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Traffic Control and Vehicle-to-Everything (V2X) Communications

How V2X improves driving safety and traffic flow

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As the number of vehicles increases, traffic accidents and waste of resources due to congestion are consistently growing every year. Cellular Vehicle-to-Everything (V2X) is a key technology improving driving safety and traffic efficiency by enabling traffic elements such as vehicles, roadside infrastructures, networks, and pedestrians to communicate with each other. Dynamic interactions between traffic elements ultimately facilitate intelligent autonomous driving. The 3rd Generation Partnership Project (3GPP) Technical Specification Group has developed a series of standards for cellular V2X features and is working on continuous enhancements for higher reliable and low latency communication. This paper provides an overview of cellular V2X use cases and 3GPP standardization, and summarizes the impact of the V2X technology.

1 Traffic Management

1.1 Why Vehicle Communication?

Vehicle communication systems have emerged as a key driver and accelerator to increase safety, capacity, and efficiency in transportation systems.

The U.S. Department of Transportation (US-DOT)'s National Highway Traffic Safety Administration (NHTSA) released fatal traffic crash data in 2016[1]. The data reports that 37,461 people were killed in crashes on U.S. roadways during 2016, a 5.6% increase from 35,485 in 2015 and a 14.4% increase from 32,744 in 2014. Despite improvements of vehicle safety, the number of traffic fatalities is growing.

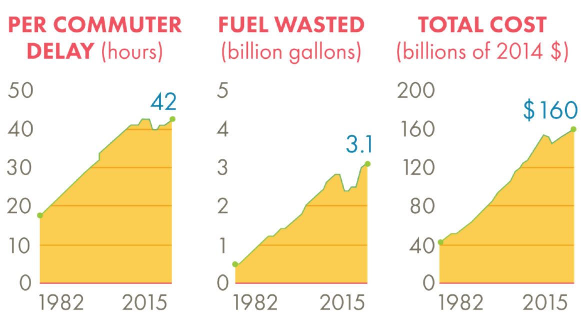

Figure 1: Congestion continues to climb.

Moreover, according to the 2015 Urban Mobility Scorecard by Texas A&M Transportation Institute[2], the increasing trend of traffic congestion has continued since a temporary easing in 2008, likely due to effects from the Great Recession. The institute projects that the total nationwide delay time will grow to 8.3 billion hours by 2020, and congestion will cost $192 billion. This growth is outpacing the investment in infrastructure and programs to address the increased demand on the transportation network. Traffic congestion is a drain on further economic growth. The deterioration of the transportation environment, despite unceasing efforts such as safer vehicles and a large amount of investment, means new solutions are essential.

V2X communications save lives, reduce congestion, and lessen the negative impact of transportation on our environment.

In this perspective, vehicle communication provides fundamental solutions. Wirelessly connected vehicles communicate with each other, roadside infrastructure, and personal mobile devices. This communication enabling valuable information sharing saves lives, reduce congestion, and lessen the negative impact of transportation on our environment.

"Cooperative Safety Control" utilizing interactions among vehicles reduces the possibility of traffic collisions by avoiding human errors. "Traffic Flow Optimization" based on wireless communication technologies relieves congestion. Surrounding traffic data collected via a radio interface contributes to fully "Autonomous Driving" considering the safety and traffic environments.

1.2 Limitations of Existing Technologies

To enable vehicle communications, the US-DOT is expected to mandate that vehicles manufactured in late 2019 and beyond deploy dedicated short-range communication (DSRC) devices[3]. DSRC is a standard, designed by the Institute of Electrical and Electronics Engineers (IEEE) to support vehicle communications, mainly focused on vehicular safety features.

However, DSRC has several limitations. First, the system relies on Road Side Units (RSUs), which are not currently deployed. Second, the physical (PHY) layer of DSRC, defined in IEEE 802.11p, has inefficiencies due to the asynchronous nature of the system, resulting in reduced performance. Finally, there is currently no significant effort (or IEEE 802.11 standards activities) to improve the DSRC PHY/Medium Access Control (MAC) layers with respect to range, robustness, and reliability.

