alllll
CISCO
The bridge to possible

Edge Computing Delivers Low Latency Connected Vehicle Applications over 4G LTE

Cisco and Verizon combine for Connected Vehicle applications on LTE

Contents

Today's connected vehicles are leveraging localized wireless networks that provide limited range but deliver on dedicated spectrum for applications that require low loss and immediate response. For many years connected vehicle applications that were delivered over cellular networks have suffered from long latencies and could not be relied upon for safety applications. The emergence of Mobile Edge Compute (MEC) systems and Edge Compute for roadways have combined to deliver a low latency infrastructure to deliver these applications over the cellular network. Cisco and Verizon have combined to show the capabilities of edge compute in both the roadway cabinets and the service provider network to drive the next generation of connected vehicle interfaces and applications.

Introduction

Current Connected Vehicles leverage LTE-V2X, using the LTE band 47 using UARFCN 55140 with a 20 MHz Channel. The LTE-V2X standard operates in only the 5.895-5.925 GHz portion of the 5.9 GHz band, or 30 MHz. This is a significant reduction of the overall ITS band that was originally granted by the FCC of 75 MHz. The reduction to 30 MHz for ITS systems to communicate with Connected Vehicles is further reduced to 20 MHz due to interference concerns with the lower 10 MHz against new outdoor unlicenced wireless operations, which is shown to limit the ability of the 20 MHz to deliver the current and future applications being developed for Safety. Cisco and Verizon have partnered to study the feasibility of moving these applications to the 4G-LTE cellular network.

Overview

Cisco has been delivering edge computing on industrial networking equipment for years. The presence of these devices in roadside cabinets led to the deployment of edge compute on these industrial networking devices. Software running on the compute resources in roadside cabinets facilitates sensor fusion and delivery of Connected Vehicle applications. Understanding native interfaces and protocols allow this software to evaluate ITS data from devices such as traffic signal controllers, LIDAR, Radar, and Connected Vehicle Roadside Units (RSUs), and utilize those data for real-time connected vehicle applications such as Incident response, pedestrian protection, emergency vehicle pre-emption, and many others. This position in the infrastructure allows edge software to integrate any system that requires live streams of data to deliver applications to the vehicles or pedestrians. The lack of spectrum for CV2X has enhanced the need for additional interfaces to reach vehicles and pedestrians. Partnering with Verizon, Cisco industrial equipment has given edge compute the ability to interface with Cellular interfaces of all kinds with the safety applications of today as well as the next generation of perception sharing applications.

Verizon has long been a leader in the delivery of LTE networks. The development of the Mobile Edge Computing architecture for positioning applications closer to the consumers of the LTE network has allowed for a high bandwidth, low latency capability for edge computing applications. The development of VZMode Connected Vehicle software is addressing a unique problem for the usage of the cellular network for connected vehicle applications; that being geolocation awareness of messaging to the vehicle. Traditional broadcast message delivery is not feasible across wide reaching cellular networks. A system to ensure that vehicles and pedestrians only receive relevant information from devices in a local proximity is required to ensure Connected Vehicle Safety applications are effective. VZMode accomplishes this by receiving location information from the edge compute software on roadside infrastructure as well as the devices registering to receive the application from the Verizon VZMode Services. Directing appropriate messages to their intended audience ensures low latency and efficient use of the LTE network.

Concerns over the latency involved in such a communication path are a primary reason these networks have not been leveraged in Connected Vehicle Applications to date. Cisco and Verizon were primarily focused on debunking those concerns and proving the systems could be designed to deliver the appropriate latencies. Once the applications were integrated the testing could show which applications were feasible based on the results. The goal of the integration is to deliver a set of applications that could be delivered in lieu of the limitations in the 20 MHz left over in the 5.9 GHz band.

