Private 5G Technology and Implementation Testing

March 2023 | Final Report

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16. Abstract

NEC developed a Video Analytics implementation for traffic intersections using 5G technology. This implementation included both hardware infrastructure and software applications supporting 5G communications, which allows low latency and secure communications. The Virginia Tech Transportation Institute (VTTI) worked with NEC to facilitate the usage of a 3,400- to 3,500-MHz program experimental license band without SAS integration to successfully implement a private 5G deployment at the VTTI Smart Road intersection and data center. Specific use cases were developed to provide alerting mechanisms to both pedestrians and vehicles using cellular vehicle-to-everything/PC5 technology when approaching a traffic intersection and a dangerous situation is detected.

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Abstract

NEC developed a Video Analytics implementation for traffic intersections using 5G technology. This implementation included both hardware infrastructure and software applications supporting 5G communications, which allows low latency and secure communications. The Virginia Tech Transportation Institute (VTTI) worked with NEC to facilitate the usage of a 3,400- to 3,500-MHz program experimental license band without SAS integration to successfully implement a private 5G deployment at the VTTI Smart Road intersection and data center. Specific use cases were developed to provide alerting mechanisms to both pedestrians and vehicles using cellular vehicle-to-everything/PC5 technology when approaching a traffic intersection and a dangerous situation is detected.

Acknowledgements

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Introduction

The automotive sector is considered one of the most prominent verticals that will benefit from the capabilities of the upcoming 5G cellular networks. Vehicular applications cover a range of use cases and thus involve a large set of associated requirements. Examples include very high data rates and timely service delivery while also considering ultra-low communication latencies. Complex scenarios where vehicles communicate among themselves and also with nearby road infrastructure, road users, clouds, etc., also known as vehicle-to-everything (V2X) communications, will not only leverage the 5G network but will play a key role in its design.

In this project, the Virginia Tech Transportation Institute (VTTI) and NEC deployed a Private 5G network supporting video analytics using camera sensors that were installed at the VTTI Smart Road intersection. Among the possible use cases of this implementation, VTTI developed six use cases using private 5G and cellular V2X (C-V2X) communications:

- Vehicle-to-pedestrian collision prediction
- Street parking vehicle
- Traffic accident detection
- Pedestrian detection at a crosswalk
- Vehicle turning (left/right) alert
- Overspeed detection

The project analyzes the technical and non-technical issues brought on by the Private 5G network and the interface with V2X systems, including roadside units (RSUs) and onboard units (OBUs).

Background

The latest data from the National Highway Traffic Safety Administration (NHTSA) indicates there were 42,915 traffic fatalities in 2021, a 10.5% increase from the previous year (National Center for Statistics and Analysis, 2022). Of these fatalities, approximately 7,342 involved pedestrians, and another 985 involved bicyclists, which means nearly 20% of all traffic fatalities in 2021 involved a vulnerable road user (VRU; National Center for Statistics and Analysis, 2022). Although data from the same year is not available for intersection-specific crashes, 2019 data suggests that "10,180 people were killed in an intersection and intersection-related crashes, which is roughly one-quarter of all roadway fatalities" (Shaw et al., 2022, p. 13). Combined, these findings show that intersections are disproportionately deadly for road users, particularly for VRUs like pedestrians and cyclists.

Technologies like pedestrian automatic emergency braking have the ability to mitigate or, in some cases, prevent traffic collisions with VRUs, but not all vehicles are equipped with these systems, and they do not work in all scenarios. This research project looked at infrastructure-based technologies for alerting when these types of collisions were likely, which could help reduce the frequency of these incidents.

This project addressed the following research questions:

- Can 5G technology provide the required latency and performance to alert pedestrians and vehicles of intersection-related situations?
- Does 5G technology provide the bandwidth and speed to process near real-time sensor data such as cameras?
- Can Private 5G and C-V2X be used to deploy safety-critical applications at smart intersections?

Method

The following tasks outline the approach taken to integrate, deploy, and test the Private 5G Video Analytics solution at the VTTI Smart Road and data center:

Task 1: Project Management

Throughout the life of this project, the project team held biweekly teleconferences to discuss the project status. Status meetings involved a discussion of the milestones/deliverables schedule, including quarterly reports, biannual activity surveys, and the final project report. In addition, the team tracked the status of the budget each month and collaborated on the final project deliverables, such as this final report and the use case data collection and performance results uploaded to VTTI Dataverse. This final report includes a specification for the Private 5G implementation at the VTTI Smart Road and the integration with C-V2X/PC5 technology for V2X communications. The technology transfer and education and workforce development activities completed also fall under Task 1.

Task 2: Infrastructure Installation

Figure 1 shows the proof-of-concept system outline. VTTI and NEC determined an appropriate approach for frequency licensing. After receiving proper approval from the Federal Communications Commission and Virginia Tech, VTTI worked with NEC to set up the Private 5G equipment to successfully use the assigned frequency band.

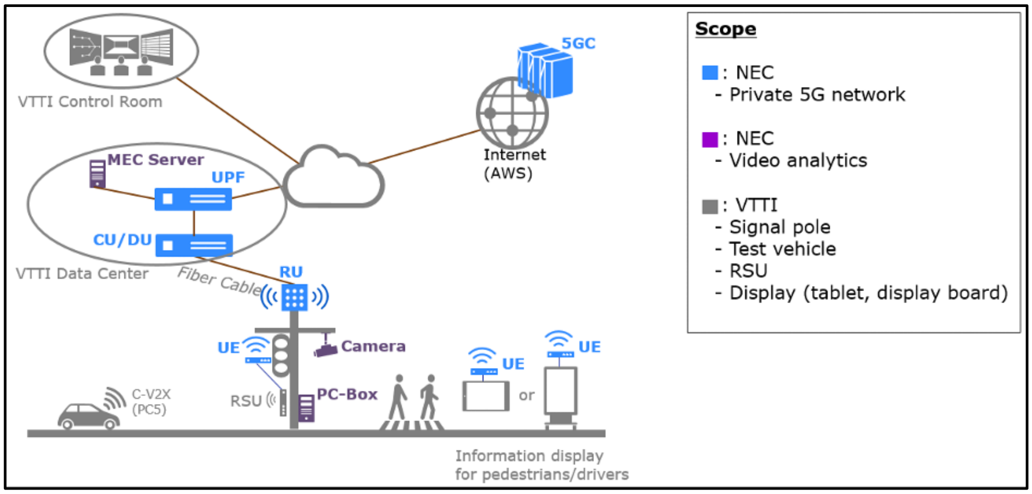


Figure 1. Diagram. Proof-of-concept system outline.

Under Task 2, the VTTI team installed NEC hardware and computing systems at the VTTI Smart Road intersection and the VTTI data center, including NEC Edge Computing for Video Analytics, centralized unit and distributed unit (CU/DU) systems at the VTTI data center, and cameras and user equipment and radio unit (UE/RU) systems at the VTTI Smart Road intersection.

Figure 2 shows the location of the radio unit (RU), user equipment (UE), cameras, and PC-Box (edge server). Locations are shown for each device, including the wiring. The RU is connected to the VTTI data center using the Smart Road fiber link. VTTI installed these components per the specifications provided by NEC.