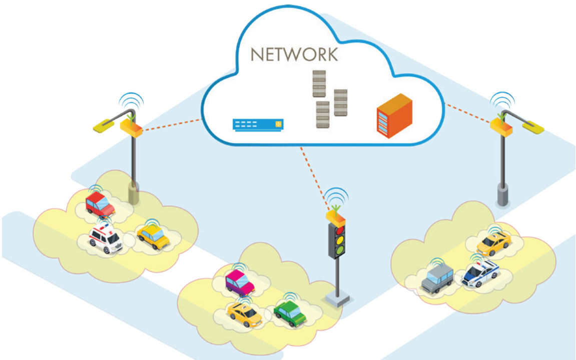

Figure 2: DSRC connection to the network and road side units (RSUs).

Many V2X use cases require vehicles to communicate with networks that distribute and manage digital security certificates for vehicles as shown in Figure 2. In the case of DSRC, this means that vehicles need to have access to networks provided via the RSU. The RSU is essential for vehicles to communicate with the V2X application server. Due to various factors, the deployment of RSUs has been limited. It is unrealistic to expect the provision of ubiquitous coverage via DSRC in the near future.

Fortunately, a complementary technology, LTE and 5G cellular systems have the potential to support existing DSRC use cases, and more challenging and futuristic features that require low-latency, high reliability, or high bandwidth.

1.3 Cellular V2X Solutions

Cellular Vehicle-to-Everything (V2X) leverages and enhances existing LTE features (e.g. machine type communication, device-to-device communication, and broadcast/multicast) to facilitate the exchange of messages among traffic elements, such as vehicles, networks, roadside infrastructures, and pedestrians. LTE cellular networks already cover nearly the entire U.S. area. Additionally, LTE networks extend the V2X communication range from 300 meters, which DSRC can achieve, to several kilometers or more.

By establishing radio link connections between different types of traffic elements, V2X provides safe, efficient, and environmentally conscious transportation, and paves the way to connected and autonomous driving.

This extended range can provide earlier notifications of accidents, road conditions, and traffic congestion. The cellular V2X system is being designed with radio layer and architectural enhancements that support existing use cases, as well as more complex safety use cases with stringent delay, reliability, and bandwidth requirements.

Cellular V2X communication defined in 3GPP includes four types of communication: vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-network (V2N), and vehicle-to-pedestrian (V2P). In V2I communication, the infrastructure can include an RSU, which extends the network range by acting as a forwarding node, or operate as a traffic control device. By establishing radio link connections between different types of traffic elements, V2X provides safe, efficient, and environmentally conscious transportation, and paves the way to connected and autonomous driving.

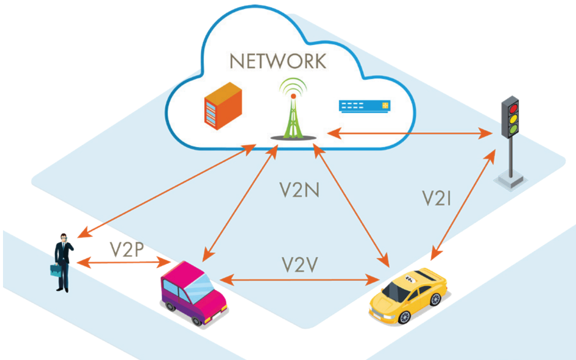

Figure 3: Types of Vehicle-to-Everything (V2X) communications.

2 Use Cases

By employing reliable and low-latency interaction among traffic elements based on cellular V2X communication, traffic collision and congestion issues are expected to decrease. Traffic data collected from surroundings will enable a fully automated driving experience.

Currently, various application layer solutions for vehicles include network based navigation systems (e.g. Google maps and Waze) and push-to-talk communication. However, without improving system level implementations of cellular networks of the application layer, those solutions do not overcome fundamental latency and reliability limitations that prevent existing network systems from handling the urgent situations described in this section. Moreover, use cases requiring close interactions among various traffic elements may not be supported by application layer solutions.

The specific use cases and service requirements for the LTE and 5G V2X system are defined by ETSI[4] and 3GPP[5][6].