System design overview

Two systems were integrated to create the full application delivery. Cisco IR1101 running edge software and Verizon VZMode software. Devices in the roadside cabinets have data processed by edge compute. Edge applications running on the IR1101 include conflict management of pedestrian locations in an intersection, incident response based on sensor inputs, etc. Another primary function of the edge software is the conversion of data between standards. The most relevant example of this is the ability to deliver multiple CV standards simultaneously. Current implementations have as many as four disparate CV standards running at a single intersection. DSRC 2009, DSRC 2016, CV2X, and the new Verizon VZMode application all being fed by edge software running on the Cisco IR1101 in their native standards. A message indicating a pedestrian J-Walking for instance, requires reading a LIDAR or video analytic then sending separate messages to a radio feeding each of the technologies a vehicle may be listening to. These require large amounts of data to be processed at the edge in near real-time then creating the appropriate message in response. Network latency is addressed by keeping processing local to the devices. The challenge then was to find a service provider who could innovate ways of delivering messages to cellular devices in a timely and efficient manner. Verizon showed they were ready to deliver.

Cisco industrial hardware with edge computing functions

Cisco delivers a secure robust network for roadway operators starting with hardened industrial switching, routing, and compute devices in many configurations. Fully integrated routing, switching and compute together, or delivering switching with compute, or routing with compute, or a standalone edge compute device, all with zero touch provisioning, best in industry security and reliability. A typical roadside deployment is depicted in figure 1. This includes networking, edge compute and software. Options for connectivity allow for Optical fiber, DSL, wireless or cellular connectivity to the roadside edge. Processing at the edge ensures relevant data is transmitted over the available resources of the connection to the network, low speed links have different aggregation policies than high speed links. Software running at the edge delivers data policies independent of local applications that are being executed like Pedestrian protection. In the case of the Verizon integration quick expansion of a connected vehicle application can be done through cellular backhaul negating the need for expensive and time-consuming Optical fiber installations, or to meet demand where Optical fiber is not feasible in the near term.
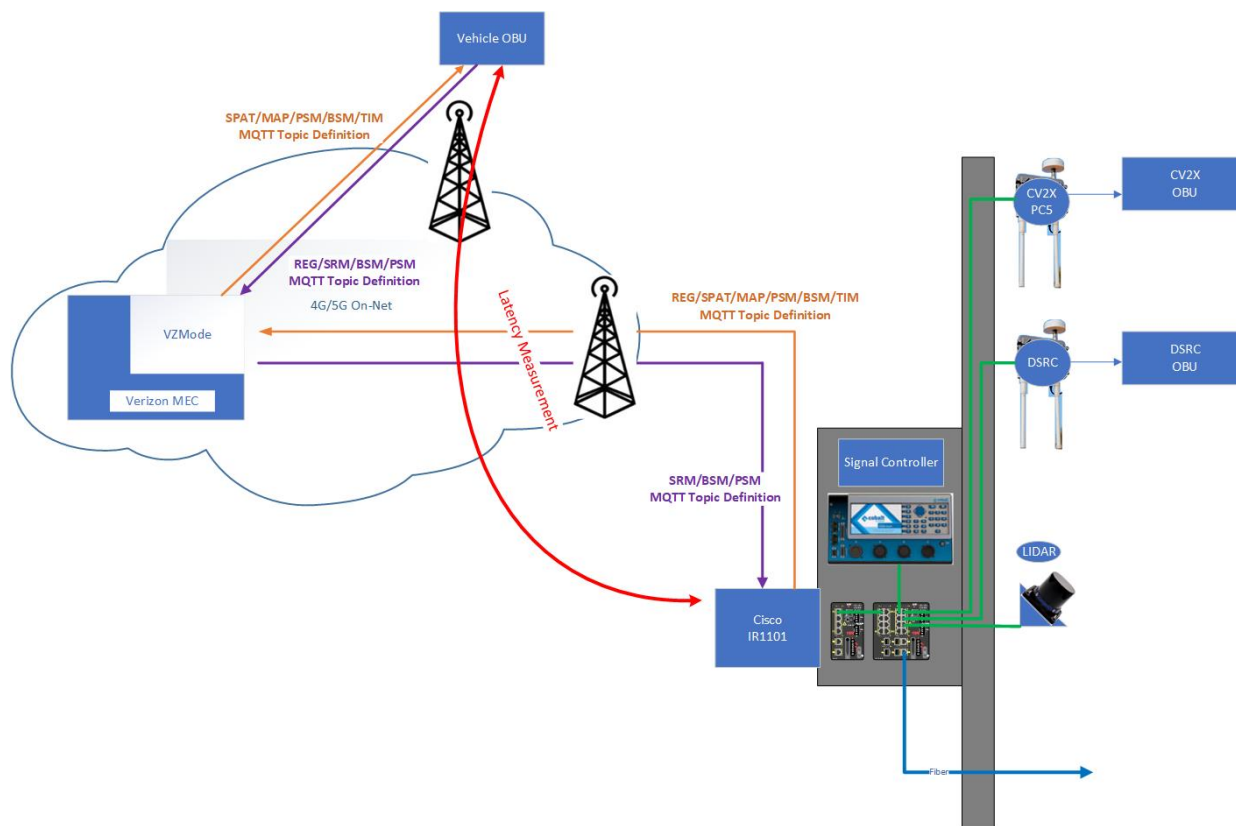
Verizon VZMode Virtual RSU

