V2I Hub

Guidebook

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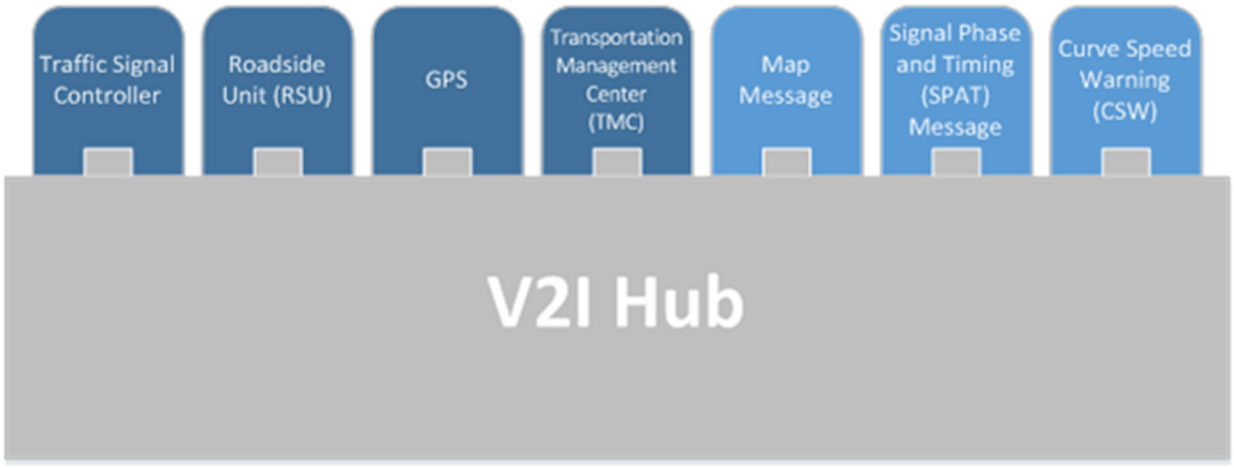

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16. Abstract

Connected and automated vehicle (CAV) technologies help reduce the number of driving-related injuries and fatalities by allowing road users to be aware of potential dangerous situations on the road. This guidebook gives an overview of infrastructure connectivity equipment supporting CAV technologies and explains the hardware and software required for the V2I Hub deployment. The V2I Hub is a connectivity platform developed to be deployed at signalized intersections with the intention of making roadways safer and smarter by reducing accidents and providing informational alerts to mobile devices.

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Table of Contents

List of Tables

List of Figures

Executive Summary

The V2I Hub Guidebook was developed for Intelligent Transportation Systems (ITS) entities, city officials, or contractors interested in deploying the V2I Hub. This guidebook gives an overview of infrastructure connectivity equipment supporting Connected and Automated Vehicle (CAV) technologies and explains the V2I Hub hardware and software required for the deployment. The V2I Hub is a connectivity platform developed to be deployed at signalized intersections or other infrastructure locations, with the intention of making roadways safer and smarter by reducing accidents and providing informational alerts to mobile devices. This document is the first in a series of six documents to be developed for different stakeholders involved in the deployment process. The rest of the documents are listed below.

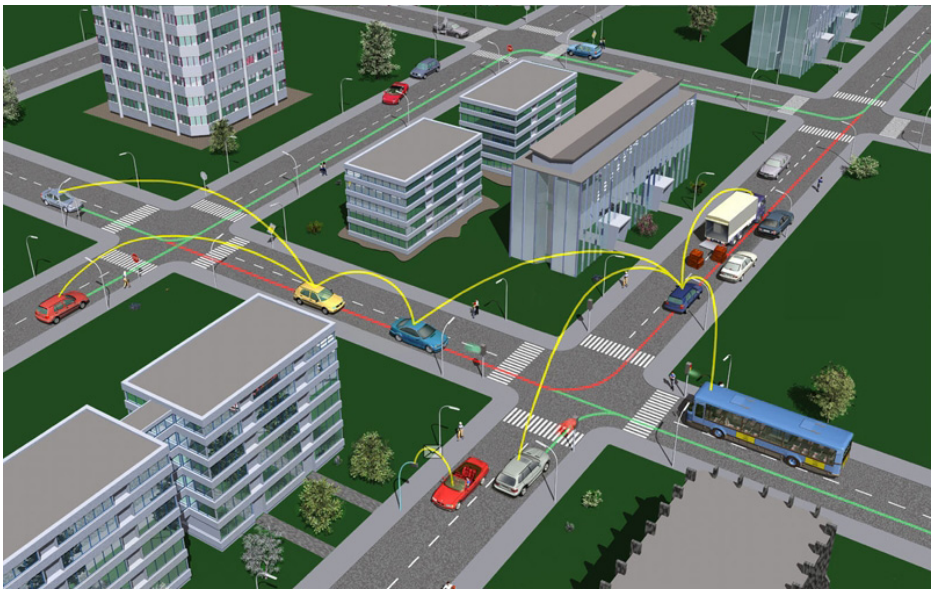
- V2I Hub Administration Portal User Guide
- V2I Hub Plugin Programming Guide
- V2I Hub Plugins
- V2I Hub Deployment Guide
- V2I Hub Software Configuration Guide