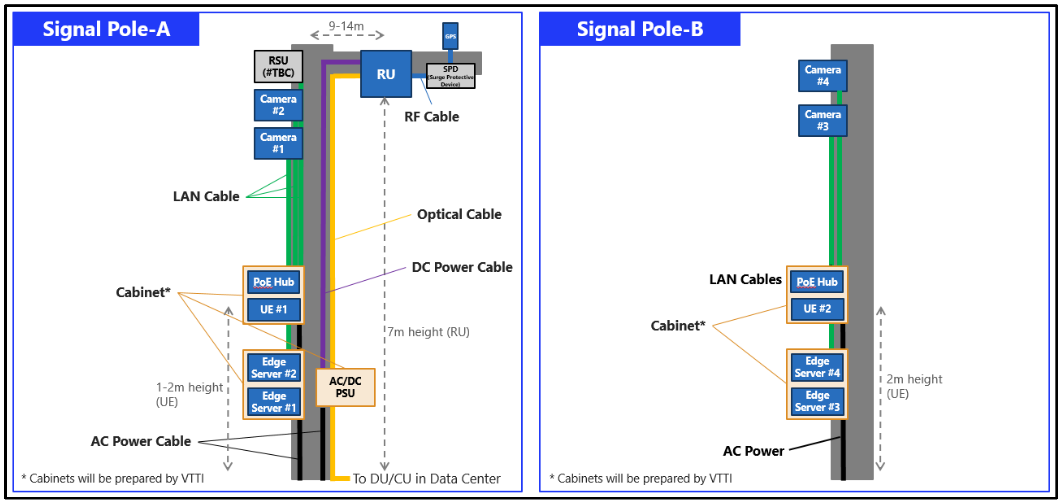


Figure 2. Diagram. NEC equipment install at Smart Road intersection.

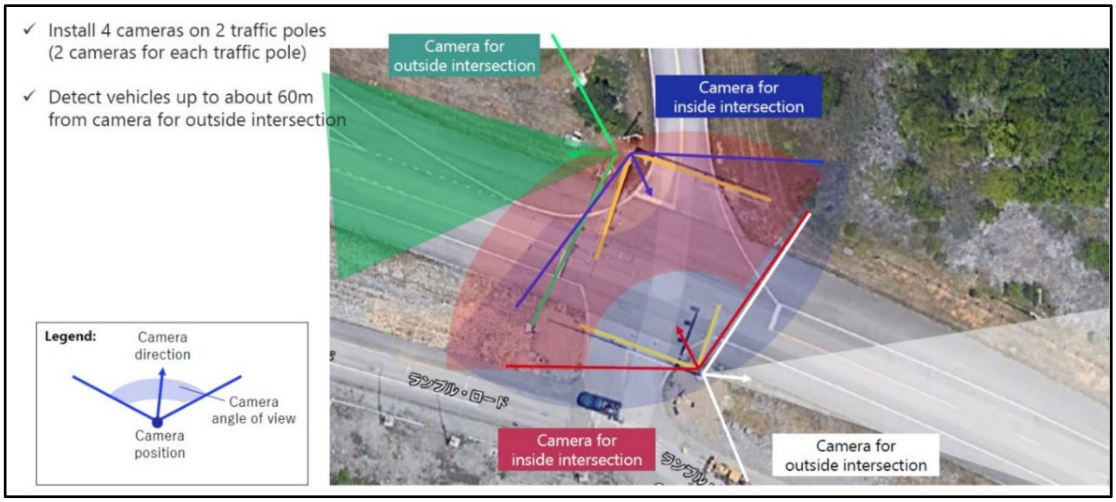


Figure 3. Photo and graphic overlay. NEC camera coverage at VTTI Smart Road intersection.

Figure 3 shows NEC's camera coverage. Two cameras face the intersection, and two additional ones face the outside. Cameras facing outside the intersection can detect vehicles within a 60-meter range from the main approaches. Cameras facing inside the intersection detect both vehicle and pedestrian traffic. VTTI installed these cameras per the specifications provided by NEC.

At the VTTI data center, two primary devices (Multi-Access Edge Computing [MEC] server and CU/DU) were installed and connected to the VTTI Smart Road network, as shown in Figure 4. A layer 3 (L3) Ethernet switch and VPN router were also installed to provide access to the 5G core (5GC). In this task, NEC was provided with remote access to the system using the same VPN router above. VTTI coordinated with NEC to enable and power the system at the VTTI Smart Road throughout the project testing schedule. The Smart Road Operations kept the system disabled while other studies used the VTTI Smart Road.

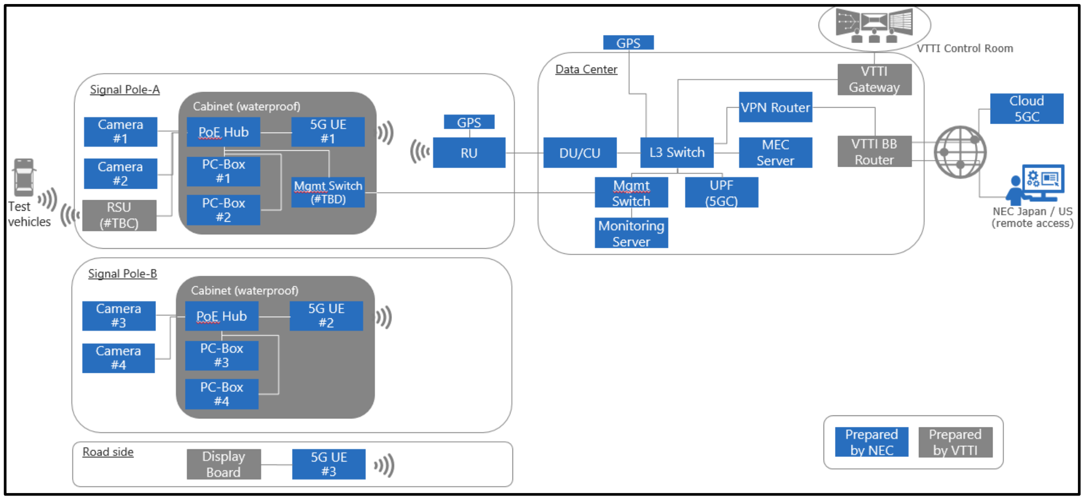


Figure 4. Diagram. NEC and VTTI system interconnection between VTTI data center and VTTI Smart Road intersection.

The hardware listed in Table 1 was installed with NEC support. VTTI worked with the NEC team to configure devices that match the VTTI network setup and verify the functionality of all the devices and software modules.

