T-MOBILE
FOR GOVERNMENT

NAVIGATING THE INTERSECTION:

VEHICLE-TO-EVERYTHING TECHNOLOGY CAN MAKE PEOPLE AND TRAFFIC SAFER.

Prevent pedestrian fatalities and serious injuries by using a T-Mobile 5G cellular network.

In 2023 alone, 40,990 people died due to motor vehicle traffic collisions on U.S. roads and highways[1]. While it's a 3.6% decrease from 2022, it's still a drastic uptick from traffic deaths at pre-pandemic levels.

As cities and technology advance, we need to effectively identify ways to leverage these innovations to keep our residents, commuters, and visitors safe. **It's possible with vehicle-to-everything (V2X) communication powered by the strength and consistency of our 5G network.**

This whitepaper addresses how connectivity—specifically network V2X—can improve safety-aware applications in technology forward or aspiring cities.

KEY HIGHLIGHTS INCLUDE:

- Defining safety-aware applications
- Understanding network V2X vs. direct V2X
- The role of latency
- The consequences of not doing something now
- Network V2X solutions and use cases
- Real world example: City of Bellevue

DEFINING SAFETY-AWARE APPLICATIONS

Before diving in, let's clarify what safety-aware applications are. The main difference between failures in safety-critical and safety-aware applications lies in their outcomes. Failures in safety-critical applications can result in death or serious injury, whereas failures in safety-aware applications lead to less severe consequences.

EXAMPLES INCLUDE:

- Lane closure signs
- Wrong way signs
- Excessive speed warnings
- Pedestrian crossing warnings

NETWORK V2X VS. DIRECT V2X

Both network V2X and direct V2X communication use wireless technology to enhance safety by enabling vehicles to connect with their surroundings.
Now let's discuss their differences.

DIRECT V2X

Direct V2X uses short-range direct radio-to-radio wireless communication for real-time, safety-critical applications that operate independently of cellular networks. Direct V2X communication uses a dedicated 5.9 GHz Intelligent Transportation System spectrum, requiring specialized 5.9 GHz radios in vehicles and public infrastructure. This direct communication path typically results in lower latency compared to network-based approaches.

Since vehicles and infrastructure require dedicated radios, the costs can add up quickly with these applications.

NETWORK V2X

Network V2X leverages existing cellular networks for wide-area communication—offering a range of services. It communicates via a mobile network operator licensed spectrum, providing an extended range of several kilometers. Network latency in V2X is slightly higher than direct V2X.

Network V2X offers cost efficiencies by working with existing technology, eliminating the need for additional infrastructure installations.

THE ROLE OF LATENCY

Latency is the time it takes for data to transfer across the cellular network from start to finish. Low latency is critical because it enables near-instantaneous transmission of data or information. As latency decreases, communication is nearly instantaneous.

LATENCY OVER CELLULAR NETWORK GENERATIONS

Measured in milliseconds (ms).

3G cellular network: 100 ms to 300 ms

4G cellular network: 25 ms to 100 ms

5G cellular network: 15 ms to 50 ms

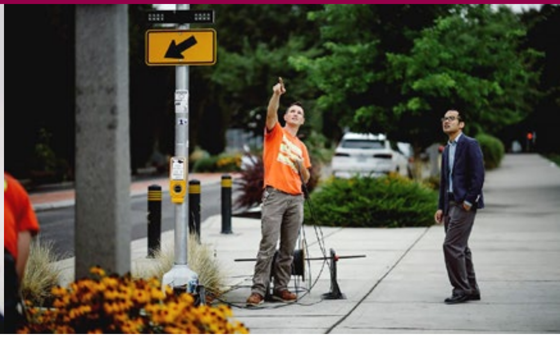
5G technology's ultra-low latency has enabled new possibilities for highly interactive and time-sensitive applications, such as autonomous vehicles and critical IoT devices. Leveraging the speed and reliability of T-Mobile 5G makes network V2X a viable option for seamless interactions in safety-critical applications.

WHY YOU SHOULD ACT NOW

As local or municipality managers identify ways to drive efficiencies and keep their cities safe, technologies like network V2X should be a high-priority decision. Failing to act now may result in missing the benefits of modern urban living and, more importantly, compromising the safety of your citizens. You could also miss out on cost savings from efficiencies offered by connectivity and smart infrastructure applications.

SUCCESS STORY:
BELLEVUE, WASHINGTON





Bellevue is a shining example of how a technology-forward city can use the power of 5G from T-Mobile alongside network V2X to enhance pedestrian safety while staying within budget.