Chapter 1. Background

The United States Department of Transportation (U.S. DOT) has been developing individual and consolidated technologies such as Signal, Phase and Timing (SPaT), MAP, and V2I Hub for the past six years. These technologies will enable safety information to be shared between road vehicles, trains, infrastructure, and mobile devices using multiple communications media. It allows Connected Vehicles (CVs) to know the location of other nearby CVs and informs users of dangerous situations.[10] The purpose of this document is to give an overview of Connected and Automated Vehicle (CAV) technology and to describe what is needed to deploy the V2I Hub. As explained later in the document, CV technology and functionality can be leveraged to optimize the development of CAV technology. This document is intended for ITS entities, city officials, or contracts interested in deploying the V2I Hub. A high-level description of the V2I Hub system architecture, design, and communication protocols is detailed below, along with an overview of the hardware and software required.

Connected and Automated Vehicle Connectivity

CV research sponsored by U.S. DOT leverages the transformative capabilities of wireless technology to make surface transportation safer and smarter. A CV is a vehicle equipped with connectivity equipment that enables it to communicate wirelessly to other connected vehicles, personal devices, and infrastructure on a rapid and continuous basis. The communication allows the sharing of real-time information between one another.[11] High data transmission rates and low latency communication are essential for safety applications.[12] There are two main types of CV communications, vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V). V2I communication takes place between vehicles and deployed roadside infrastructure connectivity equipment, which capture vehicle-generated data while providing information on safety, mobility, and environmental conditions. V2V communication exchanges wireless data between vehicles.[13] Low latency vehicle communications can reduce transportation fatalities and injuries.[14] Figure 1 shows connected CVs communicating while travelling through an intersection.



Source: Automotive World October 20, 2017

Figure 1. CAV Connectivity

CVs are able to communicate through the use of Dedicated Short-Range Communication (DSRC), which is a two-way short-to-medium-range wireless communication method intended for secure, high-speed wireless communication. In 1999, the Federal Communications Commission (FCC) allocated 75MHz of spectrum in the 5.9GHz band for vehicle safety and other mobility applications.[15] The key functional attributes of DSRC include low latency, limited interference, and acceptable performance during adverse weather conditions.[16] Although CVs currently use DSRC as the medium for communication, other communication mediums can be used to obtain the same functionality. CAVs for example may use 5th generation mobile networks (5G) or satellite-based wireless communications as a communication medium; however, they can still use CV and CAV applications.

Connected Vehicle Application Concepts

More than three dozen CV application concepts have been developed, many of which have been prototyped and demonstrated.[17] These applications are separated into three core areas:[18]

- **Safety:** Safety applications will alert a driver, through in-vehicle warnings, to situations and potential hazards even when they are not in plain sight. Imminent crash situations such as vehicles located in the driver's blind spot, lane merging, or suddenly braking will be reported to the driver.
- **Mobility:** CVs can send anonymized information, such as location and travel speed, will allow transportation managers to help make roads safer and less congested. The amount of data available will encourage developing new mobility applications that will keep traffic flowing and improve planning.
- **Environmental:** CV applications will contribute to reducing emissions and fuel usage by optimizing traffic signal phasing, and using special lanes dedicated to low-emission, high-occupancy, and alternative fuel vehicles that support eco-friendly driving.