Table 1. NEC Hardware List

Equipment	Size	Weight	Power Consumption	Quantity: Data Center	Quantity: Intersection	Notes
5GC	-	-	-	-	-	
UPF	1U	7.5 kg	AC100-240 V, Max.311 W	1		
CU/DU	2U	30 kg	AC100-240 V, Max.850 W	1		
RU	389.6(L) x 389.6(W) x 134.9(H) mm	12.0 kg	Max.100 W		1	
5G UE	49(h) x 225(w) x 124(d) mm	1.0 kg	Max.18 W		3	
Camera	404(h) x 159(w) x 143(d) mm	2.2 kg	Max.20.3 W		4	
PC-Box	198(h) x 170(w) x 360(d) mm	5.0 kg	Max.600 W		4	
MEC Server	198(h) x 170(w) x 360(d) mm	5.0 kg	Max.600 W	1		Model: Nuvo-8108GC
VPN Router	43(h) x 210(w) x 297(d) mm	1.6 kg	Max.18 W	1		
L3 Switch	1U	6.0 kg	AC100-240 V, Max.150 W	1		
Mgmt Switch	1U	6.0 kg	AC100-240 V, Max.150 W	1	1	
GPS Antenna	134(h) x 89(w) x 89(d) mm	0.3 kg		1		Model: GPSS L1G1A-STD

Task 3: Private 5G System Calibration

Under Task 3, the VTTI team worked with NEC to calibrate the deployed camera sensors, including their position, angle, and field of view, along with NEC's Video Analytics software. This involved placing some cardboard boxes of known size into the intersection and recording LiDAR and video data of said boxes. This data was used to calibrate the cameras to a known ground truth prior to dynamic scenario testing. VTTI coordinated with NEC to complete dynamic testing on the VTTI Smart Road that featured vehicle and pedestrian activity around the intersection area. Several vehicles were used for this testing, including sedans, SUVs, motorcycles, and bicycles. Each test scenario featured a variety of interacting vehicles and/or pedestrians. Maneuvers for scenarios included vehicles turning or passing through the intersection, often in coordination with another vehicle or pedestrian traffic. Several "collision" scenarios were recorded in which simulated collisions were created in a few different ways: 1) when pedestrians were involved, VTTI employed the 4activePA pedestrian target, which is commonly used for NHTSA and European New Car Assessment Programme testing (4activePA, n.d.), and 2) when simulating a vehicle collision was required, the scenario was recorded with a camera on a vehicle backing away from the scene, after which the video was reversed for use in collision detection training. Altogether, VTTI performed 138 scenarios and recorded the relevant camera views for use in the camera calibration performed by NEC. VTTI designed a plan to cover different aspects of the calibration process, as shown in Figure 5.

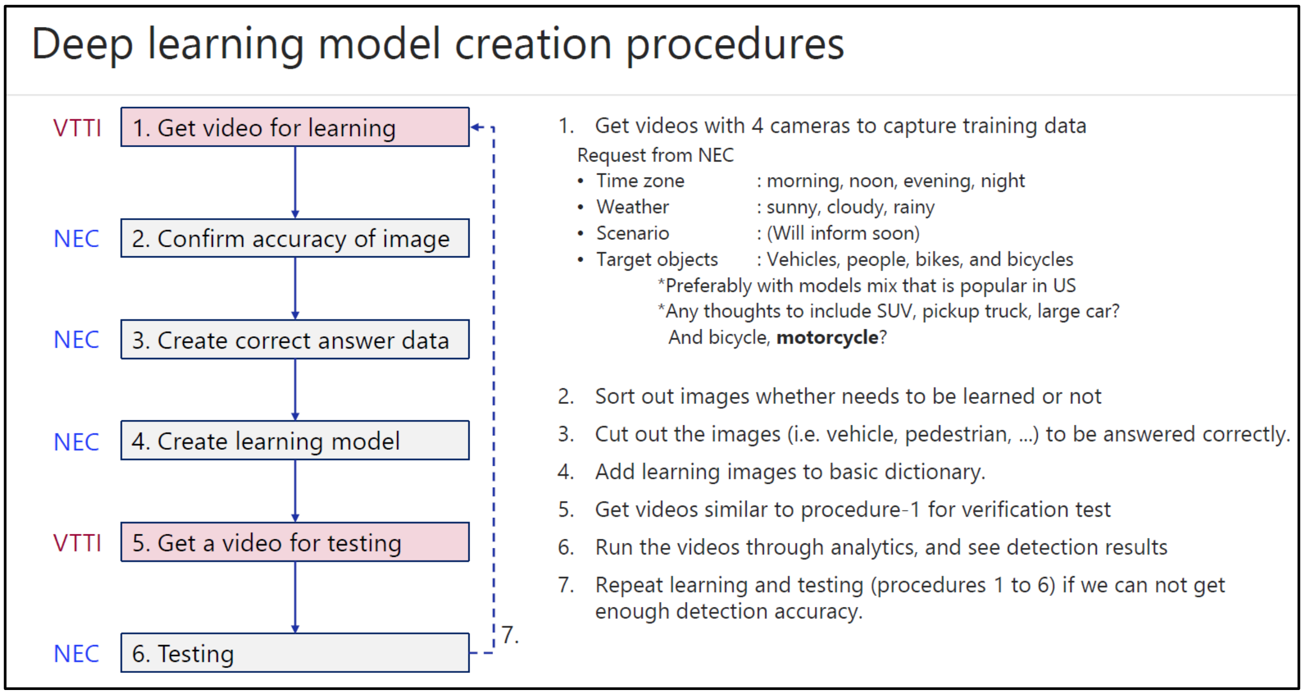


Figure 5. Flowchart. NEC camera and video analytics software calibration process.

VTTI completed the following activities under Task 3:

- Smart Road coordination plan bringing pedestrians, motorcycles, and vehicles around the intersection based on the identified use cases that NEC has shared to date (Task 4). VTTI procured the following research vehicles:
  - One research sedan vehicle Chevy Malibu (standard sedan)
  - One research SUV Chevy Tahoe (standard SUV)
  - One research van vehicle Chrysler Pacifica (standard minivan)
  - One research pickup truck vehicle
  - One research motorcycle
- Calibration execution results using NEC's calibration process

Task 4: Use Case Development for 5G/C-V2X Technology Integration

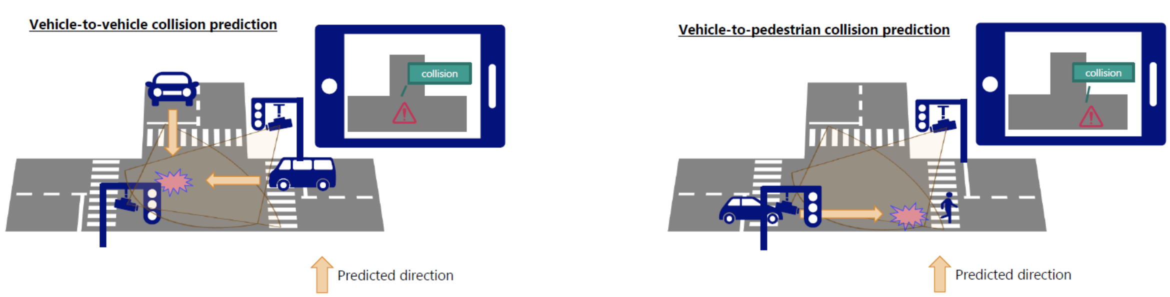
Under this task, VTTI developed the software components for the C-V2X platform, including the RSUs and OBUs. Figure 11 shows the data parsing from NEC's Video Analytics output to the C-V2X RSU, which encodes the data into the proper SAE J2735 message to be broadcasted and received by the C-V2X OBU installed on the VTTI research vehicles. C-V2X RSU and OBU firmware were developed to support all use cases by detecting vehicle or pedestrian warnings and using their GPS location, when possible, to generate simulated basic safety messages and personal safety messages. VTTI instrumented two research vehicles with C-V2X OBUs and a human machine interface (HMI) to display alerts and warnings for each use case scenario. Along with the vehicle instrumentation, the software development for the C-V2X devices supports data collection, including timestamps and object information. NEC provided six use cases to demonstrate NEC's Video Analytics alerting technology; these use cases are described below. VTTI designed the research scenario protocols considering safety and the coordination between the use case players.

