4 Future System Architecture and ITS Elements

The future City traffic signal communication system architecture will link all system elements creating one ubiquitous network on which all devices will communicate. The Master Plan architecture is conceived as a reliable and future-proof network that will meet any City transportation system need. This section presents the network and ITS elements, standardization, topology, physical and logical requirements to achieve the future communication system concept. Several architecture examples are provided to demonstrate system connectivity and resiliency. This section also presents the communication system relation to Chula Vista Smart City transportation initiatives. A schematic detailing the future traffic system communications architecture concept is provided in **Appendix D**.

4.1 Future Network Standardization

Today's "continuously connected" devices like smart phones, tablets and personal computers use Ethernet protocol to connect with each other and the internet. The world's communication systems are based on the Ethernet protocol. There are no more separate data networks or voice networks as there were during 1980's. Nowadays one common Ethernet network utilizing Internet Protocol (IP) efficiently handles both voice and data.

Since Ethernet networks are ubiquitous the cost of communications equipment has continuously declined while the communications capabilities increase. The "Internet of Things" (IoT) applications will cause even further decline in Ethernet equipment price. Additionally, there are plenty of knowledgeable network engineers and technicians to support these new networks.

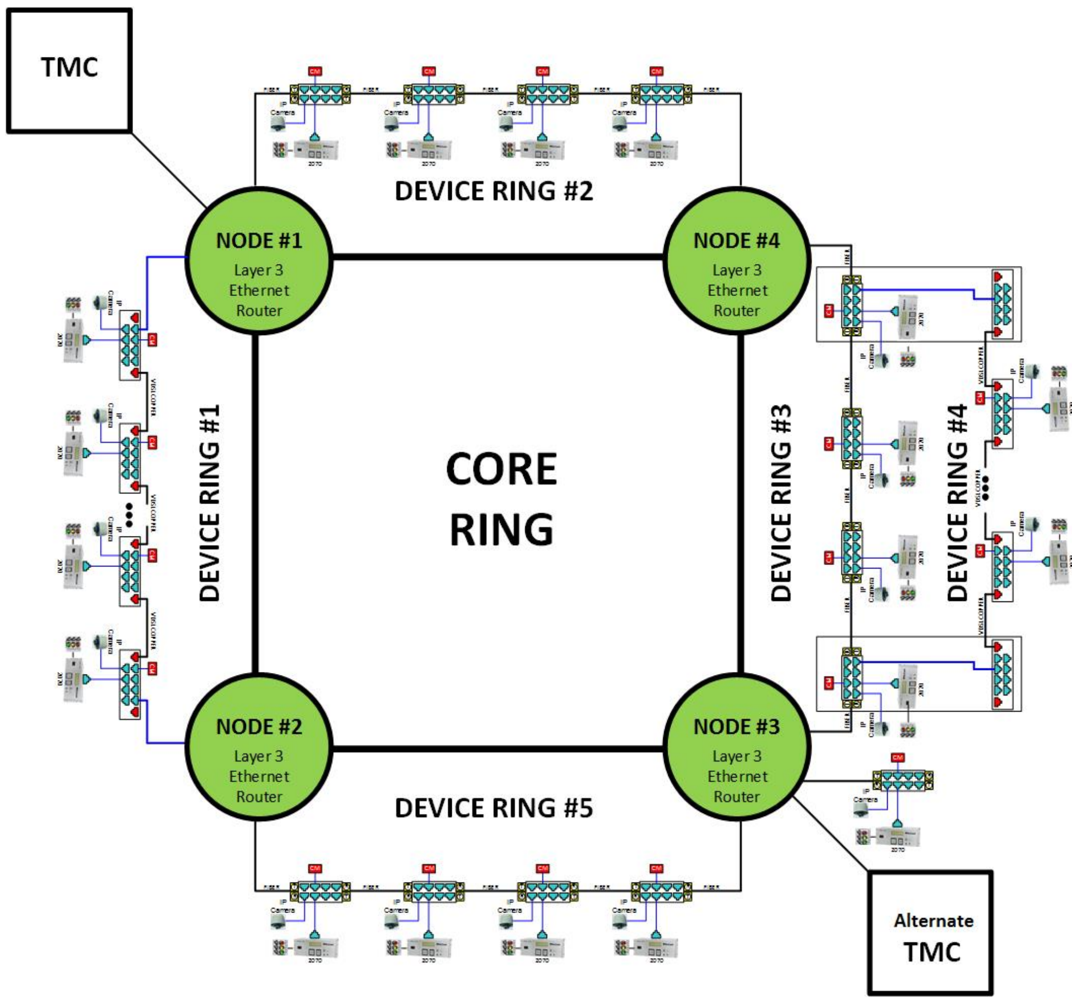
The newer traffic, transportation, and ITS devices are either standardized on Ethernet interface or offer Ethernet interface as an option. Yet to be invented future devices will most likely support Ethernet interface. Ethernet provides a "future proof" network for the foreseeable future.

- The City of Chula Vista future traffic signal communication system network will be based on Ethernet protocol.
- The future network will combine multiple communications medium such as single mode fiber, existing copper plant, point-to-multipoint wireless, and cellular.
- The future "CORE" network will use Layer 3 nodes connecting to each other via single mode fiber links.

The future Ethernet/ IP protocol network shall be designed as a two-tiered network. Tier 1 will utilize the Layer 3 node equipment connected to each other in a ring network fashion using 10 Gbps or higher speed links. Tier 2 will utilize the Layer 2 Managed Field Ethernet Switches (MFES) such as VDSL switches, field Ethernet switches, and wireless broadband radios also connected to each other in a ring network fashion at various speed links, depending on the equipment on that link. ITS devices such as traffic controllers, conflict monitors, CCTV cameras, Dynamic Message Signs (DMS), vehicle detectors, transit and emergency vehicle pre-emption devices, etc. will connect to the copper ports of Layer 2 MFES.

The network architecture topology example is shown in **Figure 4-1**. The main feature of the future traffic signal communication system is its self-healing capability. The MFES's, equipped with either dual fiber ports or dual VDSL ports, will connect to each other in a daisy chain fashion and to the Layer 3 nodes eliminating single point of failure and providing unattended, automatic self-healing capability.

Figure 4-1 Future CORE Ring Network Topology Example



At every traffic system location, the self-healing ring technology will be utilized as much as financially possible. When implemented, the City will have a state-of-the-art, future proof network that will be easily expandable to serve the city across diverse geography and services. The City of Chula Vista traffic signal communication system will simultaneously support multiple different ITS applications including:

- Existing and future traffic controllers.
- CCTV cameras.