According to U.S. DOT, fully deployed CV technologies will result in developing and implementing solutions that go beyond the safety aspect.[19] Technologies such as adaptive cruise control and vehicle platooning will help reduce congestion and vehicle emissions. Weather and road status gathered from the system's different connected points will be analyzed and distributed to road users, helping traffic planning and routing.[19]

History of V2I Reference Implementation

The first step toward creating a connected CAV environment was to develop a way for a traffic signal controller to relay phase information to a user. In 2006, the SAE J2735 DSRC Message Set Dictionary standard was created. It was revised in 2009 for the first CV deployment, Safety Pilot, in Ann Arbor, MI. This standard specifies the message set and data elements that allow SPaT broadcasts from a traffic signal controller (TSC) to a road user, along with other information related to safety, mobility, and the environment.

In 2010, the design, development and testing of a SPaT system that relayed interface messages between a TSC and a road user was successfully completed. This system communicated the signal and phasing information the TSC provided using an extended version of the NTCIP 1202 communication standard. This information was then converted to an SAE J2735 message format to be broadcast by a roadside DSRC radio and received by an on-board unit (OBU).

Moving forward, the objective was to develop a prototype solution that would support V2I technology deployment. In 2013, based on the results of the projects previously mentioned, the V2I Hub was created for the Integrated V2I Prototype (IVP) project. The IVP project's objective was to create a roadside prototype system that would supply the needed J2735 messages for CV in-vehicle applications. The IVP project would interface with more ITS equipment, not just traffic signal controllers. The V2I Hub simplified integration by translating communication between different standards and protocols into useful software messages that CV applications can interpret. While the V2I Hub was designed and developed to be used in conjunction with a signalized intersection, the V2I Hub is not limited to being deployed at signalized intersections.

The V2I Reference Implementation project provides the requirements, specifications, guidance, and training materials to support procurement, testing, deployment, and maintenance for the V2I Hub System. It delivers detailed how-to instructions and examples to simplify adopting and implementing the technology for all stakeholders involved in deploying a V2I project. This reference implementation contributes to U.S. DOT's objective of reducing and eliminating driving crashes and fatalities by aiding V2I technology deployment.

Chapter 2. V2I Hub

What is the V2I Hub

The V2I Hub is part of U.S. DOT's V2I Program, developed to help jurisdictions deploy V2I technology by reducing integration issues and enabling use of their existing transportation management hardware and systems. V2I Hub is an open-source software platform that uses plugins to translate messages between different devices and run CAV safety applications on roadside equipment.

CAVs using the J2735 message set share anonymous Basic Safety Messages (BSMs) between connected infrastructure equipment and other connected vehicles. BSMs contain important vehicle information such as size, speed, position, heading, acceleration, and brake system status among others. V2I Hub translates these messages and exchanges them in a format that is understood by both connected vehicles and infrastructure. It has an open-source design that allows it to support a variety of software plugins. These plugins allow efficient device connection, message translation, functionality, and software application developments.

Some of the advantages of deploying a V2I Hub-based system are:

- V2I Hub is an open-source platform with documentation to reduce the investment and development that often accompanies proprietary, custom systems.[20]
- V2I Hub provides secure, remote access for monitoring, configuration, and software updates to reduce operations and maintenance efforts.[20]
- The built-in message translation and plugin architecture enables V2I Hub to reduce the amount of back-end software and integration work needed for jurisdictions to support connected vehicles.[20]
- Custom plugins can be efficiently developed to meet a jurisdiction's specific operations and equipment.[20]
- V2I Hub is manufacturer neutral, providing operators with the flexibility to incorporate equipment from different vendors and add more functionality using in-house or third-party resources.[20]
- In addition to supporting communications between subscribing plugins, the V2I Hub architecture facilitates low and high latency external communications with a message manager through the use of centralized message routing. A system monitor application analyzes communications between the message router and message manager to help ensure the health of the core through management of the plugins.
- Unlike most ITS that are focused on a specific user or function, such as transit signal priority, V2I Hub can support virtually any user or scenario. In addition, new functionality can be added by developing new plugins installed remotely via a secure connection without purchasing and installation of new hardware throughout the infrastructure. For example, transit signal priority could be added to any V2I Hub-equipped intersection, or trucks could be incorporated for freight priority. Emergency vehicle preemption could be added throughout a network of intersections running V2I Hub without the need to install and wire new hardware on every intersection approach.[20]

V2I Hub distributes data and information to connected CAVs that will be used to improve safety and reduce congestion such as in-vehicle warnings when a potentially dangerous situation is detected. V2I Hub can also provide anonymous vehicle messages to Transportation Management Centers to have accurate real-time information on locations and speeds of vehicles in the system. This will be used to identify areas of traffic congestion, so traffic signals and ramp meter timings can be updated.[20]