Use Case 1

Table 2 summarizes the first use case scenario and parameters. VTTI used a C-V2X-equipped research vehicle, another research vehicle for vehicle-to-vehicle (V2V) alert, and a pedestrian for vehicle-to-pedestrian (V2P) alert.

Table 2. Use Case 1: Collision Prediction

Scenario Elements	Parameters
Use Case Goal	Warn drivers with the information of predicted collision around the intersection involving a vehicle or pedestrian.
Scenario Implementation	NEC Video Analytics predicts the V2V or V2P collision based on surveillance footage transmitted via 5G radio. VTTI will use the UDP data packets received from NEC Video Analytics software to encode into an SAE J2735 TIM message (alert) to be broadcasted from C-V2X RSU to OBU. Research Vehicle's OBU will receive the warning (SAE J2735 TIM message) and decode and generate the proper HMI warning.
KPI	- Time from predicting a collision to displaying on a tablet: less than 1 sec (= 6 m at 15 mile/h) - Detection rate: 80% (target: more than 90%)

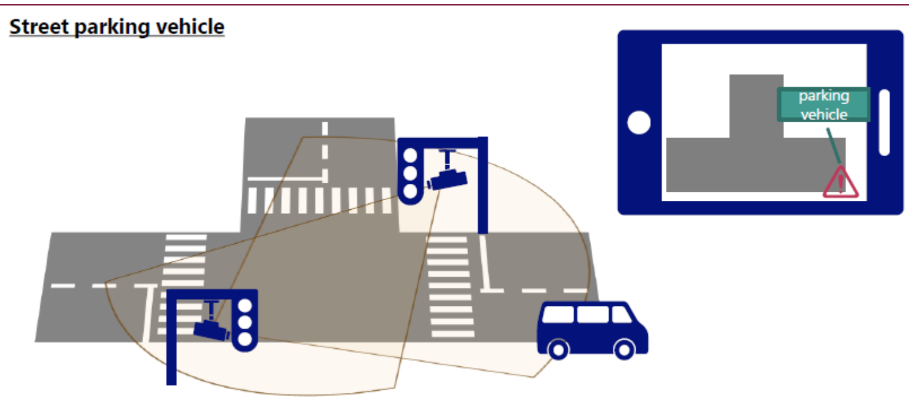


Use Case 2

Table 3 summarizes the second use case scenario and parameters. VTTI used a C-V2X-equipped research vehicle for the street parking alert and another research vehicle for the parking detection at the Smart Road intersection.

Table 3. Use Case 2: Street Parking Notification

Scenario Elements	Parameters
Use Case Goal	Detect street parking vehicles and notify drivers of their position.
Scenario Implementation	NEC Video Analytics detects the street parking vehicle using surveillance footage transmitted via 5G radio. VTTI will use the UDP data packets received from NEC Video Analytics software to encode into an SAE J2735 TIM message (alert) to be broadcasted from C-V2X RSU to OBU. Research Vehicle's OBU will receive the warning (SAE J2735 TIM message) and decode and generate the proper HMI warning.
KPI	- Time to display the position on the research vehicle's HMI. The occurrence of a street parking vehicle + 1 sec - Detectable distance: within 40 m from the camera. - Detection rate: 80% (target: more than 90%)

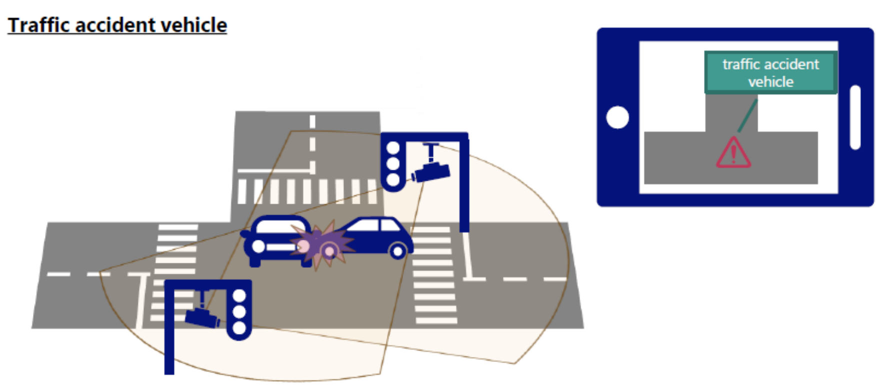


Use Case 3

Table 4 summarizes the third use case scenario and parameters. VTTI used a C-V2X-equipped research vehicle for the traffic accident detection alert and two additional research vehicles at the Smart Road intersection simulating an accident.

Table 4. Use Case 3: Traffic Accident Detection

Scenario Elements	Parameters
Use Case Goal	Detect traffic accident vehicles at the intersection and notify drivers of their position.
Scenario Implementation	NEC Video Analytics detects the traffic accident vehicle at the intersection using surveillance footage transmitted via 5G radio. VTTI will use the UDP data packets received from NEC Video Analytics software to encode into an SAE J2735 TIM message (alert) to be broadcasted from C-V2X RSU to OBU. Research Vehicle's OBU will receive the warning (SAE J2735 TIM message) and will decode and generate the proper HMI warning.
KPI	- Time to display the position on the research vehicle's HMI. The occurrence of a traffic accident + 1 sec - Detection rate: 80% (target: more than 90%)



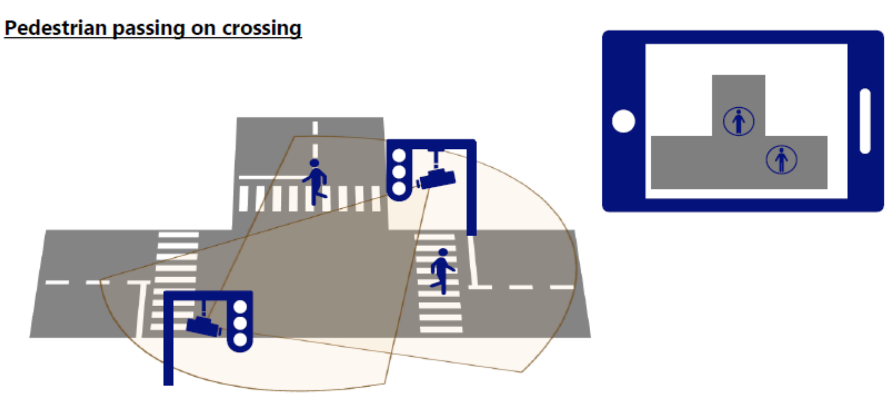
Use Case 4

Table 5 summarizes the fourth use case scenario and parameters. VTTI used a C-V2X-equipped research vehicle for the pedestrian crossing alert and two pedestrians walking using the Smart Road intersection crosswalk area.