- Conflict monitors.
- Dynamic message signs.
- Highway advisory radios.
- Vehicle detection systems, (radar, video, etc.).
- Emergency vehicle pre-emption systems.
- Bluetooth and/or Wi-Fi based travel time systems.
- Upcoming Vehicle to Infrastructure (V2I) systems and "Autonomous Vehicle" systems.

In addition to the above ITS applications, the future traffic signal communication system will support

- All future "Smart City" related applications.
- All future Wi-Fi communications anywhere in the City including the "Chula Vista Smart Bayfront" project.

The network will also support:

- Public message billboards and public messaging systems.
- Voice, video, streamed video services, and video conferencing among departments.
- Any future Ethernet based communication devices and/ or services.

At the City's discretion, the network will be able to provide bandwidth and/ or ports sharing capability to different City departments. The same network could also provide bandwidth to private enterprises.

4.2 Future Network Architecture Examples

Figure 4-2 shows one Layer 2 fiber switch based self-healing ring and four Layer 2 VDSL switch (copper) based self-healing rings. Each Layer 2 switch ring starts from a Layer 3 Ethernet router and terminates on a different Layer 3 Ethernet router. The Layer 3 ring starts at the TMC from the Layer 3 Ethernet router NODE TMC-1 and goes through NODE A, NODE B, NODE C and returns to the TMC and terminates on a different Layer 3 router NODE TMC-2. This topology eliminates any single point of failure, fiber cut or a node failure and the self-healing capability is the main principle of the future network design concept.

Figure 4-3 shows one Layer 2 fiber switch based self-healing ring starting from a Layer 3 Ethernet router NODE A and terminating on a different Layer 3 Ethernet router NODE C. In this topology if a Layer 2 fiber switch fails, the fiber switches left of the failure point will communicate to NODE A and the fiber switches right of the failure point will communicate to NODE C. All the devices attached to Layer 2 switches will recover communications to the TMC automatically. Only the devices attached to the failed switch will lose communications to the TMC. If a fiber link fails, the devices attached to that switch will recover communications to the TMC via the other port.

In addition, to illustrate the "dual homing" concept, a Layer 2 fiber switch is connected to both NODE A and NODE B and a second Layer 2 fiber switch is connected to both NODE B and NODE C. If one fiber link fails for a Layer 2 fiber switch, it will still communicate to the TMC via the other NODE.