Locations without a TSC can also benefit from V2I Hub. It can send recommended speeds to CAVs approaching a curve as an in-vehicle warning. Road and local weather sensors can be incorporated to distribute surface conditions to connected CAVs and Transportation Management Centers.[20]

V2I Hub Software

The V2I Hub software is a robust and deployment-ready solution for implementing CAV applications at the roadside infrastructure. The V2I Hub software was created and tested on Ubuntu 16.04 LTS, but can run on most Linux operating systems. The V2I Hub software uses a plugin architecture so that each installation can be configured to run a suite of different software applications and plugins. The V2I Hub software contains the communication routing for the plugins, the configuration for the plugins, and the processes to start, stop, and monitor the plugins. Each plugin in the V2I Hub software is created to do a function, such as communicate with a signal controller and produce SPaT messages.

The software architecture can be broken down into two main layers known as the V2I Hub Core and plugins. These layers are shown in Figure 2.

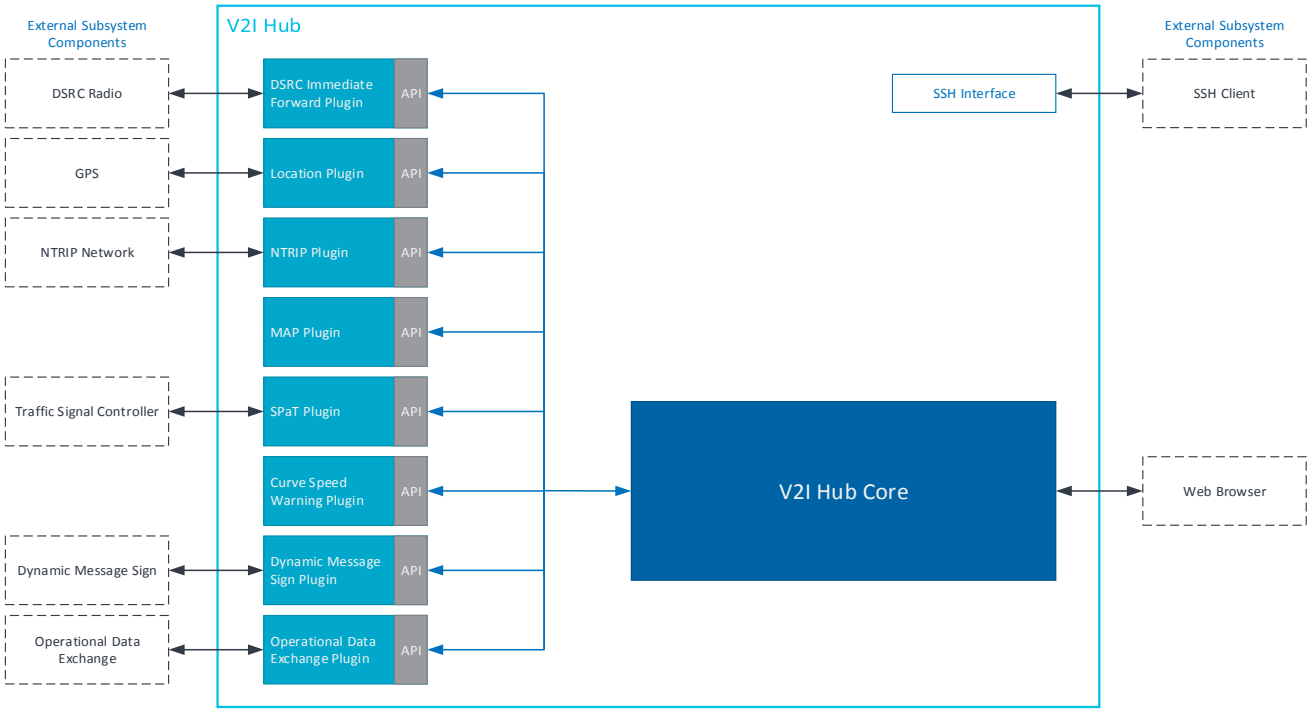


Figure 2. V2I Hub Plugins with Core

The V2I Hub Core is the heart of the V2I Hub software and performs all the message routing between the plugins. It displays the current configuration status via a web browser. Plugins are the interface for two-way communication between the V2I Hub Core and the external subsystem components shown in Figure 2. The applications running on the V2I Hub determine the plugins and the external subsystem components required to implement the application.