Table 5. Use Case 4: Pedestrian Crossing Detection

Scenario Elements	Parameters
Use Case Goal	Notify drivers around the intersection that pedestrians are passing on the crossing.
Scenario Implementation	NEC Video Analytics detects the pedestrians passing on the crossing based on surveillance footage transmitted via 5G radio. VTTI will use the UDP data packets received from NEC Video Analytics software to encode into an SAE J2735 TIM message (alert) to be broadcasted from C-V2X RSU to OBU.

Scenario Elements	Parameters
	Research Vehicle's OBU will receive the warning (SAE J2735 TIM message) and will decode and generate the proper HMI warning.
KPI	- Time from detecting a target pedestrian to displaying the position on the research vehicle's HMI. Less than + 1 sec - Detectable distance within 20 m from the camera. - Detection rate: 80% (target: more than 90%)



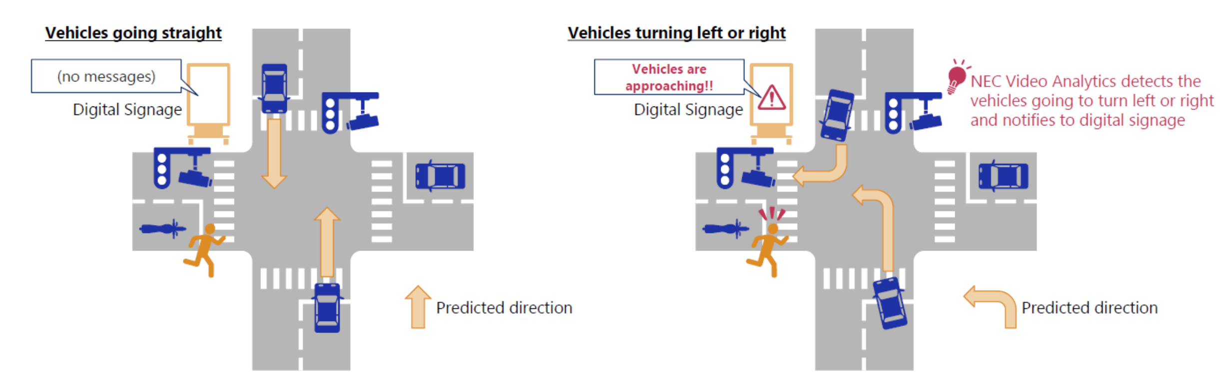
Use Case 5

Table 6 summarizes the fifth use case scenario and parameters. VTTI used two research vehicles, a motorcycle, and pedestrians, who received the alert through the portable display device when trying to use the Smart Road intersection's crosswalk area.

Table 6. Use Case 5: Vehicle Detection for Left and Right Turns

Scenario Elements	Parameters
Use Case Goal	Notify pedestrians around the intersection that vehicles are approaching.
Scenario Implementation	NEC Video Analytics detects the vehicle turning (left/right) based on surveillance footage transmitted via 5G radio. VTTI will use the UDP data packets received from NEC Video Analytics software to encode into an SAE J2735 TIM message (alert) to be broadcasted from C-V2X RSU to OBU. Pedestrian Mobile HMI's OBU will receive the warning (SAE J2735 TIM message) and decode and generate the proper HMI warning.
KPI	- Time from detecting a target vehicle to displaying the position on the research vehicle's HMI. Less than + 1 sec

Scenario Elements	Parameters
	- Detection rate: 80% (target: more than 90%)

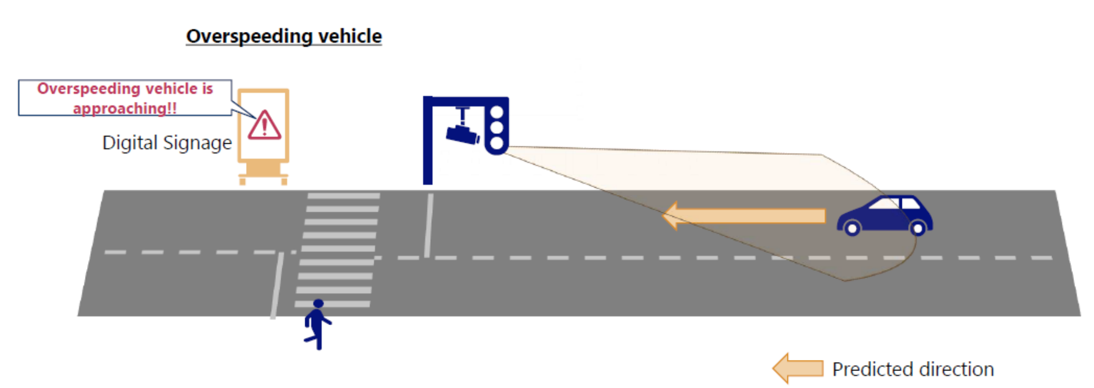


Use Case 6

Table 7 summarizes the sixth use case scenario and parameters. VTTI used a research vehicle driving through the intersection and a pedestrian who received the overspeed alert when trying to use the Smart Road intersection's crosswalk area.

Table 7. Use Case 6: Overspeed Detection

Scenario Elements	Parameters
Use Case Goal	Notify pedestrians that an overspeeding vehicle is approaching.
Scenario Implementation	NEC Video Analytics detects overspeeding vehicles based on surveillance footage transmitted via 5G radio. VTTI will use the UDP data packets received from NEC Video Analytics software to encode into an SAE J2735 TIM message (alert) to be broadcasted from C-V2X RSU to OBU. Pedestrian Mobile HMI's OBU will receive the warning (SAE J2735 TIM message) and will decode and generate the proper HMI warning.
KPI	- Time from detecting a target vehicle to displaying the notification on the Pedestrian's Mobile HMI. Less than + 1 sec from time to collision (TTC ~ 4 seconds) - Detectable speed: more than 60 km/h (configurable) / 37.5 mph based on coverage - Detection rate: 80% (target: more than 90%)



VTTI completed the following activities and deliverables under Task 4:

- Use case specification document that includes key players, data logging procedure, output data set, and analysis results.
- Testing specification document.
- Use case execution and data collection.
- Post analysis for latency and system performance metrics generation.

Task 5: Final Report and Press Release

Under this task, the VTTI team prepared and shared all the data logs collected during Task 4 and provided metrics related to the 5G technology performance, including reliability, latency, and accuracy from NEC's Video Analytics software application to the vehicle's HMI and portable display devices. Figure 6 shows the data flow from the sensor device to the vehicle's HMI or portable display devices. VTTI inserted timestamps at specific locations, including RSU, OBU, and HMI devices, for latency calculation and alert detection accuracy.

Based on the data and analysis, the VTTI team prepared a solution model for the Virginia Department of Transportation (VDOT) and the National Landing project based on their requirements. This solution model served as an input for VTTI and NEC to plan the next step of this project—commercial implementation in VDOT and National Landing.