Verizon has developed the VZMode Virtual RSU software. This software is deployed on the Mobile Edge Compute or MEC. This MEC is placed in the local region's datacenter. This proximity to the cellular interfaces in a region affords the low latency interface required for applications that will leverage the cellular network's LTE connections. Once deployed in the MEC the VZMode software is built as a cluster of services. The application stack here has many functions. First it establishes connection to each of the devices that are participating in the CV application. Registration is done using a request to the VZMode cluster by the device. When infrastructure devices connect, they give their static GPS location as a reference for all communication to and from the intersection to the VZmode Servers. Vehicles also register and receive a client ID. This ID is then used for BSM transmission into the MEC VZMode servers. This is a standard J2735 BSM message type with a lower frequency than 10hz. The reduced frequency allows for lower load on VZmode while maintaining geolocation context.

The VZmode software then utilizes geolocation algorithms to locate devices within the specified radius around an infrastructure point. The test utilized SPAT messages from intersections to demonstrate the geofencing capabilities of the VZMode implementation. Only vehicles within the defined radius of the message were transmitted the SPAT messages for this intersection. The latencies measured were based on transmission delay once a device had registered and was designated to receive the appropriate messages.

Testing Methodology

Once deployed the edge applications integrate with the Verizon VZMode cluster deployed in the local market to the customer. This ensures lower latency for connected vehicle applications. Our testing sought to prove the effectiveness of the system. Below is a mock-up of the testing apparatus.