Opportunity

The city of Bellevue is a Vision Zero community that was looking for ways to reduce traffic-related fatalities. It needed a tech partner with an extensive network and testing capabilities to help city leaders make their case for a Safe Streets and Roads for All grant (SS4A).

Solution

Bellevue partnered with T-Mobile in 2022 to develop three use cases with safety alerts that integrate 5G technology and network V2X communication for the following use cases.

- **Slow speed zone**
- **School beacon**
- **Mid-block pedestrian crosswalk**

Result

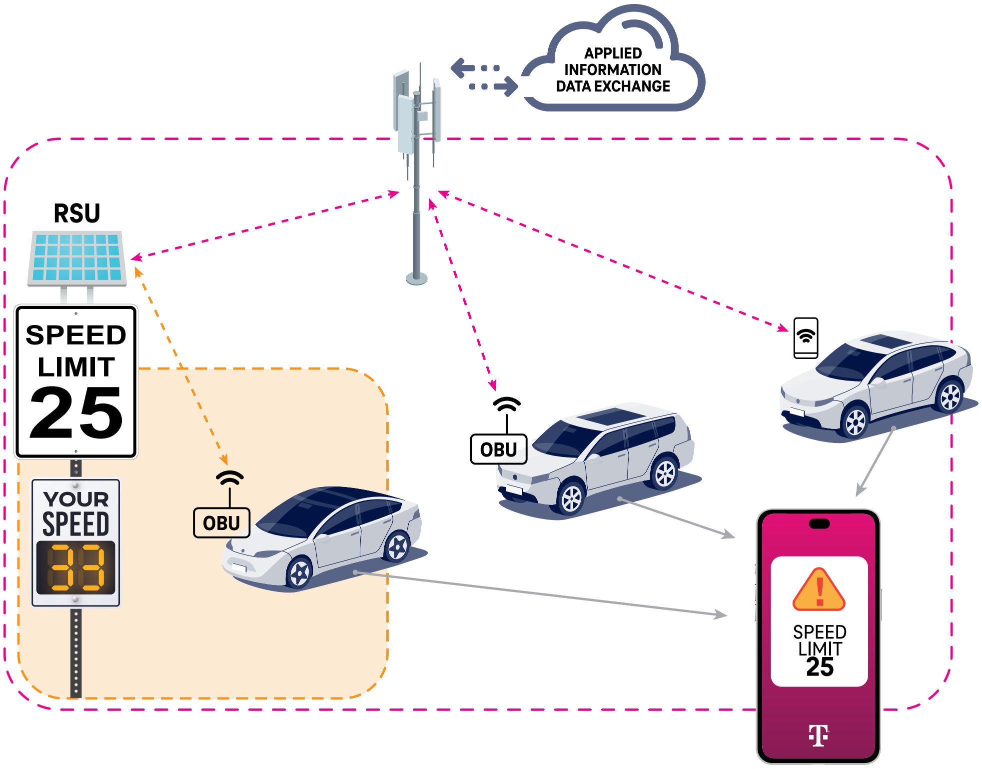
By successfully building a case for network V2X technology in safety-aware applications, the City of Bellevue secured $2.787 million in SS4A federal funding in December of 2023.

EXAMPLES OF NETWORK V2X SOLUTIONS

Bellevue submitted three examples of network V2X solutions as part of its SS4A grant application: Slow speed zone, school zone beacon, and mid-block crosswalk.

Slow speed zone

Bellevue installs radar speed feedback signs. A T-Mobile 5G cellular network enables geofenced coverage for the vehicle and app. Vehicles entering the path receive a speed limit alert via the app at a farther distance than without it. This allows the driver to slow down well before reaching the radar speed feedback sign.



School zone beacon

Bellevue sets school beacon alert times and determines a geofenced location for the school zone. The T-Mobile network enables the transmission of excessive-speed messages to vehicles entering the zone. The driver receives the message via the app and can slow down before arriving at the beacon and approaching parents and children.