2.1 Cooperative Safety Control

Vehicle Status Warning

The Vehicle Status Warning use case includes vehicle detection of abnormal safety conditions (e.g. steering, braking, etc.) and signaling the associated dangers to others. For example, this use case includes vehicle signaling of hard breaking to followers of the vehicle in an emergency. Warning following vehicles limits the risk of accident and longitudinal collision. As shown in Figure 4, the danger signaling is broadcast to others via V2X decentralized notification messages. Surrounding vehicles and RSUs receive and process the V2X decentralized notification messages.

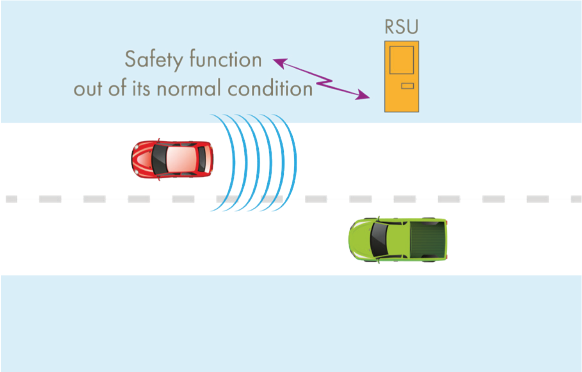

Figure 4: Vehicle status warning use case.

Traffic Hazard Warning

The Traffic Hazard Warning use case includes vehicle or road infrastructure alerting other approaching vehicles of immobilized vehicles (e.g. an accident, a breakdown, etc.) or current roadwork. This use case prevents collisions by helping vehicles to avoid a dangerously immobilized vehicle situation or roadwork. The alerts are broadcast via V2X decentralized notification messages.

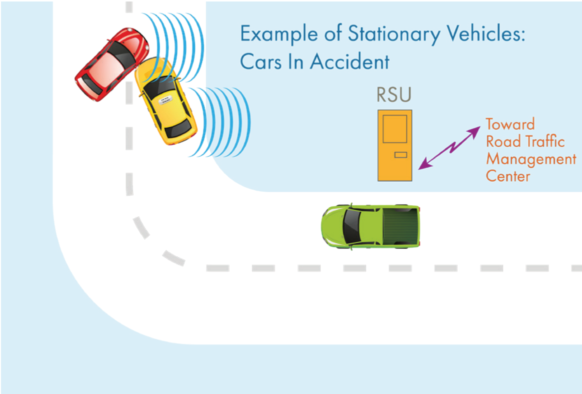

Figure 5: Traffic hazard warning use case.

Collision Risk Warning

The Collision Risk Warning use case includes informing a vehicle of approaching vehicles intending to turn across traffic. This feature mitigates the risk of collision at an intersection by warning vehicles in the affected area. An RSU detects and alerts two or more vehi-

The Collision Risk Warning mitigates the risk of collision at an intersection by warning vehicles in the affected area.

cles when there is a risk of collision between them. In Figure 6, the vehicle turning left and an RSU broadcast and/or relay the moving information of the vehicle via V2X cooperative awareness messages. The concerned vehicles receive the V2X messages and take relevant actions.

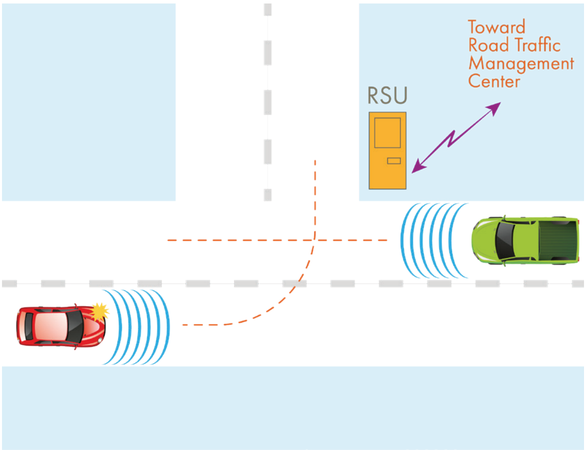

Figure 6: Collision risk warning use case.