Figure 4-2 Future Fiber and Copper Rings Network Topology Example

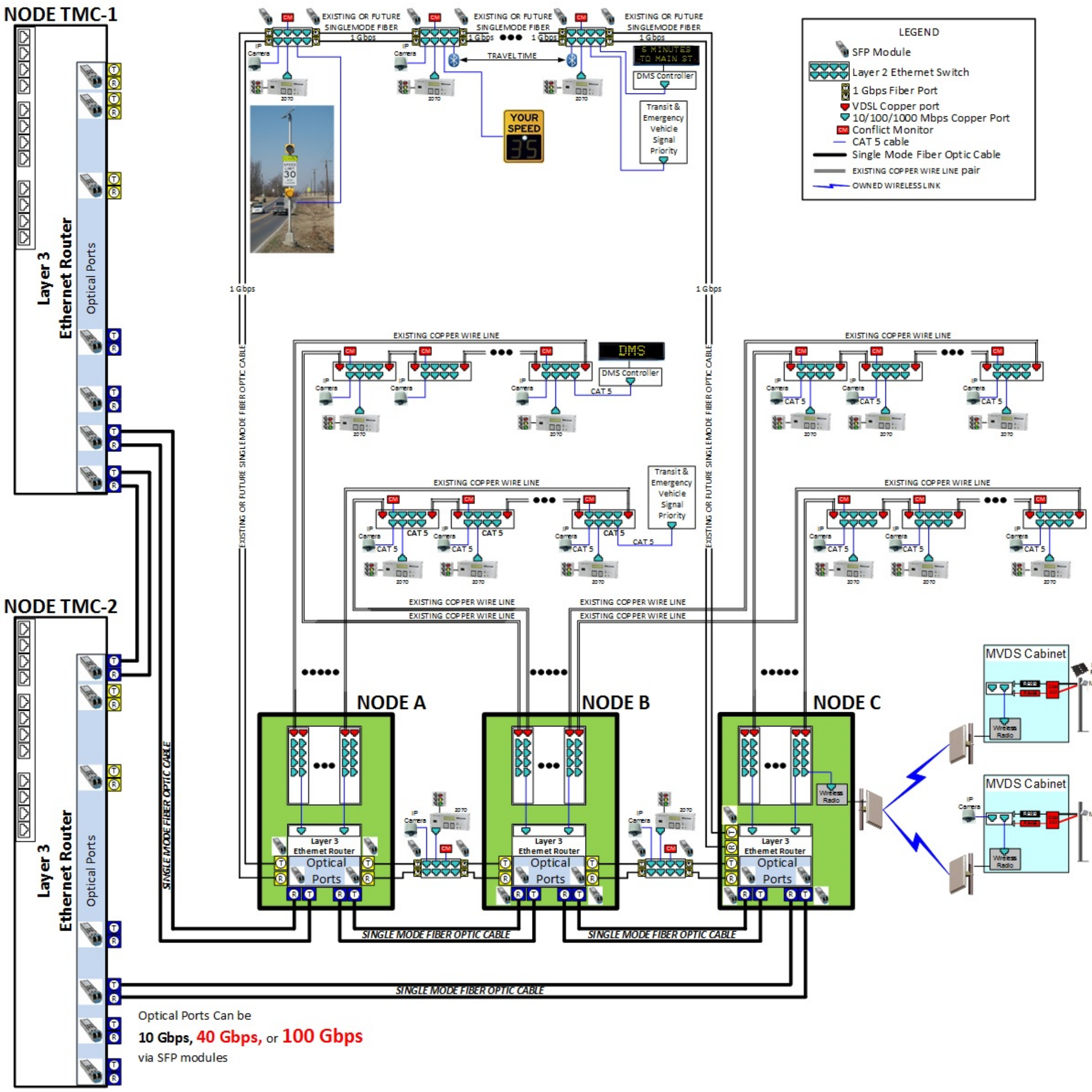


Figure 4-3 Future Fiber Switch Ring Topology Example

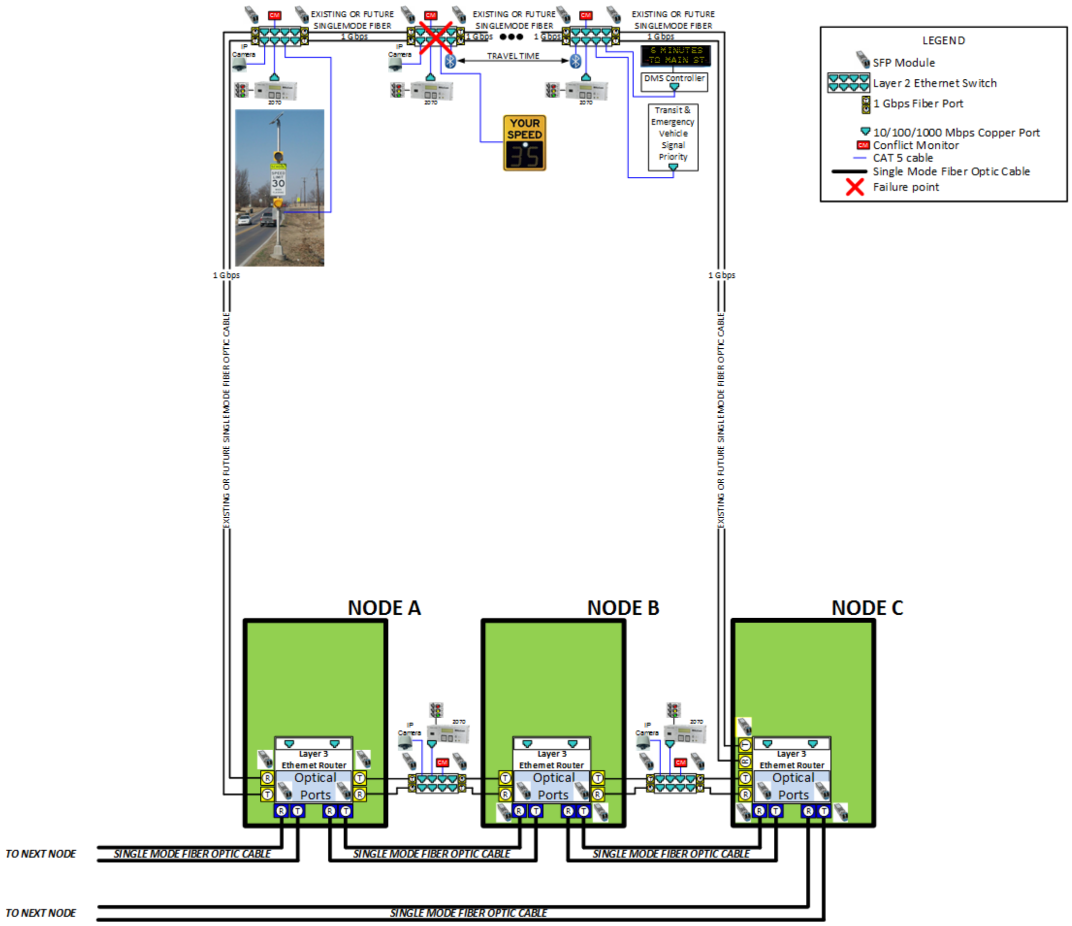


Figure 4-4 shows one Layer 2 VDSL switch (copper) based self-healing ring start from a Layer 3 Ethernet router NODE A and terminate on a different Layer 3 Ethernet router NODE B. In this topology if a Layer 2 VDSL switch fails, the VDSL switches left of the failure point will communicate to NODE A and the VDSL switches right of the failure point will communicate to NODE B. All the devices attached to Layer 2 VDSL switches will automatically recover communications to the TMC. Only the devices attached to the failed VDSL switch will lose communications to the TMC. If a VDSL link fails, the devices attached to that switch will recover communications to the TMC via the other port.

Figure 4-4 Future VDSL Copper Switch Ring Network Topology Example

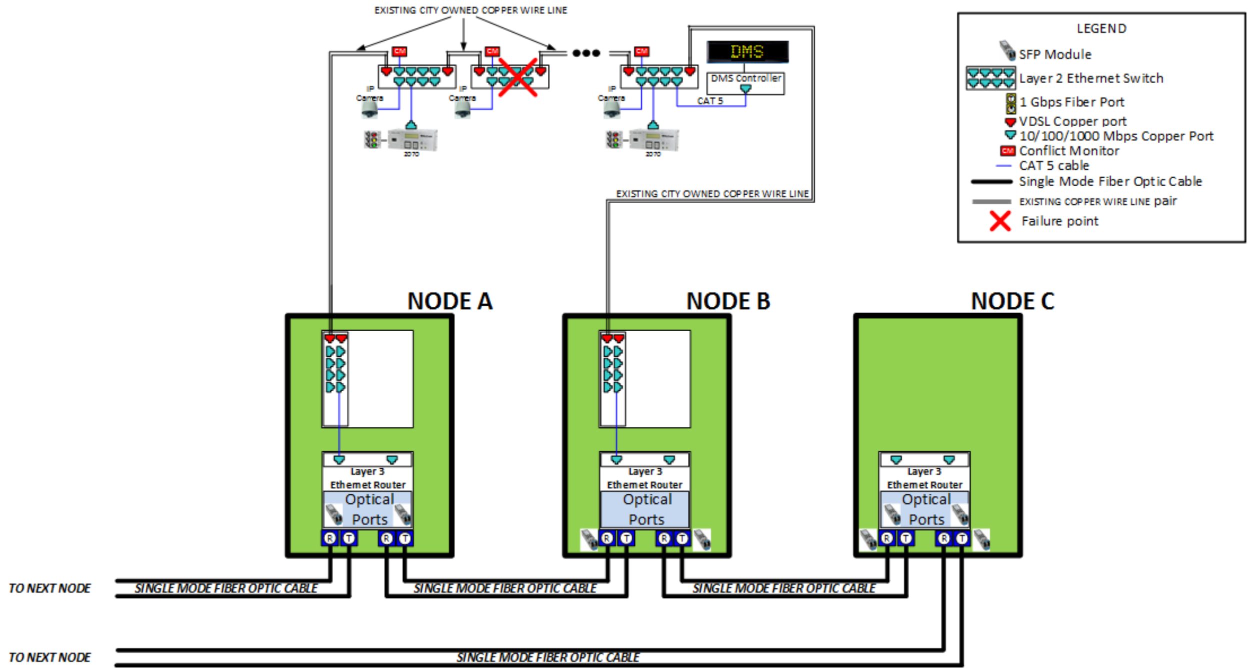


Figure 4-5 shows one Layer 2 fiber switch based self-healing ring starting from the Layer 3 Ethernet router NODE A and terminating on the Layer 3 Ethernet router NODE C. Figure 4-5 also shows a second self-healing ring composed of Layer 2 VDSL switches, starting from the Layer 2 fiber switch, Switch #1 on the left and terminating on a different Layer 2 switch, Switch #2 on the right. Fiber Layer 2 switch, Switch #1 and VDSL switch, Switch #3 are collocated on the left and Fiber Layer 2 switch, Switch #2 and VDSL switch, Switch #4 are collocated on the right. Fiber and VDSL switches connect to each other via a short CAT 5 cable inside the traffic controller cabinet.