Plugin modules are the application-specific pieces of code on the V2I Hub platform. Plugin modules are responsible for processing data extracted from external peripheral components and generating status or other information published to the V2I Hub router. Plugins can also control or communicate with external subsystem components based on processing resulting from messages received from other application plugins installed on the V2I Hub platform. Using plugins reduces the work required to add functionality or connectivity to new devices and reduces backend software and integration work required for operators to support CAVs.

Refer to the *V2I Hub Plugins document* for a detailed description and for configuration information on each of the V2I Hub Plugins. For instructions and guidance on how to create a plugin, refer to the *V2I Hub Plugin Programming Guide*. Both documents can be found in the U.S. DOT's Open Source Application Development Portal repository.

The V2I Hub plugins share and exchange information between the external subsystem components and the V2I Hub Core as shown in Figure 2 are described below:

- **DSRC Immediate Forward Plugin** – Responsible for taking internal messages flagged for transmission and ensuring they are sent out via the DSRC radio. Communications to the roadside unit (RSU) will be over User Datagram Packets (UDP) with messages as defined in the DSRC RSU V4.1 specification (see Table 2).
- **Location Plugin** – Receives location information from the external GPS receiver through an Ethernet port on the V2I Hub platform or reads static location information from a local configuration file if a GPS receiver is not connected.
- **Networked Transport of Radio Technical Commission for Maritime via Internet Protocol (NTRIP) Plugin** – Receives correction information over an internet connection after supplying the Position Correction Provider its current location information.
- **MAP Plugin** – Publishes a J2735 MAP Message. This message contains data describing the intersection's geometry, curve outlines, and roadway segments.
- **SPaT Plugin** – Receives signal, phase and timing information about the intersection from the traffic controller via an Ethernet connection with the V2I Hub and is broadcast via DSRC radio.
- **Curve Speed Warning (CSW) Plugin** – Receives CSW information from the V2I Hub and broadcasts that information in a J2735 Traffic Incident Message (TIM) to OBUs in nearby vehicles.
- **Dynamic Message Sign (DMS) Plugin** – Receives J2735 BSMs containing location information from nearby OBUs. The appropriate notification is displayed on the DMS via an Ethernet connection.
- **Operational Data Exchange Plugin** – Receives stored data from the V2I Hub, where it is uploaded to the U.S. DOT cloud repository.

V2I Hub Hardware

The hardware and software required for the deployment of the V2I Hub is largely dependent on the desired applications to be deployed. The V2I Hub software can be run on any platform running a Linux operating system, but the following specifications were used in testing and deploying the V2I Hub project.

Table 1. V2I Hub Hardware Specifications

Hardware	Computer Processors	
	ARM Hardware Specifications	Intel Hardware Specifications
Processor	Freescale i.MX6 ARM Cortex A9 Quad Core 1GHz	Intel Core i3 processor Dual Core 1.7 GHz
Memory	1GB DDR3	4GB of RAM
Hard Drive Space	16GB SSD	16 GB SSD
Operating System	Ubuntu 16.04 LTS	Ubuntu 16.04 LTS

Supported Communication Standards

As part of U.S. DOT's objective to make roadways safer, and with U.S. DOT encouragement for state and local authorities to deploy CAV technology, standardized CAV communication protocols had to be developed. The V2I Hub software was created following the applicable industry standards to provide a scalable and interoperable solution for widespread CAV deployments. The V2I Hub is compliant with the following standards listed in Table 2.

Table 2. V2I Hub Compliance with Industry Standards

Specification	Specification Description	Standard Title
IEEE 1609	The WAVE standards define an architecture and standardized set of services and interfaces for V2V and V2I wireless communication.[1]	IEEE 1609 – Family of Standards for Wireless Access in Vehicular Environments (WAVE)
NMEA 0183 v4.10	This interface standard defines electrical signal requirements and data transmission protocol for serial data bus.[2]	NMEA 0183 Standard
NTCIP 1202	This standard provides the information necessary for traffic management personnel to manage Actuated Traffic Signal Controller Units and contains object definitions to support transportation applications.[3]	NTCIP 1202 – Object Definitions for Actuated Traffic Signal Controller Units
NTCIP 1203	Provides the vocabulary (commands, responses, and information) necessary for traffic management and operations personnel to advise and inform vehicle operators of current highway conditions using DMS.[4]	NTCIP 1203 – Object Definitions for DMS