2.2 Traffic Flow Optimization

Traffic Condition Warning

The Traffic Condition Warning use case allows vehicles and roadside stations to signal to other vehicles of current traffic conditions. This function helps drivers to choose the best route and leads to less traffic congestion, and brings environmental benefits by reducing energy consumption. To support the traffic condition warning use case, a vehicle or an RSU detects a traffic jam and broadcasts traffic information via V2X decentralized notification messages. Concerned vehicles receive and process the V2X messages, and forward the messages to other vehicles to support the long-range transmission of traffic information.

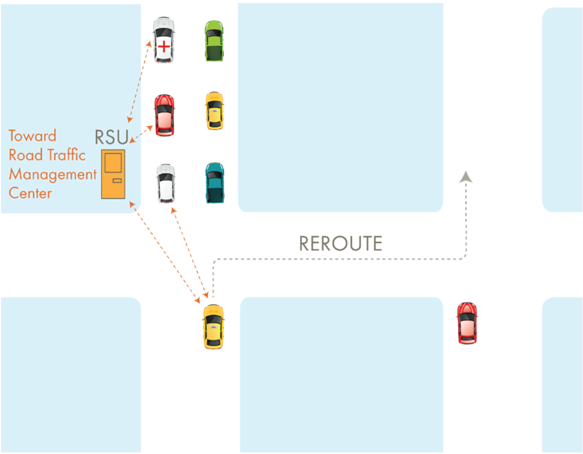

Figure 7: Traffic condition warning use case.

Cooperative Adaptive Cruise Control

The Cooperative Adaptive Cruise Control (ACC) use case uses unicast V2X cooperative awareness messages to obtain lead vehicle dynamics and general traffic ahead of a vehicle. This allows the vehicle to enhance the performances of its existing ACC. The cooperative ACC increases road safety and traffic efficiency. Further enhancement of this use case supports a platooning system on a highway or specific lane. Platooning of vehicles increases the capacity of roads, enabling fuel efficient driving and driverless cruising of following vehicles. Vehicles broadcast their capabilities and active driving state via V2X cooperative awareness messages. Following vehicles receive and process V2X cooperative awareness messages. Unicast sessions are established with other involved vehicles to exchange information.

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Extreme throughput, ultra-low latency, and enhanced reliability of 5G allow vehicles to share rich data in real-time, supporting fully autonomous driving experiences.

2.3 Autonomous Driving

Cellular V2X is a key technology enabling fully autonomous driving. While advancements in radar, light detection and ranging (LiDAR), and camera systems are moving autonomous driving one step closer to reality, these sensors are limited by their line of sight. V2X complements the capabilities of these sensors by providing non-line-of sight awareness, extending a vehicle's ability to see further down the road - even at blind intersections or in bad weather conditions through eyes of neighboring vehicles and infrastructures. Co-operative safety control and traffic flow optimization features enable isolated vehicles to interwork with their environments.

Technology evolution expands safety requirements and use cases for autonomous vehicles. The path to 5G delivers this evolution starting with cellular V2X defined in Release 14 and Release 15 of the 3GPP specification. Building upon cellular V2X, 5G brings expanded possibilities for connected vehicles. Extreme throughput, ultra-low latency, and enhanced reliability of 5G allow vehicles to share rich data in real-time, supporting fully autonomous driving experiences.

Figure 8: Cooperative adaptive cruise control use case.

3 Enabling V2X Implementation

The initial V2X standard of Release 14 was completed in September 2016[7][8], focused on V2V communications. Further enhancements to support additional V2X operational scenarios will follow in the future releases as shown in Figure 9[9]. V2V communications are based on Device to Device (D2D) communications defined as part of Proximity Services (ProSe) services in Release 12 and Release 13. V2V features utilize direct communications via a PC5 interface (i.e. sidelink) and network-based communications via a Uu interface (i.e. radio interface) employing the Multimedia Broadcast Multicast Service