In this topology if a Layer 2 switch (fiber or VDSL) fails, both the fiber switches based ring and the VDSL switches based ring will automatically recover communications to the TMC via either Switch #1 or Switch #2. Only the devices attached to the failed Layer 2 switch (fiber or VDSL) will lose communications to the TMC. If a link (fiber or copper) fails, the devices attached to that switch will recover communications to the TMC via the other port.

Figure 4-5 Future VDSL Copper Switch Ring to Fiber Switch Ring Topology

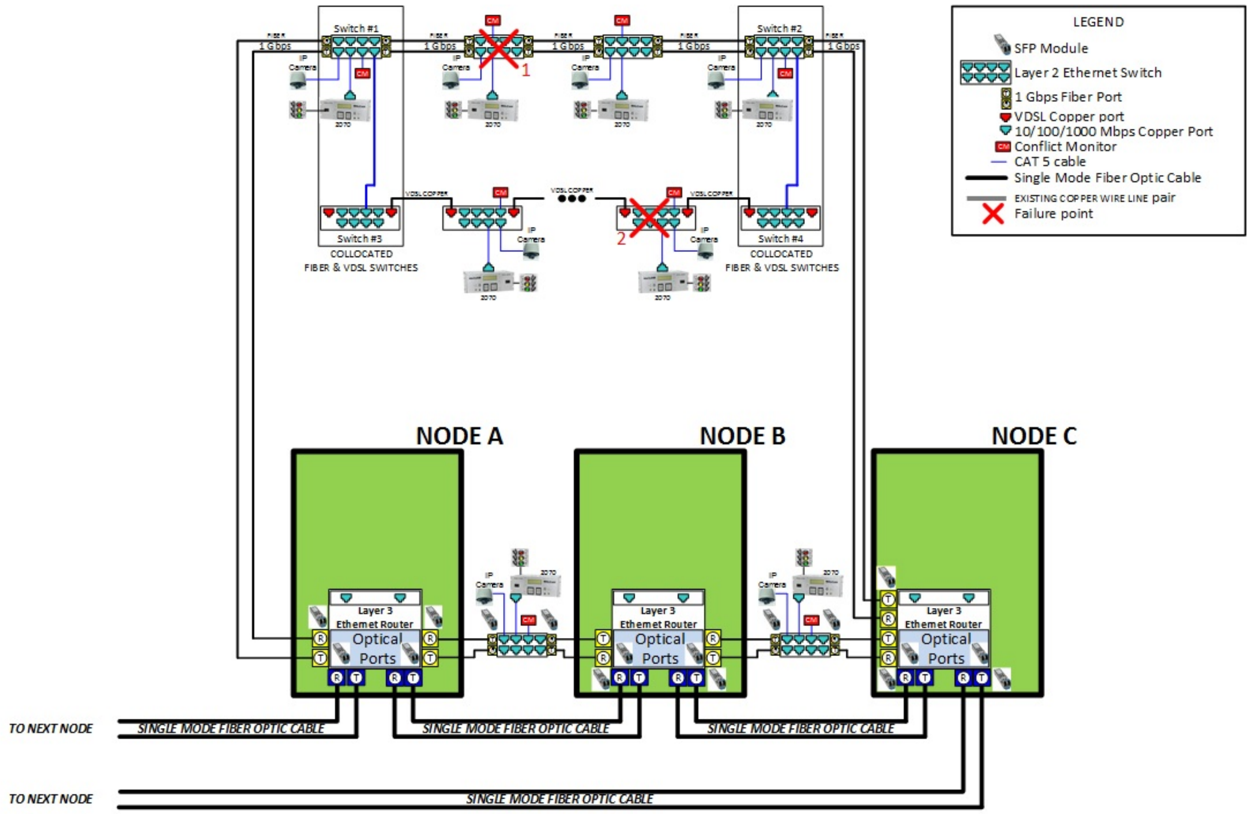


Figure 4-6 shows isolated signals that are not on fiber routes on the city-owned copper wire routes, and signals that are on the city-owned copper wire routes but with no direct connection to a Layer 3 router. These isolated signals will use a 4G wireless router (also called a cellular modem) and communicate to the TMC over the 4G cellular service provider owned IoT service.

Those signals that are on the city-owned copper wire routes but with no direct connection to a Layer 3 router will also communicate to the TMC using a 4G wireless router collocated with the "head-end" Layer 2 VDSL switch over the same 4G cellular service provider owned IoT service.

In this topology, if a 4G router fails, only that single signal or the whole VDSL line is lost. If the IoT router, or the Firewall at the TMC or the link to the IoT service from the TMC fails, the communication to the 4G routers will be recovered via the second IoT link from NODE B.