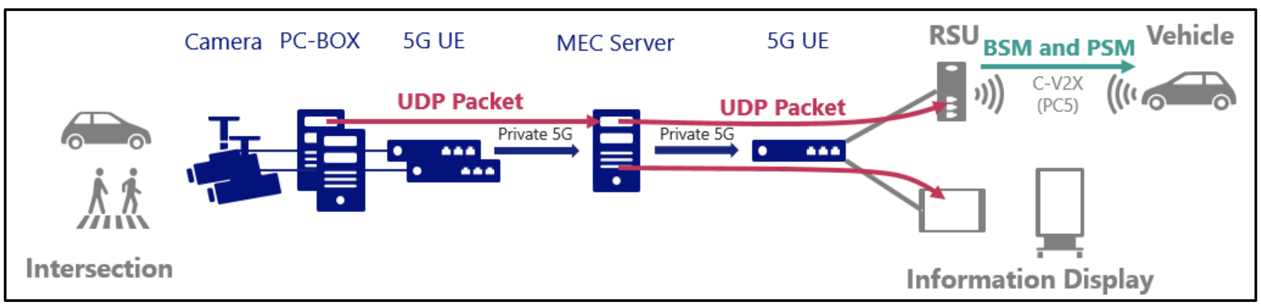


Figure 6. Diagram. Packet flow from Video Analytics to HMI devices.

Task 5 also included a press release effort that was a collaboration between NEC and the VTTI team. In addition, VTTI prepared a showcase video for NEC Private 5G technology based on the use cases from Task 4.

Results

System Integration

The hardware implementation for this project consisted of three primary efforts: mounting the RU to the intersection cantilever beam, installing computing and communication components with proper environmental protections, and designing and building a pedestrian warning system.

RU Mounting

The team at VTTI was asked to provide a vertical pole between 1.5 and 3 inches in diameter and between 40 and 60 inches long mounted to the intersection cantilever beam to hold up the pole-mounted RU. A custom aluminum and durable plastic bracket were used to tighten the tapered beam, while rubber-cushioned U-bolts and two straight bolts affixed the vertical pole to the bracket.

Figure 7. Photos and illustrations. RU mount and installation.

Computational and Communication Hardware Enclosures

From Table 1, The VTTI team was tasked with enclosing the Smart Road traffic intersection's hardware components into a weatherproof enclosure.

The initial design was composed of four boxes, two per pole, with most components in the primary boxes mounted on two DIN rails and the two large graphics processing units (GPUs) affixed to a back plate. The primary boxes also were designed with the implementation of active air exchange for cooling. However, the client wished to maintain a higher environmental ingress protection rating, so the intake and exhaust fans were omitted. The primary boxes were further supported by adjustable aluminum bases to accommodate the weight of the single box.

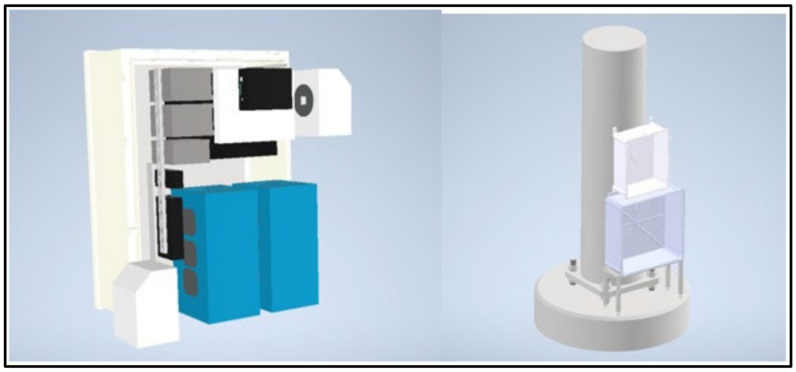


Figure 8. Illustration. Intersection enclosure setup.

As the installation date approached, shipment of the large primary box continued to be pushed back due to supply chain issues related to the COVID-19 pandemic. As a secondary course of action, the primary box was split into two smaller boxes, as shown in Figure 8, for a total of three boxes per pole.

Pedestrian Ground HMI

The VTTI team was tasked with designing a way to notify a crossing pedestrian of a crossing vehicle. The team installed high-brightness LED panel arrays into modified cable ramps that could display messages using color and shape to pedestrians looking downward who were possibly distracted by a smartphone or something similar. This mock-up could represent in-ground LED arrays or lead to a more refined weatherproof unit currently being developed (Figure 9).

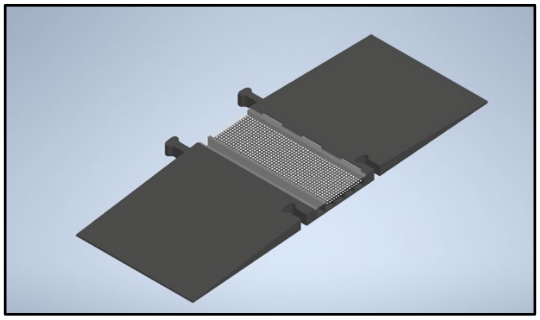


Figure 9. Illustration. Pedestrian HMI.

Private 5G Implementation

Private 5G Radio Setup

The VTTI and NEC teams configured the Private 5G hardware using the specifications shown in Table 8. Following Federal Communications Commission experiment approval, the equipment was tuned to specifically use the frequency band from 3,400.195 to 3,500.165 MHz. The VTTI team supported the Smart Road intersection hardware installation shown in Figure 10. The VTTI team also developed all necessary software interconnectivity between the Private 5G network and VTTI's C-V2X RSU network. C-V2X technology was used to broadcast the alerts to vehicles and pedestrians when a specific scenario was detected.

Table 8. Private 5G Specifications

Parameters	5G RU (Radio Unit)	5G UE (User Equipment)
Model	RHON-7800	iR730B
Unit Quantity	2	5
Frequency Band	3.4-3.5GHz	3.4-3.5GHz
Radiated Power	38dBm, EIRP, Peak	24.5dBm, EIRP, Peak
Station Class	Fixed	Fixed
Emission - Mod. Type	X	X
Signal Nature	7	7
Info.Type	W	W
Modulation Signal	OFDM	OFDM
Necessary Bandwidth	100 MHz	100 MHz

Figure 10. Photos. VTTI Smart Road 5G installation.

Private 5G Network Performance

Another essential performance metric for the Private 5G network is the bandwidth and ping roundtrip time (RTT), as shown in Table 9. The Private 5G network provides ultra-low latency, which is important for critical safety applications, and enough bandwidth to transfer sensor data from the Smart Road intersection to VTTI's data center, where the Video Analytics software resides.

Table 9. Private 5G Network Performance

Test Ues	Items	Test Results
5G UE#1	TCP Uplink TCP Downlink ping RTT	123.6 Mbps 72.3 Mbps 49.1 msec
5G UE#2	TCP Uplink TCP Downlink ping RTT	127.5 Mbps 91.8 Mbps 50.4 msec

Use Case Evaluation

The VTTI and NEC teams executed the 138 scenarios involving different vehicle types, motorcycles, and pedestrians. Table 10 shows the final testing results for all six use cases. The average notification time is 144 ms, with a 96% detection rate.