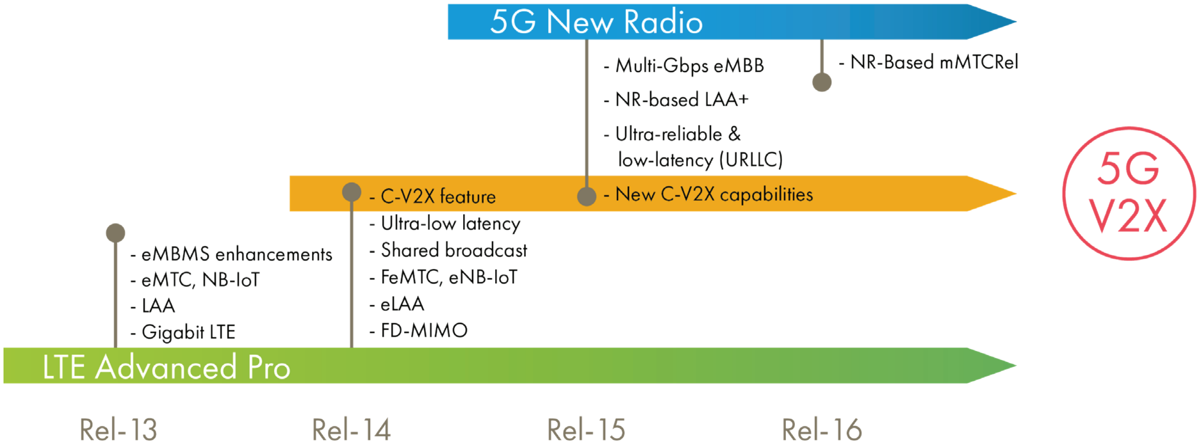

Figure 9: 3GPP V2X standardization.

(MBMS) function. The current D2D interface, PC5, specifically supports high speed (up to 250km/h) and high density (thousands of nodes) communications.

Moreover, LTE supports semi-persistent scheduling (SPS) to efficiently transmit V2V traffic, which is mostly periodic in nature. Based on traffic estimation, radio resources are scheduled for V2V packet transmissions. This technique increases service reliability and reduces latency by simplifying the signaling procedure for radio resource allocation.

3.1 Direct Communication

Direct communication uses the LTE PC5 interface, which is based on the ProSe feature defined in Release 12. ProSe is enhanced to accommodate high speed, high doppler, high vehicle density, precise synchronization, and low message transfer latency. Direct communication is suitable for proximal direct communications (e.g. hundreds of meters) and for V2V safety applications that require low latency (e.g. advanced driver assistance systems, situational awareness). It works both inside and outside of network coverage.

LTE V2V communicates over a sidelink channel in two different modes. In the first mode, resource allocation is performed by the network (i.e. base station). Devices with data to transmit send a request to the network for a radio resource allocation. In response, the network allocates resources and notifies the device. In this mode, to transmit data, devices need to wait until the network transmits resource allocation information. Thus, the signaling procedure for scheduling request and resource allocation results in increasing transmission latency. In the second mode, devices select the resource autonomously. The autonomous mode reduces latency, but issues related to possible collisions and interference may arise. Optimization of resource allocation procedures is being considered, with emphasis in the autonomous mode, due to its lower latency.

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V2V features utilize direct communications via a PC5 interface and network-based communications via a Uu interface employing MBMS function.

3.2 Network-Based Communication

Network-based communication uses the LTE Uu interface between the UE (e.g. vehicle, pedestrian, or infrastructure) and the eNB (e.g. base station). UEs send unicast messages via the eNB to a V2X application server, which in turn rebroadcasts the unicast messages via evolved Multimedia Broadcast Multicast

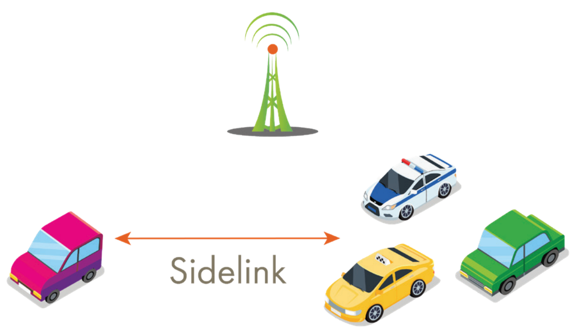

Figure 10: Direct Communication.