Figure 4-6 Future IoT over Cellular Wireless Network Topology Example

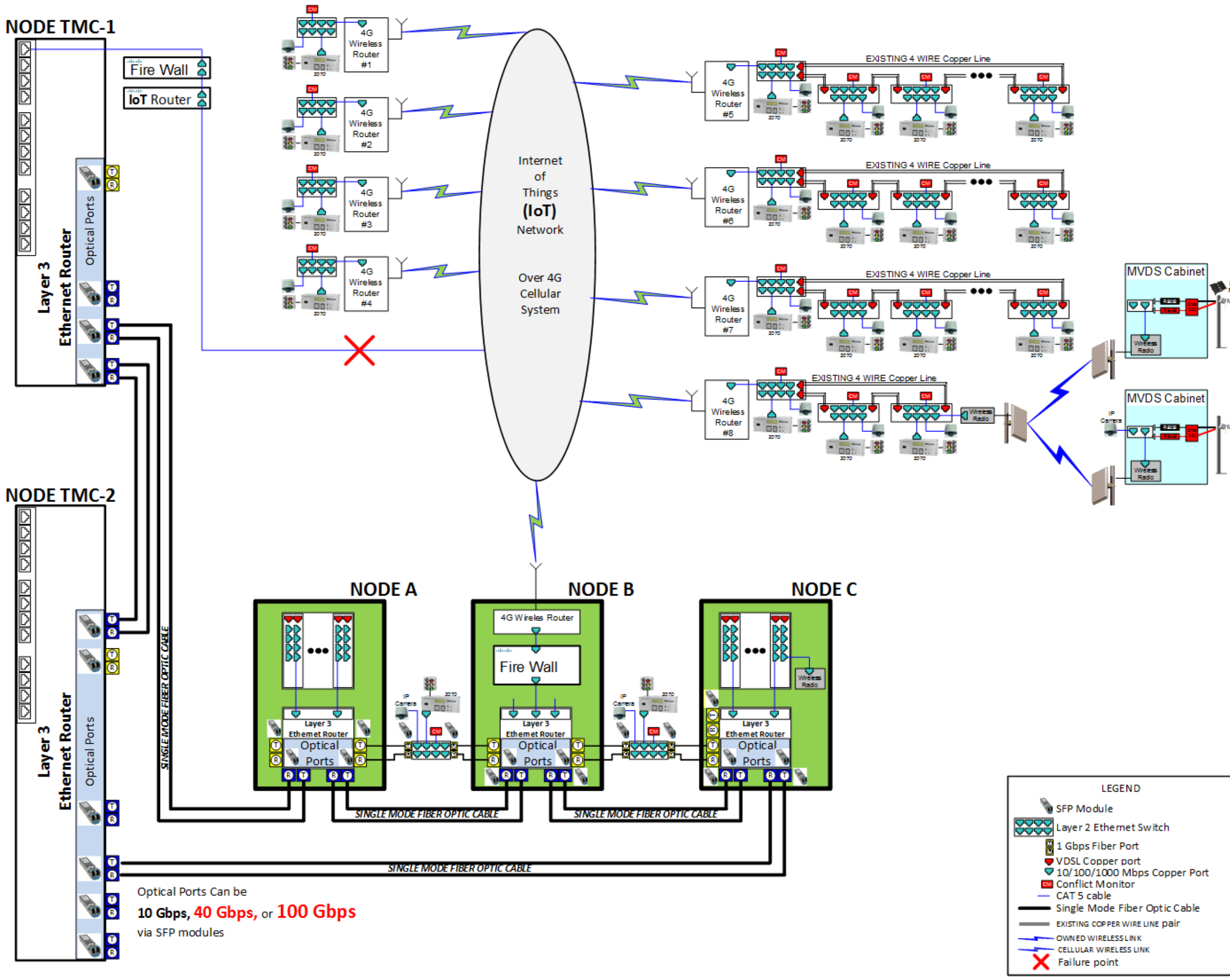


Figure 4-7 shows three different owned wireless network topology examples utilizing 802.11 ac (or the latest technology) wireless radios with integrated and external antennas. The same self-healing scenarios explained in prior cases also apply. If a remote radio or the wireless link from that remote radio location fails, only that location loses communications to the TMC. If a master radio fails, all the locations communicating with the master radio fails. Where geographically possible, mesh wireless links should be used.