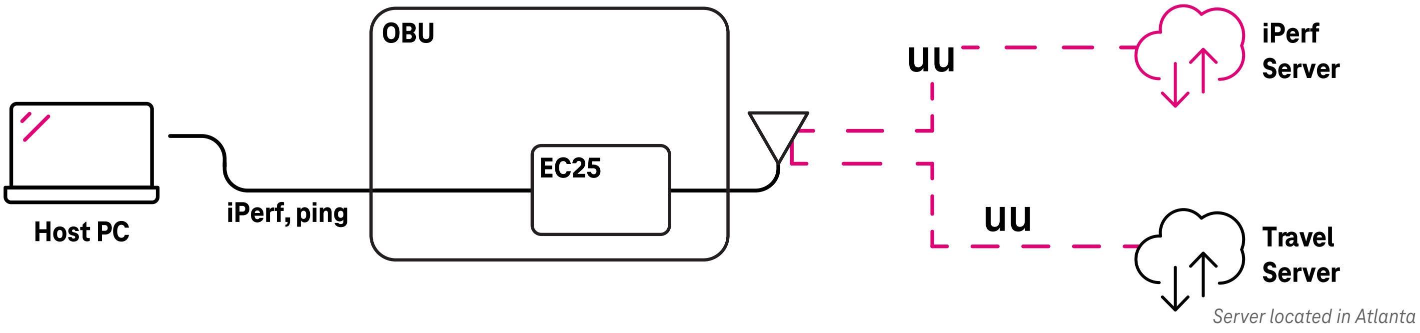
Mid-block crosswalk

A pedestrian pushes the crosswalk button. Then, the roadside unit sends an alert over the T-Mobile network to the vehicle entering the path via the app, giving the driver time to slow down before reaching the pedestrian crossing.

THE LATENCY TEST: NETWORK V2X VS. DIRECT V2X

NETWORK V2X

We conducted a network V2X test incorporating an onboard unit and cellular device to gauge latency levels.



Setup

The onboard unit (OBU) had a cellular modem with a T-Mobile SIM card inside. The OBU communicated with any roadside unit (RSU) within its coverage radius. The RSU had a cellular modem that communicated with the cellular tower (Uu), just like a normal cell phone.

The cellular tower was located near the destination server—like the iPerf server, which is commonly used to measure how well a network can handle traffic under different conditions, including varying bandwidth and network latency. Or the iPerf server was far and reachable through the public internet like the applied information data exchange/travel safely server*. The iPerf server was not part of the deployment but was used to measure latency in isolation of the internet. The server provided the intelligence to identify users to share messages with and notify road users of the relevant message. We deployed devices at approximately 11 locations around Bellevue—including the pedestrian crossing at the park downtown.

Test

Latency was measured when the cellular modem inside the OBU communicated through the cellular tower and then to either of the two servers to capture network differences.

We captured measurements from multiple devices across the 11 locations. These locations included deployments for various scenarios around the city, including midblock pedestrian crossings, intersections, school zones, and slow speed zones.

Uu Latency

Device Type	Device Count	Destination	Sample Size	Latency (ms) Round Trip Time.			Loss %
				Min	Avg.	Max	
RSU/OBU	11	iPerf Server	3000	30	76	841	0.08
RSU/OBU	11	Glance Server	3000	102	133	434	3.58
Phone (S20)	1	iPerf Server	200	26	47	133	0
Phone (S20)	1	Glance Server	2100	98	109	270	3.67

Results

Network V2X latency rivaled that of cellular devices—even with a more distant server. While closer servers yielded slightly better results, overall latency remained remarkably similar to the mobile device. With only one-fifteenth of a millisecond loss in communication.

*Applied information data exchange = company providing the infrastructure. Travel safely = their software application.

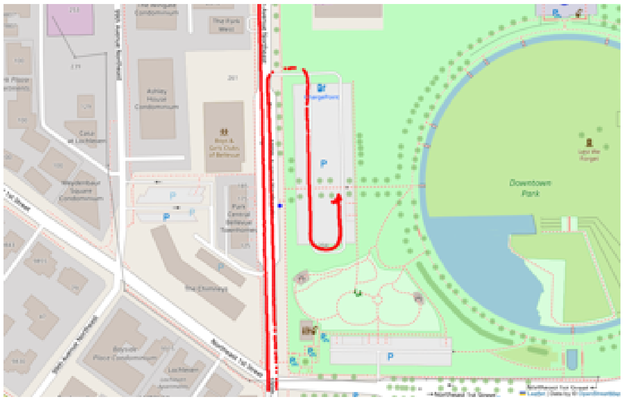
DIRECT V2X

We conducted a direct V2X test with a wireless modem to gauge latency levels and identify communication gaps in a dense urban area.

Setup

We installed a direct V2X wireless modem in a vehicle located in a densely populated downtown park. In the inset map, the roadside unit is depicted with a blue dot, and the red line is the route.

GPS Plot



Summary for TX Equipment ID 95
Packet count: 1397
Test duration: 00h 06m 25s 517ms
Latency log (ms): min 7.56, mean 17.07, max 48.9, 99 percentile 40.12, null 0
IPG calculated (ms): min 65.54, mean 276.16, max 60976.03
PER calculated: 63.77%

Test

The car drove the route within the park and received roadside unit messages along the way. We wanted to observe if there would be communication gaps. Breaks in the red line represent communication gaps when the vehicle did not receive RSU messages as it traveled along the route.