Table 10. Use Case Testing Results

No	Use Cases	KPI	Applicable Scenarios	Result of 5G/Video System
1	Collision Prediction	The system notifies HMI within 1 sec Detection rate: 80% or more	Priority-1: 65,75,82, 105 Priority-2: 18,28,34,36,77,78,79,80	Passed Avg. Notification Time: 125 ms Detection Rate: 100%
2	Stree Parking Notification	The system notifies HMI within 1 sec Detection distance: 40m from the camera Detection rate: 80% or more	Priority-1: 113, 115, 118, 120 Priority-2: 114,116,117, 119	Passed Avg. Notification Time: 142 ms Test Distance: 45m Detection Rate: 88%
3	Traffic Accident Detection	The system notifies HMI within 1 sec Detection rate: 80% or more	Priority-1: 126,127,129,131 Priority-2: 125,128,130	Passed Avg. Notification Time: 159 ms Detection Rate: 89%
4	Pedestrian Crossing Detection	The system notifies HMI within 1 sec Detection distance: 20m from the camera Detection rate: 80% or more	Priority-1: 1,7,9,15 Priority-2: 3,5,11,13	Passed Avg. Notification Time: 137 ms Test Distance: 40m Detection Rate: 100%
5	Vehicle Detection for Right & Left Turns	The system notifies HMI within 1 sec Detection rate: 80% or more	Priority-1: 138 Priority-2: 132,133,134,135,136,137	Passed Avg. Notification Time: 162 ms Detection Rate: 100%
6	Overspeed Detection	The system notifies HMI within 1 sec Detection rate: 80% or more	Priority-1: 121,122,123,124	Passed Avg. Notification Time: 121 ms Detection Rate: 100%
			Total	Avg. Notification Time: 144ms Detection Rate: 96%

Discussion

The VTTI and NEC teams collaborated on the Private 5G network deployment and the edge/MEC server installation on VTTI grounds. Alert triggering was successfully tested for vehicle and pedestrian detections using C-V2X technology. Figure 11 shows how the data travels from the sensor source (camera) to the edge, MEC, and VTTI's C-V2X network. The average end-to-end notification time is around 350 ms.

The VTTI and NEC teams identified improvement opportunities for latency on 5G and C-V2X data transportation channels. The VTTI team will improve the gateway to RSU latency by enhancing the user datagram protocol (UDP) packet forwarding from VTTI's Angelica Server (Gateway) to the C-V2X RSU. The NEC team plans to improve the data upload/download bandwidth and latency between the UE and RU at the VTTI Smart Road traffic intersection in the second phase of this project.

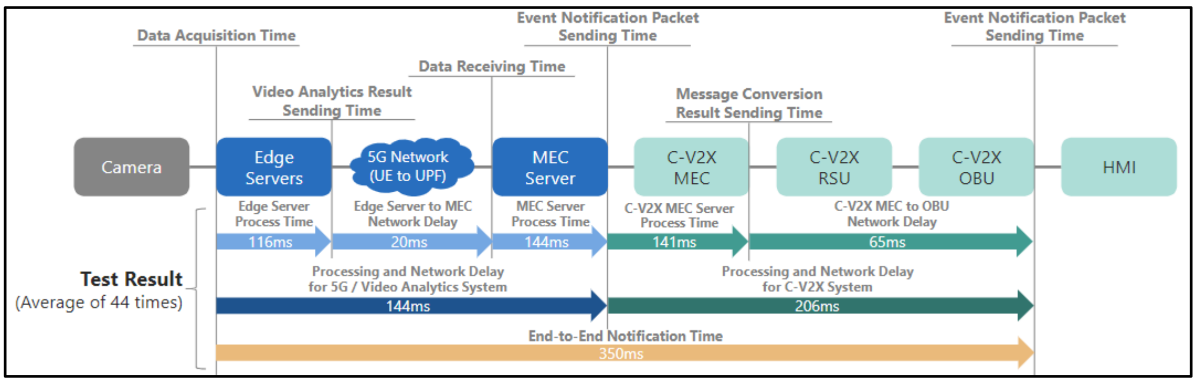


Figure 11. Diagram. Private 5G notification travel time.

After testing the alert HMI for pedestrians (the surface-mounted LED board), the research team has discussed improving the alert colors to better suit color-blind road users, especially those with red-green color blindness, and also implementing an auditory alert for blind and low-vision pedestrians for whom a visual notification would be ineffective.

Based on our testing results in latency and video analytics outputs, the NEC Private 5G network and software application provides reasonable latency (~144 ms) to alert vehicles and pedestrians for intersection-related situations. This latency is comparable to other safety application latency, such as dedicated short-range communications/C-V2X. In addition, the Private 5G network provided bandwidth to forward camera stream to VTTI's data center, where NEC's MEC server resides and has live remote desktop capabilities to all four edge servers deployed at the VTTI Smart Road intersection.

Conclusions and Recommendations

This project consisted of a Private 5G network implementation for traffic intersection safety for road users, including vehicles, motorcycles, and pedestrians. The Private 5G network allows ultra-low latency communications between multiple cameras installed around the intersection and the edge and MEC servers to run video analytics for alert generation based on six specific use cases:

1. Collision prediction
2. Street parking notification
3. Traffic accident detection
4. Pedestrian crossing detection
5. Vehicle detection for right and left turns
6. Overspeed detection

The total system latency for this phase of testing was approximately 350 ms, i.e., from the time the event actually started to when pedestrians and vehicles would receive the alert. Although the research team was encouraged by the achieved latency, every second counts for safety-critical alerts such as these. Therefore, improvements would increase the effectiveness of such alerts.

The VTTI team analyzed different aspects of the Private 5G system deployment and provided some improvement opportunities to help migrate the system installation in an actual traffic intersection. The more essential enhancements are the following:

- Reduce calibration time for actual traffic intersection deployment.
- Reduce the hardware footprint by combining GPU-based platforms.
- Provide an API to access Video Analytics metrics in real-time.
- Improve detection and alert generation to be within the 100 ms time window.

The NEC and VTTI teams will work on the second phase of this project. The main goal is to address the latency by enhancing the Video Analytics software engine and improving the intercommunication between the Private 5G Network and VTTI's C-V2X network.

Additional Products

The education and workforce development and technology transfer products created as part of this project are described below and are listed on the Safe-D website here. The final project data set is located on the Safe-D Dataverse.

Education and Workforce Development Products

The following are the conducted education and workforce development procedures.

Planned Learning Modules

A PowerPoint presentation was developed that describes the current implementation of the 5G and C-V2X/PC5 smart intersection technology that can be used to educate industry and DOT partners. The presentation addresses the value of the 5G implementation, including how it provides lower latency and higher bandwidth communications, which are required to support the temporal requirements of safety applications. The presentation is designed to be delivered as a short 12- to 15-minute discussion that can be used to describe the local implementation while educating about the value of 5G technologies.

Student Funding

This project was leveraged to provide a meaningful, experiential learning experience for a graduate student at Virginia Tech. The student was funded on a 6-month graduate research assistantship and focused on helping to validate data during testing, design, and orchestration of the demonstration; develop talking points for the promotional video; conduct the demonstration; and write the final report and conference paper. The project provided exposure to early-stage 5G deployment in an applied setting.

Other Activities

The student-led demonstration section showcases the 5G and C-V2X/PC5 smart intersection implementation on the Smart Road during the Commonwealth Cyber Initiative Technology Showcase event that occurred in Blacksburg, VA, in the spring of 2022. The student helped to educate transportation and cybersecurity professionals about the details of the implementation and the performance and security implications.

