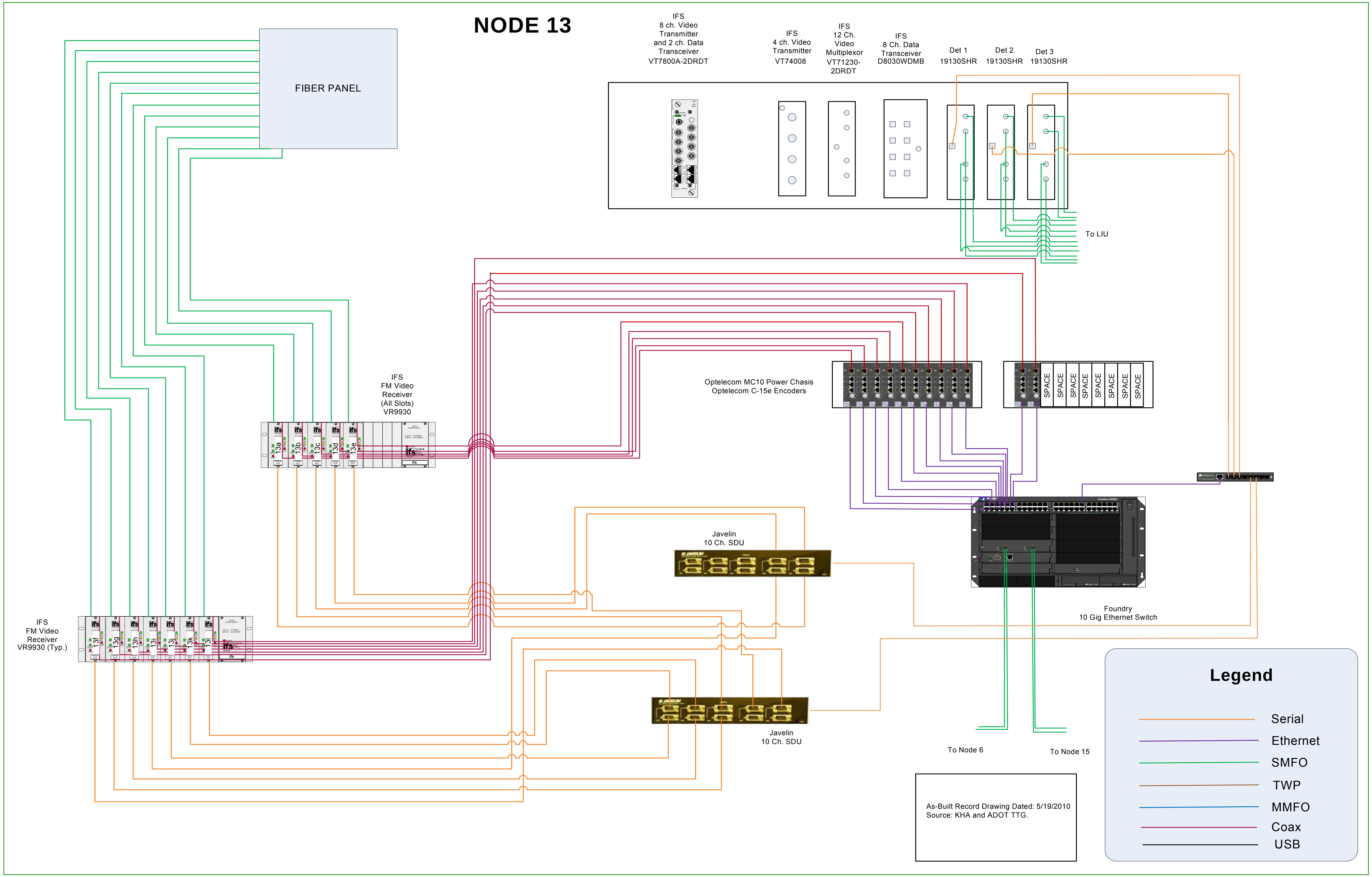


Figure B-9: Node 13 Layout

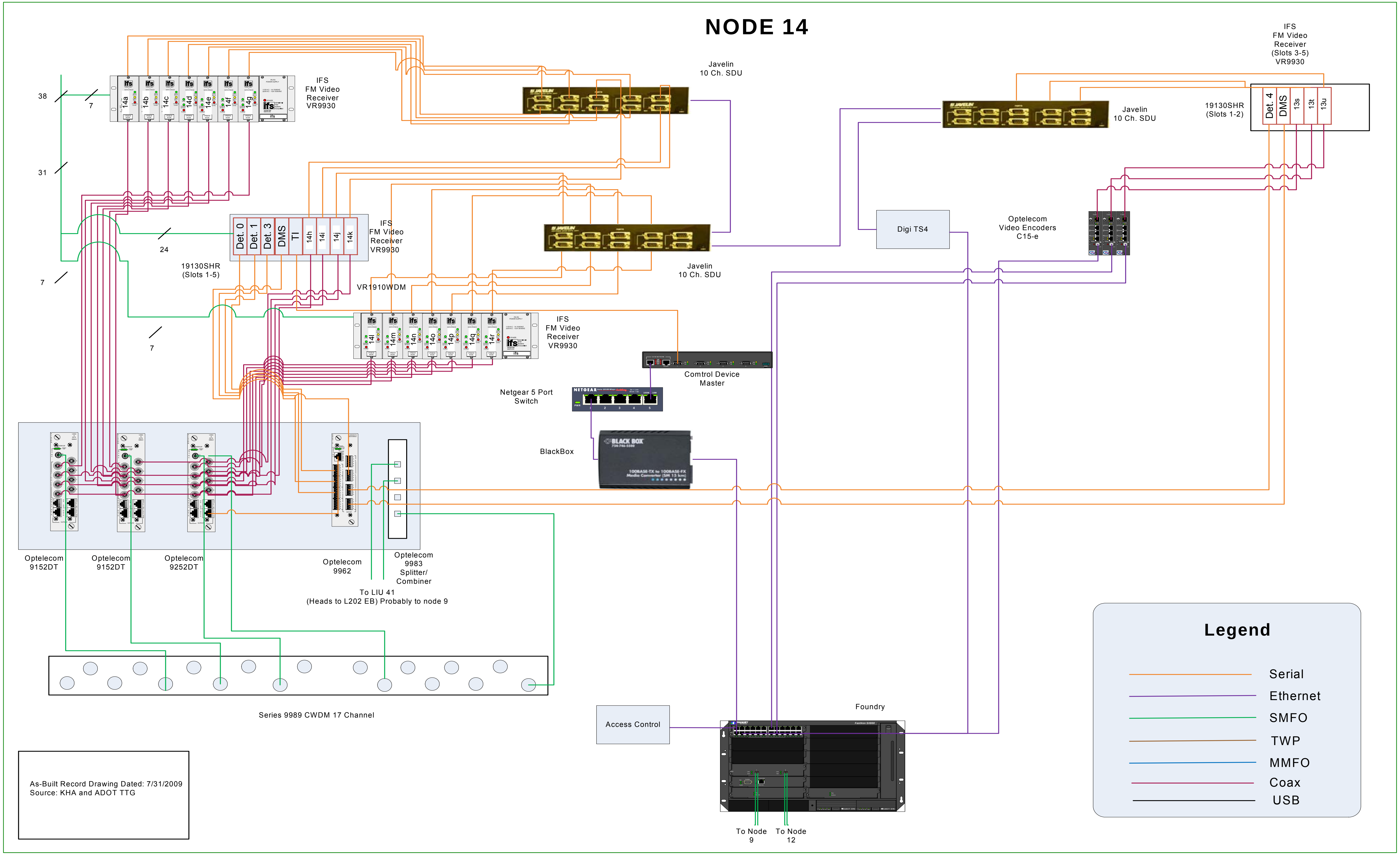


Figure B-10: Node 14 Layout

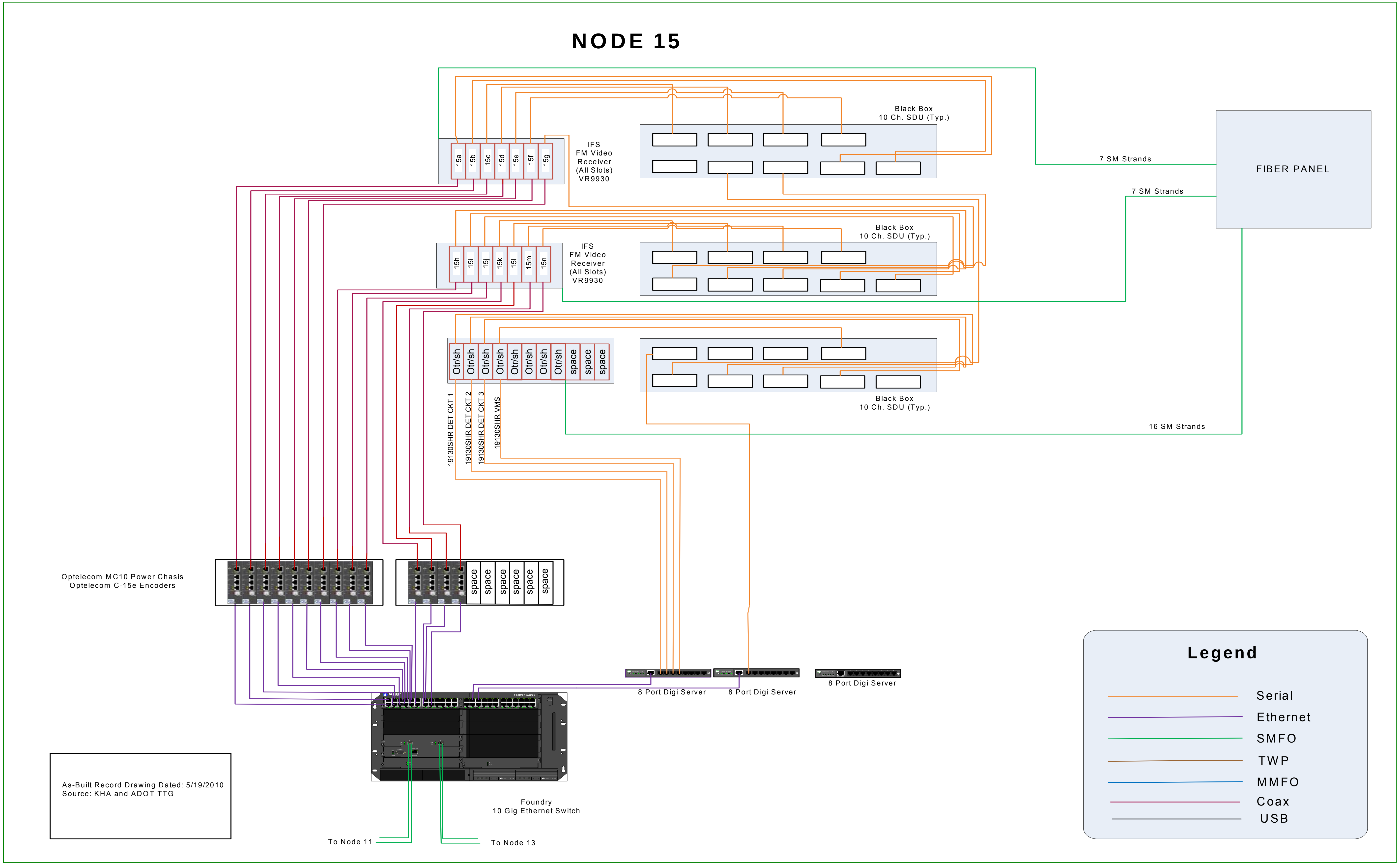


Figure B-11: Node 15 Layout

Table B-1: CCTV Location Table

Roadway	Direction	Node #	General Location	Node Diagram Reference No.
I-10	EB	3/4	W of 7th Ave	3a
I-10	M	3/4	19th Ave	3b
I-10	M	3/4	E of 27th Ave	3c
I-10	EB	3/4	E of 35th Ave	3d
I-10	EB	3/4	E of 43rd Ave	3e
I-10	WB	6	W of 16th St	6a