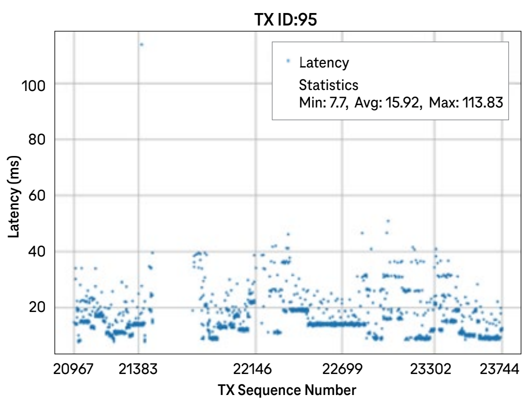


Figure 1: The x-axis represents the sequence number of received packets. The sequence numbers are generated at the transmitter side. They are incremented by 1. This figure shows the sequence numbers in the x-axis. The y-axis represents round-trip latency. A communication loss is represented by a gap in the data points on the axis, which are the same gaps as those in the red line in the map above.

Results

As the car continued its route, it lost data when it entered the dense urban environment. Out of the received packets, 80% were received within 20 milliseconds (ms), whereas 100% were within 40 ms. Although direct V2X is known for its low latency, there were still prominent gaps in coverage.

OVERALL ANALYSIS:
NETWORK AND DIRECT V2X TESTS

Despite the higher latency, network V2X can still facilitate vulnerable road user (VRU) safety use cases in slower-speed environments. To put this in perspective, see the graph below, which depicts a car going 30 mph with network V2X vs. direct V2X. (Note that 30 mph translates to 44 feet.)

TYPE OF COMMUNICATION	LATENCY	TIME (seconds)	SPEED (feet/second)	DISTANCE TRAVELED (speed x time)
DIRECT V2X	20 ms	0.02 seconds	44 feet	0.88 feet
NETWORK V2X	125 ms	0.125 seconds	44 feet	5.5 feet

While the difference is measurable, it doesn't compromise critical safety features and is imperceptible to human reaction times—both time intervals fall within the average duration of a human eye blinking (100–400 ms).

Range is another important factor and opportunity for network V2X. Some applications or use cases are sensitive to range and not to latency. Direct V2X's coverage range is within a radius around the RSU. The farther you get from the RSU, the more you'll lose communication. Network V2X allows you to receive communication from anywhere that has network connectivity using cellular towers or other connectivity means.

Overall, there's value in having both direct and network V2X in safety-aware applications. Smart cities that are more budget-conscious should consider network V2X since there is only a millisecond difference in latency—all while saving resources by using technology already available.

CONCLUSION

Network V2X, backed by America's largest 5G network from T-Mobile, can strengthen your safety-aware applications, protect vulnerable road users, and prevent pedestrian fatalities on city streets.

Our partnership with the City of Bellevue highlights what network V2X can do—and it doesn't stop here. As more cities adopt advanced 5G technology, it will enable opportunities for advancement and innovation within the safety-aware space.

4 KEY TAKEAWAYS

- **Traffic deaths are still a critical concern for cities everywhere.**
- **Network V2X technology is an advanced 5G, cost-effective option.**
- **The ultra-low latency of our 5G cellular network can support safety-aware applications.**
- **Opportunities for network V2X include slow speed zone, school zone beacon, and mid-zone crosswalk.**

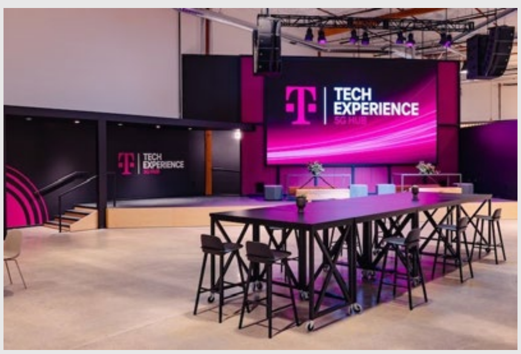
POWER THE FUTURE OF CITY INFRASTRUCTURE
WITH OUR NETWORK.

Partner-centered approach

Expertise in network applications

Custom solutions

Ecosystem partners



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1: National Highway Traffic Safety Administration, 2024: https://www.nhtsa.gov/press-releases/2022-traffic-deaths-2023-early-estimates#:~:text=The%20agency%20estimates%20that%20 40%2C990,the%20second%20quarter%20of%202022.

2: MVNO, 2024: https://mvno-index.com/the-latency-of-the-different-mobile-networks/