Specification	Specification Description	Standard Title
DSRC RSU v4.1	This standard sets the minimum requirements for DSRC roadside units.[5]	DSRC Roadside Unit Specifications v4.1
RTCM 10402.3 v2.3	This worldwide standard is used by differential satellite navigation systems.[6]	RTCM 10402.3 – Recommended Standards for Differential GNSS (Global Navigation Satellite Systems) Service, Version 2.3
SAE J2735 2016	The DSRC Message Set Dictionary supports interoperability among DSRC applications.[7]	SAE J2735 – Dedicated Short Range Communications Message Set Dictionary
SAE J2945 2016	This standard sets the minimum performance requirements for V2V safety system interoperability.[8]	SAE J2945/1 – On-board Minimum Performance Requirements for V2V Safety Communications

In addition to following the standardized communication protocols, an Intelligent Transportation Service (Non-Public Safety) license must obtained from the FCC to deploy a DSRC radio at a roadside location. This license is only required for stationary roadside transmission and is not required for DSRC transmission from mobile DSRC radios installed in vehicles. The roadside transmitting device must be deployed within one year of receiving the license and is valid for up to ten years.

Chapter 3. Deployment Overview

Deployment Considerations

Deploying the V2I Hub or any other infrastructure connectivity equipment requires careful consideration through the deployment process. A list of these considerations is described below:

- **Site Selection** – Physical and technical limitations shall be considered to select a site.
- **Stakeholder Identification and Coordination** – Stakeholders will vary from location to location. Example stakeholders include municipalities, regional and state DOTs, utility owners (such as power and telephone poles), electrical contractors, Traffic Management Centers, and Internet providers.
- **Licensing and Permitting** – Applying for the required licenses and permits.
- **Hardware Procurement** – Identifying the party responsible for purchasing the required hardware.
- **Installation** – Identifying an electrical contractor or other agency responsible for installing and maintaining the deployed system.
- **Configuration** – Identifying the party responsible for configuring the hardware and software once the system has been installed.

Refer to the V2I Deployment Guide for additional guidance on how to deploy the V2I Hub.

Sample V2I Hub Deployment

Our sample roadside V2I Hub deployment consists of subsystems that reside at the roadside infrastructure: the V2I Hub, a TSC, and an RSU. The V2I Hub will be connected to the TSC to obtain SPaT data, and to the RSU to transmit J2735 data over DSRC. The V2I Hub also has the option of being connected to an external system such as a Traffic Management Center where it can send and receive messages.

Design Overview

Since the V2I Hub was designed for infrastructure, or roadside deployments, the basic design of a roadside deployment would consist of a V2I Hub, external hardware, an RSU, and a network. A block diagram of a typical V2I Hub system roadside deployment at a signalized intersection is shown below in Figure 3.