Table 11. Education and Workforce Development Checklist Table

Education and Workforce Development Activity or Product	Date Expected	Completed?
Participate in the design and conduct of the Smart Road demonstration of the 5G smart intersection implementation.	2/15/2022	Yes
Write technical paper describing the 5G deployment on the Smart Road intersection and the value the low latency, high bandwidth communication brings to the demonstrated applications.	4/25/2022	Yes
Develop a PowerPoint presentation that educates industry and DOT partners about the value of 5G implementation for smart intersection safety applications.	6/1/2022	Yes
Lead a demonstration section that showcases the 5G and C-V2X/PC5 smart intersection implementation on the Smart Road during the Commonwealth Cyber Initiative Technology Showcase event.	6/15/2022	Yes

Technology Transfer Products

The technology developed and tested throughout this project demonstrates to the industry how 5G technology can provide the required data exchange bandwidth and low-latency communications to support smart intersection technologies. The resulting technology demonstration, publication, and webinar activities showed the 5G, OEM, and infrastructure owner-operator (IOO) communities the value of the 5G implementation.

Planned Stakeholder Involvement

The project team collaboratively developed the project plan with our industry partner, NEC. NEC expressed interest in using the resulting research products of this project to support their efforts to promote broader 5G implementation. Masahiko (Mack) Nakagawa, Vice President of NEC Corporation of America, served as our project champion and agreed to keep our team engaged with both the NEC North America personnel and the core technical teams in Japan. During the University Transportation Center (UTC) proposal and statement of work generation, the project team met regularly with NEC to exchange the necessary architectural and technical information to define a system that could be deployed on the Virginia Smart Road intersection. Upon beginning this project, the VTTI team held a kickoff meeting with NEC and subsequently held biweekly technical meetings with their team to indicate progress and receive feedback from them. The project team worked with NEC to develop a demonstration video that shows the system and discusses the value of 5G in the implementation.

Planned Technology Transfer Activities and Products

The following technology transfer activities and products were executed in this project.

- On-Road Demonstration: The project team conducted an on-road demonstration on the Virginia Smart Roads and captured video and project team member interviews. The video was edited and provided to NEC to support their efforts to promote 5G implementation.
- UTC Webinar: The project team developed a webinar presentation to be presented during a UTC webinar session. The presentation includes showing the demonstration video and is marketed to OEMs, IOOs, telecommunications groups (5GAA, MEC4Auto, etc.), and UTC stakeholders.
- Publications: A conference paper was developed and submitted for publication at a relevant industry conference, which was determined after the evaluation of the results.
- The project team regularly met with IOO/OEM, Connected Vehicle Pooled Fund Study, and other industry working groups and actively sought out opportunities to update members on this project.
- The project team actively sought out opportunities to follow up on this project with potential deployment on selected VDOT-controlled intersections in Northern Virginia.

Data Products

The data uploaded to the Dataverse includes over 10,000 data points collected at the VTTI Smart Road running different use cases that triggered alerts to the C-V2X vehicle and pedestrian HMIs. The collected data set includes data entries for several road users detected by the cameras and classified as vehicles, pedestrians, motorcycles, or bicycles. Each packet (UDP) contains timestamp data, object location, scenario (use case) number, and debugging fields used during testing at VTTI’s Smart Road. The data set can be accessed on the VTTI Dataverse here: https://doi.org/10.15787/VTT1/OH9JG0.

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Appendix A: Radio Propagation Simulation

Figure 12 shows a simulation for the Private 5G radio coverage around VTTI's Smart Road intersection. This simulation confirms the entire range between the RUs and UE units used in the deployment and ensures an excellent signal-to-noise ratio between the devices.

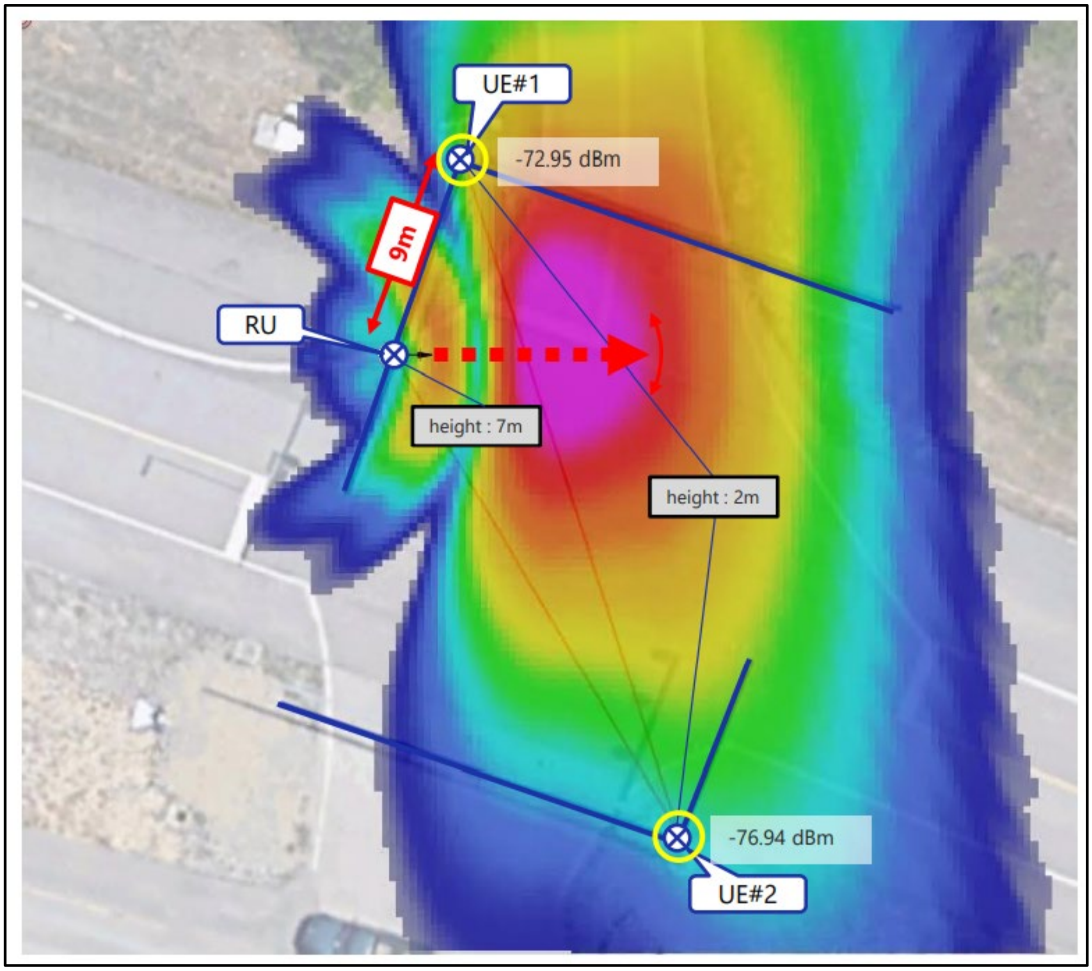

Figure 12. Map. Radio propagation simulation.