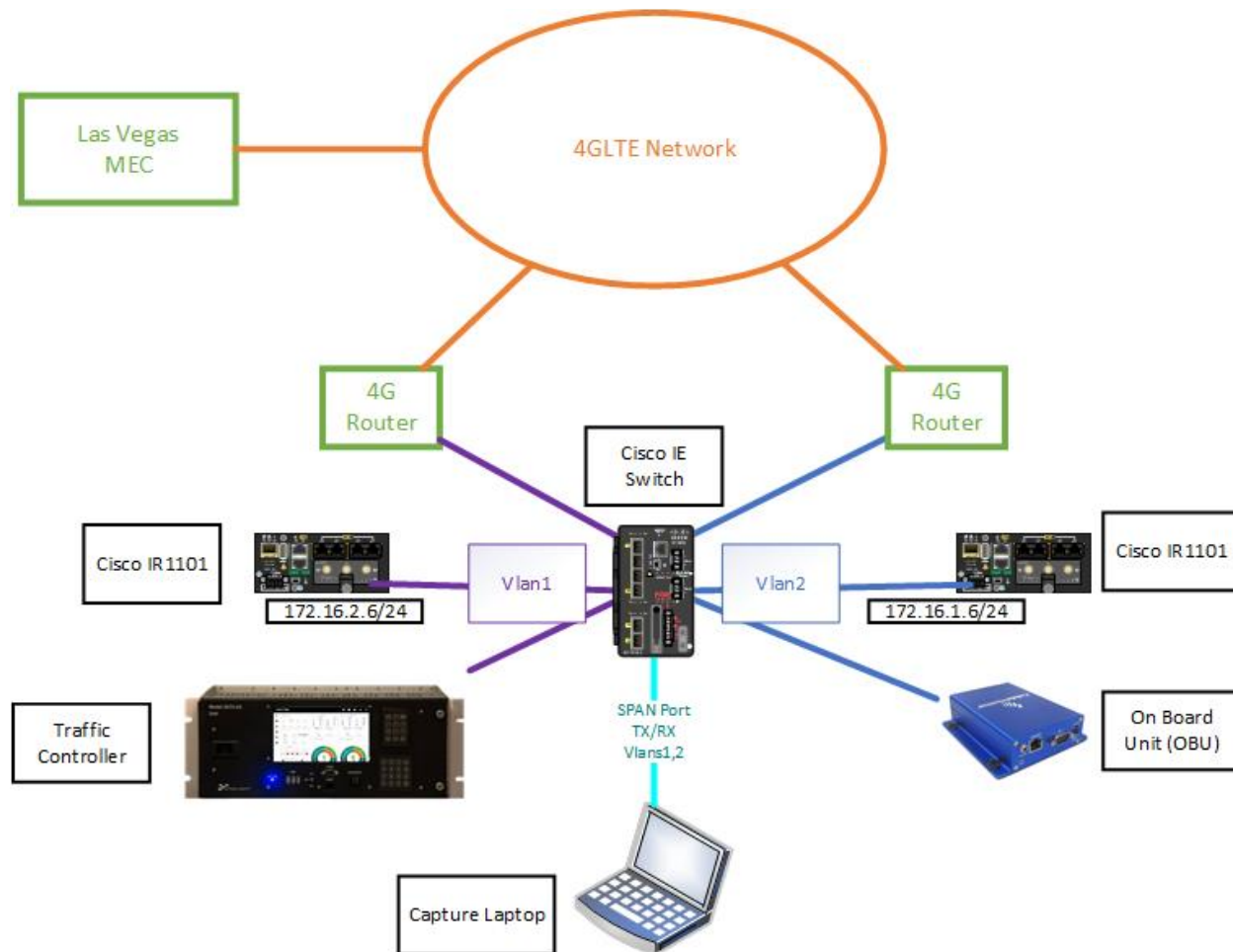
A hardwired design was chosen because of the requirements for sub-millisecond synchronized measurements. The vehicle was tethered to the intersection by optical fiber to ensure all packets were captured in a single time source. The virtual LAN of the intersection, Vlan1, was passed through the IE switch along with the in-vehicle network, Vlan2. All traffic from both Vlans were monitored on a capture laptop. This ensured that even though the packets were being routed through a segmented layer 2 switch they would be seen by the capture laptop on a single interface.

Test Results

Packet traces were completed over two days during normal business hours on the 4G LTE network. No special configurations accompanied the cellular router interfaces. Pedestrian and business traffic was visible throughout the testing periods, mornings, and afternoons. Figure 3 shows one packet trace. Filters were used to capture the conversations of SPAT messages exiting the intersection. This is the first of the messages in each conversation. It is a Verizon VZMode MQTT packet with compressed data and a specialized header. The second message in each conversation is the SPAT message being received at the Vlan2 interface at the OBU. Edge software on the Cisco IR1101 was running the SPAT application for DSRC and CV2X during these tests in the intersection, but the packet trace only shows the packet as it leaves the intersection bound for the VZMode servers. In the vehicle each conversation only shows the receipt of the SPAT message at the Vlans level, not after processing by the OBU. This ensured that application latency of any kind was left out of the latency calculations.
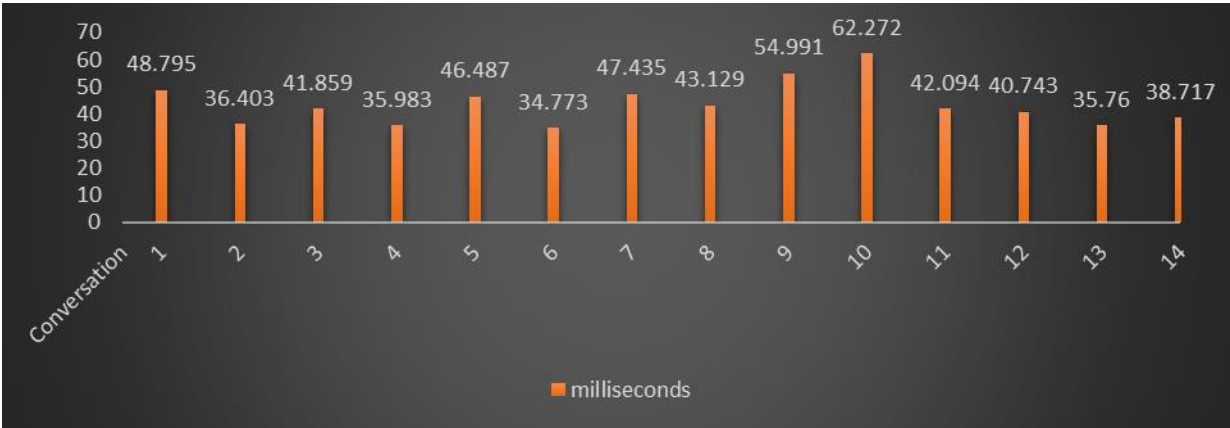