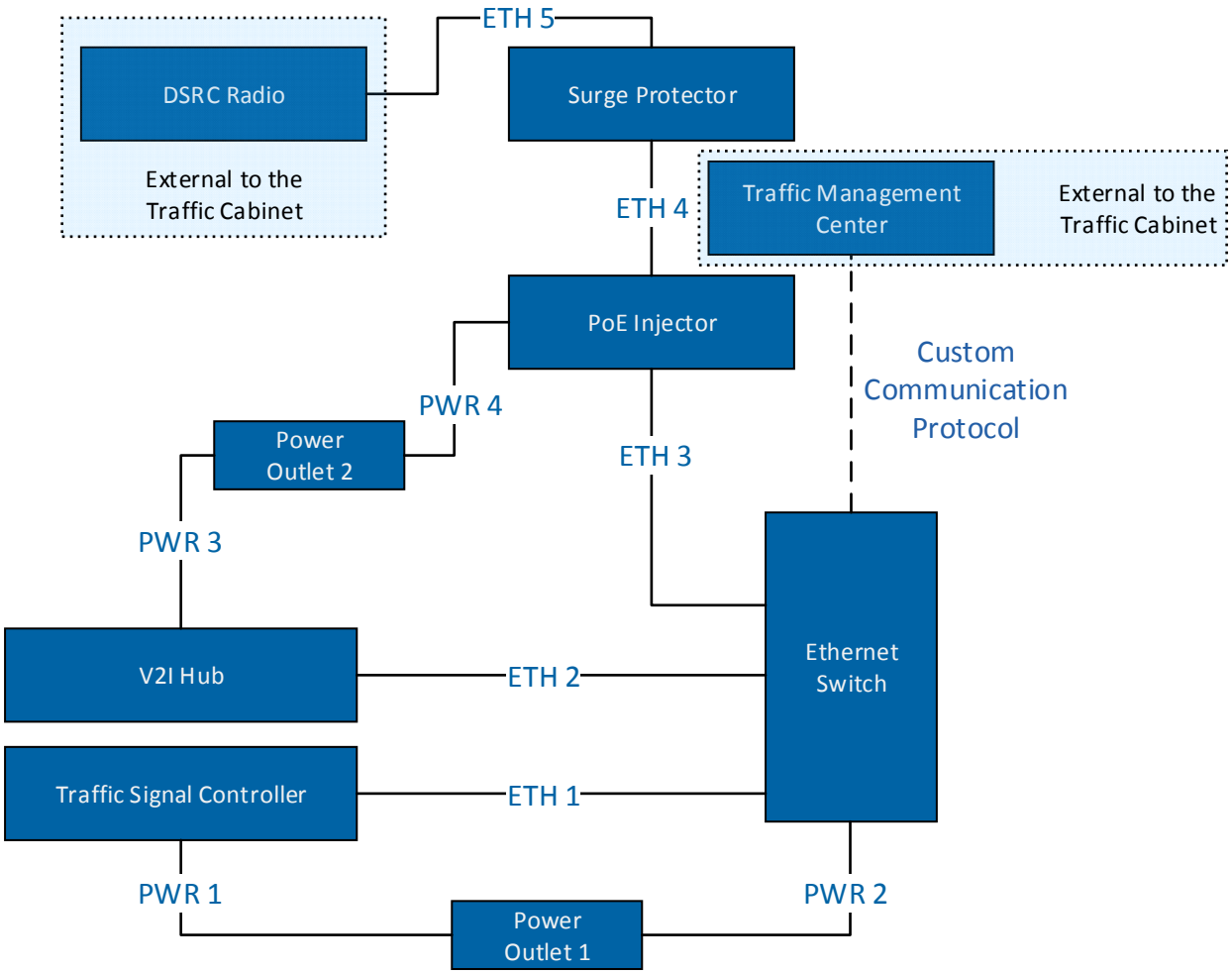


Figure 3. V2I Hub Block Diagram

Table 3. Hardware Required for V2I Hub Deployment

Hardware Component	Hardware Function
Industrial Computer (V2I Hub)	• Hosts the V2I Hub software
Traffic Management Center	• Allows remote connectivity for monitoring, managing, and configuring the V2I Hub
RSU (DSRC Radio)	• Transmits and receives CAV messages
GPS Antenna	• Transmits GPS location information
(2) DSRC Radio Antennas	• Transmits and receives CAV messages
Traffic Signal Controller	• Provides SPaT information about the intersection

Hardware Component	Hardware Function
Ethernet Cable 5	• Connects the externally mounted RSU to the surge protector
Ethernet Cable 4	• Connects the surge protector and the PoE injector
Ethernet Cable 3	• Connects the PoE injector and the Ethernet switch
Ethernet Cable 2	• Connects the V2I Hub to the Ethernet switch
Ethernet Cable 1	• Connects the TSC to the Ethernet switch
Surge Protector	• Prevents electrical damage from lightning strikes
Ethernet Switch	• Allows multiple Ethernet connections to be made on one device on the same network
(3) Power Outlets	• Provide power for the hardware installed in the traffic cabinet

*All hardware components shall be installed internally to the traffic cabinet, apart from the DSRC Radio, the GPS and DSRC antennas attached to the DSRC radio, and a portion of Ethernet Cable 5 that will be routed from inside the traffic cabinet to outside the traffic cabinet where the RSU is installed.

Six of the eight V2I Hub plugins have two-way communication between the V2I Hub Core and the external subsystem components. These relationships are listed in Table 4 below.

Table 4. Relationship Between V2I Hub Plugins and their Corresponding External Subsystem Components

V2I Hub Plugins	Corresponding External Subsystem Components
DSRC Immediate Forward Plugin	DSRC Radio
Location Plugin	GPS
NTRIP Plugin	NTRIP Network
SPaT Plugin	Traffic Signal Controller
DMS Plugin	DMS
Operational Data Exchange Plugin	Operational Data Exchange

The MAP and CSW V2I Hub plugins are not listed in Table 4 because they do not have corresponding external subsystem components.