I-10	M	6	7th St	6b
SR-51	NB	6	S of Highland	6c
SR-51	NB	6	N of Thomas	6d
SR-51	NB	6	N of McDowell	6e
I-10	M	7	Mini-Stack--@ N	7a
I-10	WB	7	Van Buren	7b
I-10	WB	7	Mini-Stack--@ S	7c
I-10	EB	8	I-17 Split	8a
I-10	WB	8	Buckeye	8b
I-17	SB	8	S of 7th St	8c
SR-143	SB	9	Washington	9a
L-202	WB	9	E of 24th St	9b
L-202	WB	9	E of 32nd St	9c
L-202	WB	9	E of 40th St	9d
L-202	WB	9	SR-143	9e
US-60	EB	10	Val Vista	10a
US-60	WB	10	Greenfield	10b
US-60	EB	10	Higley	10c
US-60	WB	10	W of Superstition	10d
US-60	WB	10	Power	10e
US-60	WB	10	Sossaman	10f
US-60	WB	10	L-202N Super Red Tan	10g
US-60	EB	10	L-202S Super Red Tan	10h
US-60	WB	10	Ellsworth	10i
US-60	WB	10	Crismon	10j
I-10	WB	11	L-101W	11a
L-101	SB	11	McDowell	11b
L-101	SB	11	Indian School	11c
L-101	SB	11	Camelback	11d
L-101	SB	11	Bethany Home	11e
L-101	SB	11	Glendale	11f
L-101	SB	11	Northern	11g
L-101	NB	11	Olive	11h
L-101	SB	11	Peoria	11i
L-101	SB	11	N of Grand	11j
L-101	NB	11	Thunderbird	11k