The graph above outlines 14 conversations distributed throughout the capture period. Each were pulled to include random areas throughout the capture as well as the best and worst latency conversations in each capture. In this capture the lowest latency is 34.773 the highest was 62.272.

Conversation	Packet	Time	Latency	Milliseconds	Source	Dest			
1	2821	2.777583			172.16.2.6	155.146.114.49	MQTT	291	Publish Message
1	2849	2.826378			155.146.114.49	172.16.1.6	MQTT	257	Publish Message
1			0.048795	48.795					
2	2965	2.932273			172.16.2.6	155.146.114.49	MQTT	290	Publish Message
2	3013	2.968676			155.146.114.49	172.16.1.6	MQTT	257	Publish Message
2			0.036403	36.403					
3	3149	3.109983			172.16.2.6	155.146.114.49	MQTT	290	Publish Message

Conversation	Packet	Time	Latency	Milliseconds	Source	Dest			
3	3175	3.151842			155.146.114.49	172.16.1.6	MQTT	257	Publish Message
3			0.041859	41.859					
4	3173	3.147483			172.16.2.6	155.146.114.49	MQTT	291	Publish Message
4	3221	3.183466			155.146.114.49	172.16.1.6	MQTT	257	Publish Message
4			0.035983	35.983					
5	3233	3.185348			172.16.2.6	155.146.114.49	MQTT	291	Publish Message
5	3291	3.231835			155.146.114.49	172.16.1.6	MQTT	257	Publish Message
5			0.046487	46.487					
6	3405	3.362544			172.16.2.6	155.146.114.49	MQTT	291	Publish Message
6	3451	3.397317			155.146.114.49	172.16.1.6	MQTT	257	Publish Message
6			0.034773	34.773					
7	3587	3.495374			172.16.2.6	155.146.114.49	MQTT	291	Publish Message
7	3633	3.542809			155.146.114.49	172.16.1.6	MQTT	257	Publish Message
7			0.047435	47.435					
8	3605	3.536289			172.16.2.6	155.146.114.49	MQTT	291	Publish Message
8	3667	3.579418			155.146.114.49	172.16.1.6	MQTT	257	Publish Message
8			0.043129	43.129					
9	3733	3.644787			172.16.2.6	155.146.114.49	MQTT	291	Publish Message
9	3825	3.699778			155.146.114.49	172.16.1.6	MQTT	257	Publish Message
9			0.054991	54.991					