The external subsystem components shown in Figure 2 are listed below:

- **DSRC Radio** – The primary means of achieving V2I communications for the V2I Hub platform. It is a component of equipment positioned along highways, at traffic intersections, and other locations to support wireless communications between connected CAVs and infrastructure.
- **GPS** – A GPS receiver obtains location information and is a precise time source for the V2I Hub.
- **NTRIP Network** – A source of data from a network of base stations providing Radio Technical Commission for Maritime Services differential corrections for location and time position that allows a user to calculate a more accurate determination of position than an unassisted user typically offers.
- **Traffic Signal Controller** – It controls the flow of vehicular and pedestrian traffic by displaying phases on the traffic lights.
- **DMS** – An electronic traffic sign beside roadways used to give travelers information about special events. These events include traffic congestion, accidents, incidents, roadwork zones, or speed limits.
- **Operational Data Exchange** – A cloud-based data repository created by U.S. DOT for storing connected CAV data obtained from deployments.
- **SSH (Secure Shell) Client** – SSH Protocol is a method for creating a secure and encrypted remote connection between a client and a server.[9]
- **Web Browser** – Uses internet connectivity to facilitate access to the V2I Hub for remote configuration and maintenance. Examples include Internet Explorer or Google Chrome.

Chapter 4. Next Steps

Efforts to create a V2I solution started years ago with the development of the SAE J2732 DSRC Message Set Dictionary standard, which specified the messages and data sets to relay phase information from a traffic controller. Based on this effort, a SPaT system was developed that communicated the signal and phasing information the TSC provided. A prototype solution called V2I Hub was created following industry standards to provide interoperability and scalability for CAV deployments. The V2I Hub allowed CAVs to transmit their position, direction, speed, and other safety-related information to surrounding connected vehicles and infrastructure. This information was also made available to existing Traffic Management Centers.

The hardware and software required for the V2I Hub are dependent on the applications to be deployed. The software residing in the system is ready to implement CAV applications. Each CAV application is known as a plugin; they determine the external subsystem components needed. Using plugins reduces the work required to add functionality or connectivity to new devices and reduces backend software and integration work required for operators to support connected vehicles.

Implementing a connected solution using V2I Hub helps achieve the U.S. DOT's goal of a complete deployment of CAV technologies in the United States. CAV connectivity allows safety information sharing between road vehicles, trains, infrastructure, and mobile phones. This will help reduce the number of traffic-related injuries and fatalities, optimize traffic flow, and reduce vehicle emissions.

The goal of this guidebook is to provide a general description of the V2I Hub, an overview of its software modules, and a high-level description of the hardware needed to deploy it. This guidebook is part of a series of documents created to provide guidance and training materials to support procurement, testing, deployment, and maintenance for a V2I Hub system. The other documents in this series are listed below with a brief description and target audience.

- **V2I Hub Deployment Guide** – This document is geared towards ITS deployers. It describes what is needed to deploy a V2I Hub at an intersection. The deployment handbook goes into everything to be considered, including site selection, deployment design, hardware procurement, licensing, etc.
- **V2I Hub Software Configuration Guide** – This document targets the ITS technical staff. It contains information on how to configure, monitor, and maintain a V2I Hub deployment.
- **V2I Hub Administration Portal User Guide** – This document is the user guide for the V2I Administration Portal. This document targets ITS technical staff and will be needed as a reference for the V2I Hub Software Configuration Guide.
- **V2I Hub Plugin Programming Guide** – This document targets V2I Hub plugin developers and will describe the steps needed to create plugins.
- **V2I Hub Plugins document** – This document describes the V2I Hub plugins and their configuration details for deploying the V2I Hub.

The V2I Hub software is available on the Open Source Application Development Portal.

Appendix A. Acronyms

BSM	Basic Safety Message
CAV	Connected and Automated Vehicles (vehicles benefiting from connectivity in this guidebook)
CV	Connected Vehicle
DSRC	Dedicated Short-Range Communications
FCC	Federal Communications Commission
GPS	Global Positioning System
ITS	Intelligent Transportation System
IVP	Integrated V2I Prototype
NTCIP	National Transportation Communications for Intelligent Transportation System Protocol
NTRIP	Networked Transport of Radio Technical Commission for Maritime via Internet Protocol
OBU	On-Board Unit
RSU	Roadside Unit
SPaT	Signal, Phase, and Timing
TIM	Traffic Incident Message
TSC	Traffic Signal Controller
U.S. DOT	United States Department of Transportation
UDP	User Data Package
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle

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