Figure 4-7 Future Owned Wireless Network Topology Example

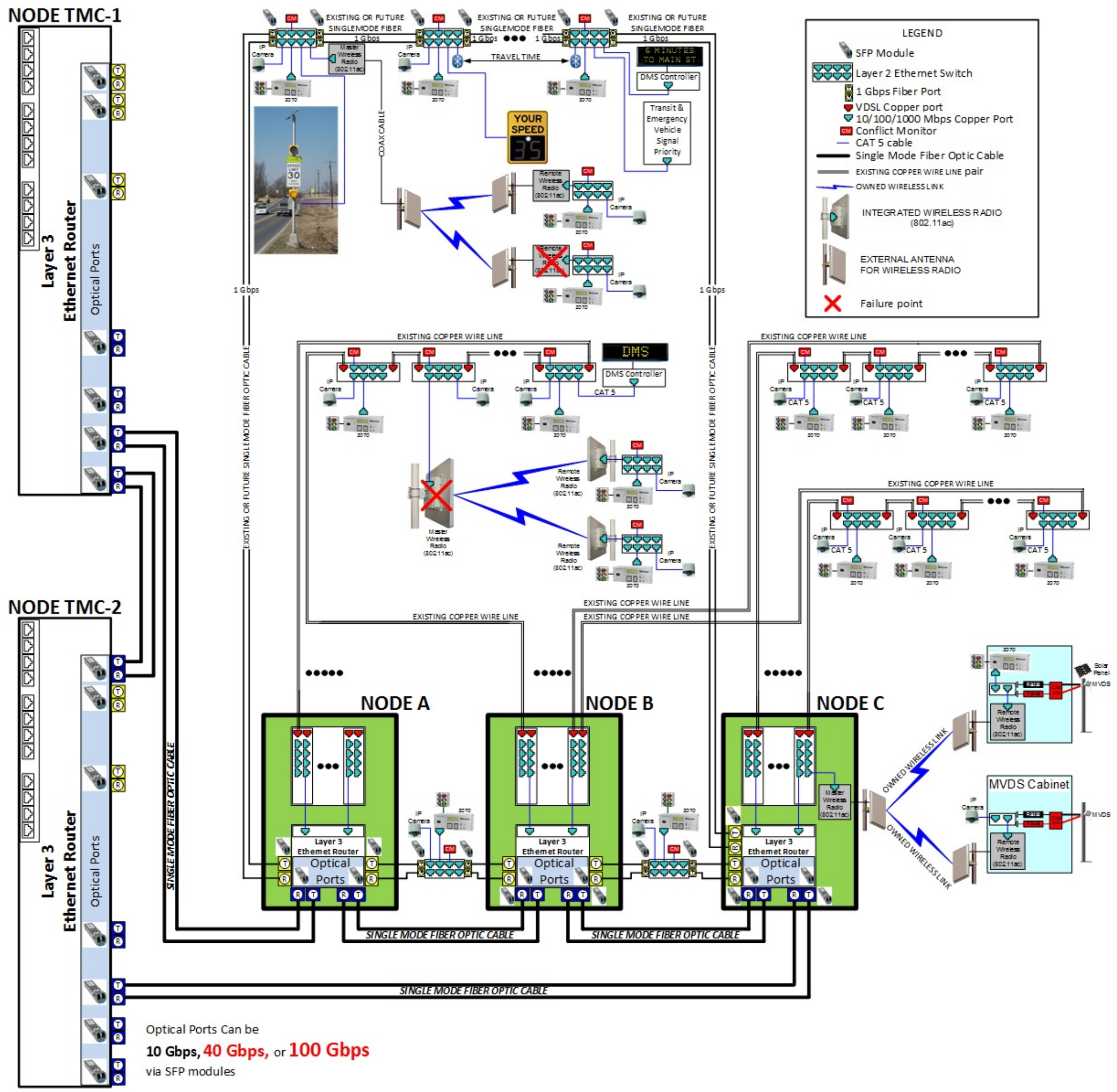
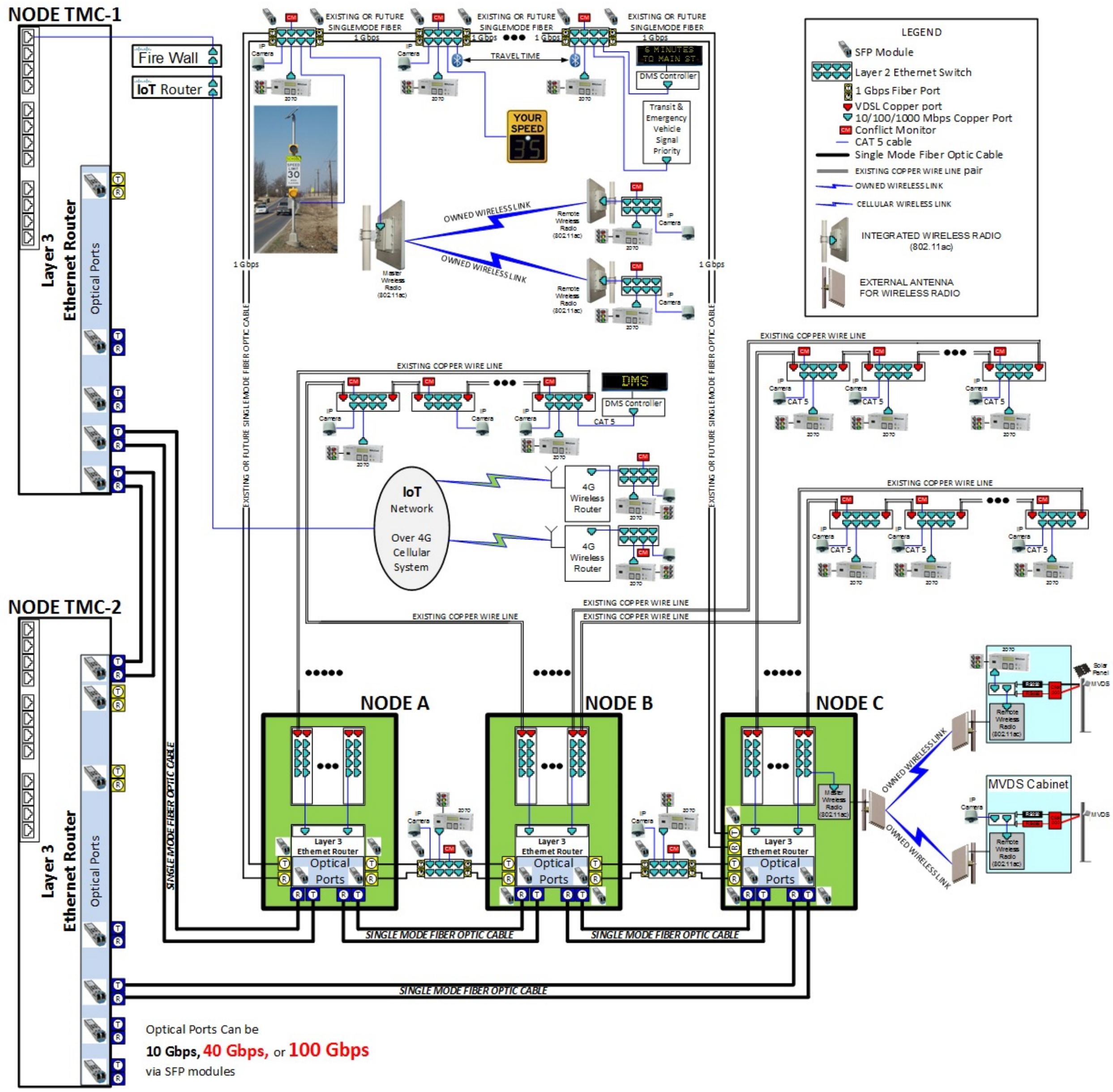


Figure 4-8 Future Redundant and Self-Healing Ring Architecture



4.2.1 TSCC Communication Ports

All the Digi boards at the TSCC will be removed, discarded and replaced with “Virtual Com Port” software provided by Digi. The Virtual Com Port software allows the existing traffic controller software that was communicating with the existing 170E controllers over its Serial port to communicate over the new Ethernet network without any hardware or firmware changes to the 170E controller in the field. Only a new Digi N2S-170 Card will be installed in the modem slot of the 170E controller.

4.2.2 Bandwidth Requirements

The vast bandwidth of a modern Ethernet network dramatically increases accessibility to all ITS devices and applications within the traffic signal network, including streaming video from CCTV cameras and emerging technologies such as Connected Vehicles and Smart City applications. While the initial upgrade to Ethernet will effectively over-provision the capacity requirements of existing technology, the use of managed network switches allows for resource reservation control mechanisms ensuring Quality of Service (QoS) can be delivered to critical applications and/or devices.

4.2.2.1 Traffic Signal Cabinet Assemblies and Components

The assemblies and components of a traffic signal cabinet were originally developed under the restrictions of legacy communication networks where bandwidth was a scarce resource. These utilize a minimal portion of the overall bandwidth available in an Ethernet network. A single IP surveillance camera consumes several orders of magnitude more bandwidth than bandwidth consumed by all the traffic controllers within the same network. However, cumulative impact of thousands of devices can overload the network. The traffic control devices consuming minimal bandwidth include:

- Traffic Controller Unit
- Conflict Monitor Unit
- Preemption Phase Selector
- Battery Backup Unit

4.2.2.2 IP Surveillance Cameras

Real time video streaming over IP is the chief consumer of network bandwidth in a traffic signal communication network. Live video is paramount to the effective management of signal operations at individual intersections and along arterial routes. Video detection cameras and Pan-Tilt-Zoom (PTZ) cameras are commonly used to monitor the flow of the traffic. The bandwidth utilized by cameras ranges from 0.5 to 5 bps per camera[1]. The following parameters affect the actual bandwidth consumed by an IP video camera system and one must consider the following factors:

- Video encoding algorithm, like H.265 (AVC), H.264, MPEG-4, MPEG-2, Motion JPEG.
- Resolution.
- Frames per second.
- Number of Cameras.

4.2.2.3 Dynamic Message Signs

Dynamic Message Signs (DMS) provide travelers with real-time or advanced notice information for traffic conditions, roadway incidents, construction, community events, and other alerts. LED signs are most common and are energy-efficient, bright, and highly legible. Character size and number of lines differ among manufacturers and signs are capable of multi-colored and graphical displays, providing the City with advertisement placement opportunities. Signs can be managed remotely utilizing the traffic systems communications network. DMS include portable and fixed sign deployments or installations.