L-101	SB	11	Bell	11l
L-101	SB	11	Union Hills	11m
L-101	WB	11	67th Av	11n
L-101	WB	11	51st Av	11o
L-101	WB	11	I-17	11p
I-10	M	11	E of 83rd Ave	11q
I-10	EB	11	E of 75th Ave	11r
I-10	EB	11	E of 67th Ave	11s
I-10	WB	11	E of 59th Ave	11t
I-10	WB	11	E of 51st Ave	11u
US-60	EB	12	E of Priest	12a
US-60	EB	12	E of McClintock	12b
US-60	EB	12	E of L-101	12c
US-60	EB	12	E of Dobson	12d
US-60	EB	12	E of Alma School	12e
US-60	WB	12	E of Country Club	12f
US-60	EB	12	E of Stapley	12g
US-60	EB	12	E of Gilbert	12h
US-60	WB	12	W of Val Vista	12i
US-60	WB	12	Gilbert	12j
US-60	WB	12	E of Mesa	12k
US-60	WB	12	Country Club	12l
US-60	WB	12	McClintock	12m
US-60	WB	12	E of Rural	12n
US-60	WB	12	Rural	12o
US-60	WB	12	E of Mill	12p
US-60	WB	12	Priest	12q
I-10	WB	12	E of 32nd St	12r
I-10	EB	12	Salt River Bridge	12s
SR-143	NB	12	N of University	12t
SR-143	NB	12	University	12u
I-10	WB	12	E of 40th St	12v
I-10	WB	12	48th St/SR-143	12w
I-10	WB	12	Southern	12x
I-10	EB	12	E of US-60	12y
I-10	WB	12	E of Baseline	12z
I-10	EB	12	W of Elliot	12aa
I-10	EB	12	W of Warner	12bb
I-10	EB	12	W of Ray	12cc
SR-51	NB	13	S of Bell	13a
SR-51	NB	13	S of Northern	13b
SR-51	NB	13	S of Thunderbird	13c
SR-51	SB	13	S of Greenway	13d
SR-51	SB	13	N of Glendale	13e

SR-51	NB	13	S of Shea	13f
SR-51	SB	13	N of Northern	13g
SR-51	SB	13	S of 32nd St	13h
SR-51	NB	13	S of Cactus	13i
SR-51	SB	13	Bethany Home	13j
SR-51	SB	13	Colter St	13k
SR-51	SB	13	S of Glendale	13l
L-202	EB	14	E of Van Buren	14a
L-202	WB	14	E of 52nd St	14b
L-202	WB	14	Priest	14c
L-202	EB	14	E of Priest	14d
L-202	WB	14	McClintock	14e
L-202	WB	14	E of McClintock	14f
L-202	M	14	L101 Red Mountain	14g
L-101	NB	14	University	14h
L-101	NB	14	Broadway	14i
L-101	NB	14	N of Southern	14j
L-202	WB	14	Scottsdale	14k
L-101	SB	14	Elliot	14l
L-101	SB	14	Warner	14m
L-101	NB	14	Ray	14n
L-101	NB	14	Chandler	14o
L-202	EB	14	L101	14p
L-202	WB	14	W of L-101	14q
L-202	WB	14	E of L-101	14r
L-101	SB	14	US-60	14s
L-101	SB	14	Baseline	14t
L-101	SB	14	Guadalupe	14u
L-101	WB	15	L101 WB E of I-17	15a
L-101	EB	15	L101 EB 7th Ave	15b
L-101	WB	15	L101 WB 7th Ave	15c
L-101	WB	15	L101 WB 7th St.	15d
L-101	EB	15	L101 EB E of 16th St.	15e
L-101	WB	15	L101 WB Cave Creek	15f
L-101	EB	15	L101 EB W of SR51	15g
L-101	M	15	L101/SR51 Overpass	15h
L-101	WB	15	L101 WB Tatum Blvd	15i
L-101	WB	15	L101 WB 56th St	15j
L-101	WB	15	L101 WB Scottsdale Road	15k
L-101	EB	15	L101 EB Hayden	15l
L-101	WB	15	L101 WB E of Hayden	15m
L-101	NB	15	Princess Dr	15n