This capture of conversations is shown to validate the conversation paths for each of the messages that were published. The application instance in the intersection is 172.16.2.6 transmitting the SPAT from the controller to the Verizon VZMode server. That specific SPAT message being sent from the VZMode cluster to the vehicle is shown in the second message sourced from 155.146.114.49 and sent to the vehicles' OBU at 172.16.1.6. The latency of each conversation is calculated from the time stamp each packet was received. For the second capture the same process was followed. Random conversations throughout the capture are outlined, with the lowest and highest latencies also recorded.
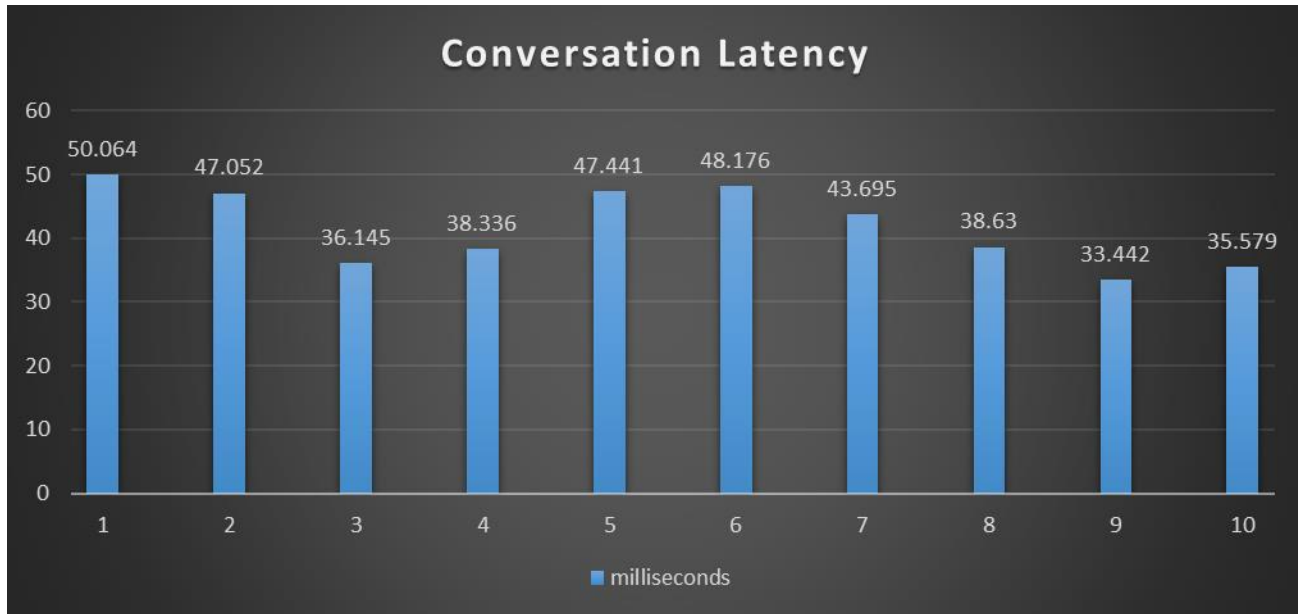
Conversation	Packet	Latency	Milliseconds	Source	Dest			
1	233	0.647425		172.16.2.6	155.146.114.240	MQTT	302	Publish Message
1	261	0.697489		155.146.114.49	172.16.1.6	MQTT	257	Publish Message
1		0.050064	50.064					
2	257	0.693248		172.16.2.6	155.146.114.240	MQTT	302	Publish Message
2	267	0.7403		155.146.114.49	172.16.1.6	MQTT	257	Publish Message
2		0.047052	47.052					
3	295	0.867648		172.16.2.6	155.146.114.240	MQTT	301	Publish Message
3	303	0.903793		155.146.114.49	172.16.1.6	MQTT	257	Publish Message
3		0.036145	36.145					

Conversation	Packet	Latency	Milliseconds	Source	Dest			
4	337	0.992402		172.16.2.6	155.146.114.240	MQTT	302	Publish Message
4	345	1.030738		155.146.114.49	172.16.1.6	MQTT	257	Publish Message
4		0.038336	38.336					
5	393	1.171022		172.16.26	155.146.114.240	MQTT	302	Publish Message
5	415	1.218463		155.146.114.49	172.16.1.6	MQTT	257	Publish Message
5		0.047441	47.441					
6	411	1.213207		172.16.2.6	155.146.114.240	MQTT	302	Publish Message
6	431	1.261383		155.146.114.49	172.16.1.6	MQTT	257	Publish Message
6		0.048176	48.176					
7	445	1.311765		172.16.2.6	155.146.114.240	MQTT	302	Publish Message
7	457	1.35546		155.146.114.49	172.16.1.6	MQTT	257	Publish Message
7		0.043695	43.695					
8	491	1.437837		172.16.2.6	155.146.114.240	MQTT	302	Publish Message
8	503	1.476467		155.146.114.49	172.16.1.6	MQTT	257	Publish Message
8		0.03863	38.63					
9	501	1.471203		172.16.2.6	155.146.114.240	MQTT	302	Publish Message
9	521	1.504645		155.146.114.49	172.16.1.6	MQTT	257	Publish Message
9		0.033442	33.442					

As seen in the two captures the average latency across the two test days was a staggering fast 42.833 ms. This is the overall time to deliver a packet from the infrastructure to a vehicle, through the 4G interface on both the intersection as well as the 4G interface with the vehicle. Through the Geolocation facilities inside of the VZMode Application and end to end from a transmission perspective. This result was stable as the fastest conversation occurs within 33.442 ms and the longest time a packet took to transmit through the 4G LTE network and the MEC was 62.272 ms.