Portable DMS are mounted to a trailer with hydraulic lift mechanisms and positioned on the side of a roadway prior to diversion points or connecting roadways. Portable DMS are self-powered utilizing solar panels or batteries and the messages are typically changed remotely from the TMC utilizing wireless or cellular communications. The City currently owns two portable DMS signs that are used exclusively by the Chula Vista Police Department. Two additional portable DMS signs are recommended for City Traffic Operations staff use.

Fixed DMS are larger overhead signs that are mounted to a fixed pole and positioned at central areas of interest to provide the greatest benefit for shared travel information. Fixed DMS utilize a local power source and can communicate with the TMC through the cable based traffic systems communications network. It is recommended that the City install fixed DMS signs in advance of freeway ramps and at the Chula Vista Amphitheater.

Both portable and fixed DMS should be used to share traffic information related, but not limited to: recurring congestion, traffic incidents, special events, construction, maintenance activities, road closures, detour routes, etc. To ensure security, rights for device use, including both view and control, should be assigned to prevent unauthorized access.

4.2.2.4 Demand for Real-Time Data

Future transportation management systems will exchange traffic data with a multitude of independent and/or integrated mobility applications that will allow travelers and system operators to make informed decisions. Smartphone applications like, Waze, HERE WeGo, Inrix Traffic, etc. are now connecting to traffic management systems to exchange data. The data exchange is typically provided through a separate internet connection at the TMC.

4.2.3 IP Addressing Scheme

Since the future traffic signal communications network devices are going to be IP based, each device in the network must have at least one IP address. IP addresses are in the form of First Octet. Second Octet. Third Octet. Fourth Octet. An example IP address is 192.168.1.123. The future IP scheme for the City of Chula Vista Master Plan is as follows.

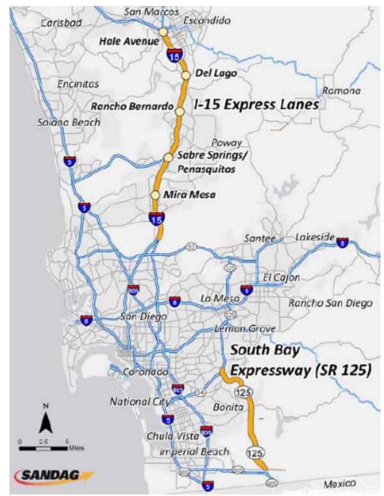
- First Octet = ABC.
- Second Octet = XYZ.
- Third octet = Device ID organized by associated hub and location east or west of I-805.
- Fourth Octet = Intersection ID organized by corridor and direction, east to west or north to south.

The IP addressing scheme is provided to the City in a separate document due the sensitivity of the information.

4.3 Smart City Chula Vista

The City is implementing a vision of a 21st century Smart City that includes building a robust, technically advanced transportation network that connects the City both geographically and on the information superhighway. The Master Plan is compatible with Chula Vista's Smart City initiatives and advances several Smart Infrastructure applications including: video, lighting, parking, transportation, public transportation and shuttles, zero emissions vehicles, environmental sensors, and public safety. The ITS improvements will reduce congestion throughout the City, advance the City's Climate Action Plan goals, and promote sustainability.

4.3.1 Automated Vehicle Proving Grounds

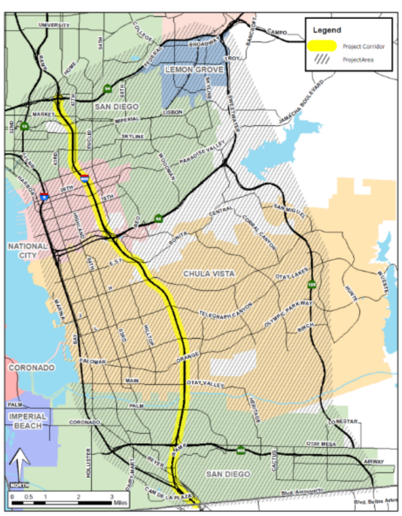


In January 2017, the U.S. Department of Transportation (US DOT) designated 10 Automated Vehicle (AV) proving ground pilot sites to encourage testing and information sharing for AV technologies across a variety of climates, entity types, speed zones, and concentration. SANDAG, Caltrans, and City of Chula Vista were jointly selected in response to the US DOT pilot program application solicitation[2].

The San Diego region has three proving ground environments: the I-15 Express Lanes from SR-163 to SR-78, the SR-125 South Bay Express Way from East Chula Vista to the United States-Mexico border, and the City of Chula Vista. The local network of streets and roadways in Chula Vista will be used as a testbed for AV technology[3].

4.3.2 I-805 Active Traffic and Demand Management

The City of Chula Vista is a stakeholder in the Active Traffic and Demand Management (ATDM) program which will be deployed on the I-805 South corridor from SR-94 to the United States-Mexico border. This heavily-utilized commuter corridor provides access to and from National City, Chula Vista, San Diego, and beyond. The ATDM project seeks to utilize technology and interagency communications to optimize and maintain trip reliability, increase throughput, minimize delay, promote institutional coordination, and increase technical integration across all modes and jurisdictions. Travel information will be collected, processed, and shared with roadway users to enhance planning for timely arrival at destinations. Twenty-five different ATDMS strategies have been identified in the ATDM Concept of Operations with deployment categorized by timeframe: Short Term (1-3 Years), Medium Term (4-7 Years), and Long Term (8-10 Years). The strategies outlined will be enhanced by the additional operational functions the City currently has and/or is



improving including: travel time monitoring on Telegraph Canyon Road and implementation of the new Adaptive Traffic Signal Control system.

4.3.3 Connected Vehicle Technology

Connected vehicle applications have many benefits including increased roadway safety with the potential to greatly reduce or eliminate collisions, improve mobility and roadway capacity, environmental sustainability, and infrastructure management. Connections between vehicles and infrastructure (V2I) is a critical element of the connected vehicle environment and requires infrastructure preparation on the part of public agencies that own and operate transportation systems. V2I deployments have emerged over the past several years with the most prevalent issued by AASHTO; the National Connected Vehicle Signal Phase and Timing (SPaT) challenge. The goal of the SPaT challenge is to deploy roadside Dedicated Short Range Communications (DSRC) radio infrastructure to broadcast SPaT data on at least 1 corridor or street network in all 50 states by January 2020[4].

Connected vehicle technology requires reliable, secure, fast communication with low latency that is not vulnerable to environmental conditions or multipath transmissions, and has wide interoperability. DSRC is the most standardized and tested connected vehicle communication technology. The FHWA is currently proposing a mandate for DSRC to be built into all new vehicles by 2022[5]. Other wireless communications technology alternatives to DSRC have emerged including cellular and cellular hybrid.

The most likely near term (say 5 year) deployment of V2I in the City would be associated with a pilot demonstration deployment. If connected vehicle technology is mandated by the FHWA to be built into new vehicles there would be a significant interest on the part of transportation agencies to widely deploy connected vehicle communications technology in infrastructure. The infrastructure side of the V2I communication link requires a roadside unit (RSU), compatible traffic signal hardware, and communication systems. The most limiting factor with connected vehicle technology deployment is cost, both cost to vehicle manufacturers and transportation infrastructure owners and operators. Opportunities in the form of federal aid funds will likely become available in the future to deploy these communications systems.

The recommendations made in this Master Plan will support the service requirements of future V2I network traffic. The communication system architecture concept includes an over provision of bandwidth, is distributed throughout City, and utilizes NTCIP-complaint hardware and Ethernet communications protocols for a V2I ready infrastructure platform.

4.3.3.1 Predictive Traffic Signals

Advancements in V2I communications include traffic signal and in-vehicle systems that can utilize SPaT information to communicate information to the driver. Several in-vehicle information systems and smart phone applications for predictive traffic signal technology have already been developed and deployed. Generally, information from traffic signal controllers and/ or the central traffic management system is collected and communicated to a third-party data aggregation provider. SPaT data is processed through algorithms and predicted traffic signal red or green state and red times are pushed through an internet connection, typically cellular communications, to display in-vehicle or on the driver's smartphone. This type of information can enhance the way a motorist makes decisions when approaching signals based on the signal state, travel speed, and time. These features ultimately reduce idling, stop-and-go traffic, pollution, and red-light violation collisions.

Third-party data aggregation providers, such as Traffic Technology Systems (TTS) and Connected Signals, Inc. have deployed predictive traffic signal technology in cooperation with automotive manufacturers. TTS is teamed with Audi to deploy an in-dash subscription service which provides a countdown for red lights, 4 second alert before a red-light change, and a heads-up display when a vehicle approaches a signal that is about to change phases. The agency's central traffic management system connects to the TTS system "cloud" to transmit SPaT data. The TTS receives the SPaT data and then sends the predictive information to the OEM backend system which sends it to the vehicle. This system has been successfully demonstrated in Las Vegas, NV and active deployments are planned throughout the US[6]. The City of Chula Vista is currently considering a partnership agreement with TTS.

Connected Signals developed the EnLighten application to provide predictive traffic signal information for BMW vehicles through an in-dash subscription service as well as to drivers that do not own compatible vehicles through their smartphone application. Countdown information is displayed when stopped at a red light and a chime alert sounds seconds prior to the light turning green. Connected Signals utilizes a device on the agency premises to connect to the internet and central traffic management system for receiving SPAT data. The Connected Signals cloud receives the SPaT data and then sends the predictive information to the user's smart phone or in-vehicle system. EnLighten is currently available in Portland

and Eugene, Oregon with testing in progress in the City of San Jose in cooperation with BMW and the U.S. Department of Energy's Argonne National Laboratory[7].

4.3.4 Intelligent Street Lighting

Networked street lighting control systems reduce costs associated with operating and maintaining street lights. The City of Chula Vista was the first in the region to implement LED lighting technology Citywide and is currently working with multiple vendors to install and test street lights, as part of a pilot, with communication and sensor technologies that create a smart grid street light system. The system can also be leveraged to capture high-density time-stamped real-time and historical event data, using the Internet of Things (IoT) cloud storage, for a variety of Smart City applications including vehicle traffic, pedestrian traffic, and parking. Travel data includes vehicle speed, direction, lane use, volumes, pedestrian activity, and parking utilization. This information will enable the City of Chula Vista to more accurately:

- Identify recurring traffic, flow issues, high-incident areas, traffic violation patterns.
- Perform more extensive 'before and after' analyses to illustrate changes in driver behavior.
- Identify sidewalk and crosswalk utilization to enhance pedestrian safety.
- Develop strategic demand-based parking pricing based on parking usage and vacancy periods.
- Provide better parking enforcement for overstay, no-parking zone, and loading zone violations.

The City of San Diego has recently partnered with Current, powered by GE, to deploy 3,200 sensor nodes on City street lights to create a multi-application City IoT network. The nodes can perform a variety of applications including vehicle, pedestrian, and bicycle monitoring, parking availability, air quality sensing, and gunshot detection. The data from the sensor nodes will be processed and stored on a cloud-based server. The deployment of the nodes is slated to begin August 2017 and be completed in July 2018[8].

4.3.5 Advanced Transportation Controllers (ATC)

Chula Vista currently uses "Type 170" traffic signal controllers that are built on an old technology platform with limited processing, memory, program, and communications functionality. These legacy controllers are incapable of collecting High-Resolution (Hi-Res) controller data required for advanced traffic measurement and monitoring. The 2070 ATC controller platform will enable collection and reporting of High-Resolution (Hi-Res) controller data. Industry advancements in Hi-Res data processing provide multiple ITS-related applications pertaining to autonomous vehicles, connected vehicles, connected infrastructure, and Smart City technologies. The Intelligent Transportation Systems Joint Program Office (ITS JPO) has provided research data across all modes for these technologies and has outlined how the data collected is being used by public and private organizations[9].

4.3.6 Future Technology Applications

Table 4-1 provides a summary of the various data types and ITS usage applications that the City of Chula Vista may seek to implement in the future to advance the Smart City Chula Vista vision and increase overall travel safety and efficiency throughout the City.

Table 4-1 ITS Data Applications Summary

ITS DATA TYPE	DATA UTILIZED	AGENCY USES
SPaT	Signal status, signal timing, timing plans, detection	Red light running detection, signal retiming studies, arterial performance measures
Trajectory	Vehicle Location, Speed, Heading	Model development and refinement, new development impact studies, ride sharing applications, vehicle type and route comparisons
Parking Space Availability	Parking lot location, number of spaces, available spaces, size of spaces by vehicle type	Planning and system use analysis, parking applications, traveler information
Safety Messages	Vehicle size, current location, speed, heading, acceleration status, brake system status	V2V and V2I deployment testing and evaluation
Infrastructure Alerts	Infrastructure-to-Vehicle	In-vehicle messaging for variable speed limit signs, dynamic message signs, work zone alerts, tolling rates, and red light running
License Plate Recognition	License plate data	Arterial performance measures, travel time analysis, signal retiming studies
Automated Shuttle	Synchronized scheduling	Self-driving testing, Transit Signal Priority testing, obstacle bypass testing