Taking these response times into consideration we look at the guidance set around the SAE J2735 message set for CV applications. The J2735 standard message types as well as standards in the J2945 and J3161 defining CV application requirements, outline latency tolerances for applications for Weather, Road Safety, Traffic Signals, Probe Data, Emergency and Transit applications. Many of these applications could be delivered across the 4G LTE network with the VZMode application running on a regional MEC.

Table 2 [1]

Table 1. Different traffic families and corresponding priority.

Traffic Type	Safety Services				Mobility Services		
Traffic Families	Critical V2V	Essential V2V	Critical V2I – I2V	Essential V2I – I2V	Transactional	Low Priority	Background
Traffic Direction	V2V		V2I – I2V		V2I – I2V		
Minimum PPPP	2	5	3	5	6	7	8
Minimum PDB	20 ms	100 ms	100 ms	100 ms	100 ms	100 ms	100 ms
Example Messages	Critical BSM, EVA	BSM	RSM, MAP	SPaT	EFC/Toll	TIM	TCP, UDP

Next steps

The tests are clear that the current integration of roadside edge compute and mobile edge compute can combine to deliver the latency required by safety applications. The routing of packets to individual devices based on geolocation proximity to the sources ensures the best use of the cellular interface, when moving from a broadcast-based medium such as the 5.9 GHz spectrum currently utilized for CV2X PC5 interfaces.

Optimization is the obvious next step. Defining applications for I2V that leverage the 4G LTE network will help to study the cellular spectrum limitations and capacities and help to ensure that as we move testing to 5G millimeter wave and 5G c-band implementations, clear outcomes can be properly assessed and documented. Feedback into the industry and standard organizations will help to show how changes in future standards can drive to a more stable and flexible cellular implementation of transportation safety.

Conclusion

It is important to recognize the capabilities of the Verizon 4G network with VZMode MEC applications combined with the Cisco IR1101 and edge software. A complete solution for roadway operators looking to quickly expand the capability to deliver services to their constituents. Hardware for security and connectivity regardless of current infrastructure. Capabilities to deliver edge applications for pedestrians, traffic management and incident response, combined with the ability to deliver instantaneously across current and future Connected Vehicle Technologies. The integration of the VZMode platform addresses scale by utilizing the existing 4G LTE network, delivering applications to vehicles and constituents over this network to existing installed devices that are 4G LTE enabled. Phones, Vehicles, and endpoints that have 4G interfaces could be leveraged to deliver roadway safety applications now. The integration of legacy sensors and devices to the 4G LTE network mean that customers are ready for the 5G and beyond without large investments in forklift upgrades of their ITS systems. As Verizon scales its deployments of 5G millimetre wave small cell and mid-band or C-Band 5G, applications can grow in number of edge devices and capabilities.

The 4G LTE network is ready to deliver on safety applications. Cisco and Verizon are working to expand the capabilities of V2X to well known devices to see innovation across devices in our hands today. These latencies clearly show how further work is needed to move connected vehicle applications forward for greater adoption.

References

[1] SAE CV2X Technical Committee, J3161 standard application delay packet budget table.

Version:	1
Date of publication:	
Document type:	White Paper
External publication:	Yes

Cisco Systems, Inc.

Cisco Systems, Inc.

Internet

https://www.cisco.com

Copyright notification

1. No part may be reproduced except as authorized by written permission. The copyright and the foregoing restriction extend to reproduction in all media.

2. Cisco and the Cisco logo are trademarks or registered trademarks of Cisco and/or its affiliates in the U.S. and other countries. A listing of Cisco's trademarks can be found at www.cisco.com/go/trademarks. Third-party trademarks mentioned are the property of their respective owners. The use of the word partner does not imply a partnership relationship between Cisco and any other company.