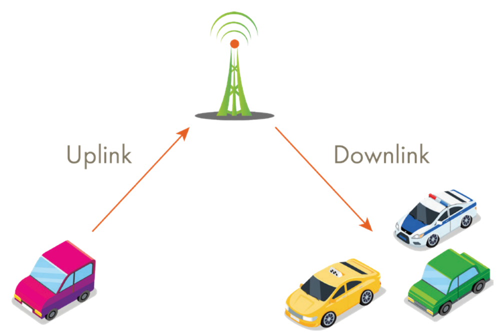

Figure 11: Network-Based Communication.

The 3GPP standardization roadmap for 5G RAT is driven by market demand for the early deployment of 5G networks and the need for the 5G specification to satisfy ITU IMT-2020 requirements.

Service (eMBMS) for all UEs in a relevant geographical area. This mode utilizes the existing LTE network and is suitable for wide area services such as situational awareness, traffic flow control, or mobility services.

3GPP introduced MBMS for LTE in Release 9[10]. Release 12 and Release 13 enhanced MBMS to allow third-party applications to interact with the MBMS system and distribute application traffic. This feature supports V2X services. In Release 14, 3GPP further specified Quality of Service (QoS) handling and local server discovery for V2X to meet the 100ms latency requirements for some of the V2N services. This latency reduction is mainly accomplished by using a new QoS class identifier with a very short packet delay budget to carry V2X data traffic within the core network together with the user-plane processing node of eMBMS residing near the base station.

4 Conclusion

Based on research on crash data from 2004 to 2008, USDOT has concluded that a V2X system can address 81 percent of unimpaired light vehicle crashes (4.5 million crashes) in accident scenarios between vehicles as shown in Figure 12[11].

With respect to traffic congestion, the City of Pittsburgh and the Carnegie Mellon University reported that a fully implemented V2X system can be expected to reduce vehicle idle time by 40% and travel time by 25%. Moreover, the report concludes that those results will contribute to a 20% reduction in emissions[12].

Cellular V2X communication will enhance traffic safety and efficiency by supporting use cases for: Cooperative Safety Control, Traffic Flow Optimization; and Autonomous Driving. Governments and car companies are pushing LTE and 5G into vehicles to obtain the public safety, efficiency, and emissions benefits. This will aid the implementation of V2X. The global market of connected car technology is estimated to grow from 45.2 billion USD in 2016 to 168 billion USD by 2022, with an annual investment growth rate of around 24.5%. The market in 2017 is strongest in US with approximately 20.2 billion USD.

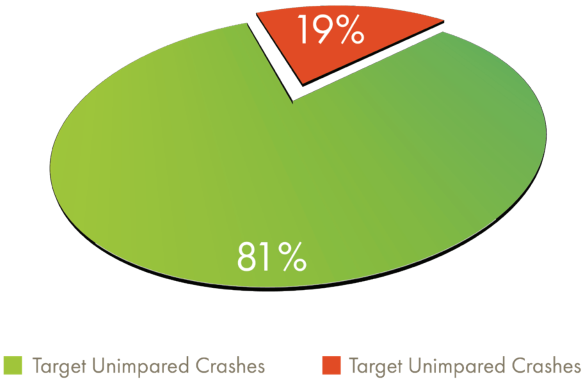

Figure 12: Unimpaired Light Vehicle Crashes Potentially Addressed by V2X.

3GPP is pursuing further improvements for advanced V2X services targeting Vehicle Platooning, Extended Sensors, Advanced Driving, and Remote Driving. These improvements are scheduled for Release 15 and beyond of the 3GPP specifications[13]. V2X communications are a critical component of the future connected car. The cellular network connection of vehicles will enhance vehicle safety and traffic flow efficiency, and ultimately become a key technology to support autonomous driving by supporting V2X functionalities of LTE evolution and 5G. That will provide an enjoyable and safer traffic environment to passengers and pedestrians. In addition, the existing enormous coverage of cellular networks will enable the V2X service market to spread out to rural and urban areas at a low installation cost.

Glossary

3GPP	3rd Generation Partnership Project
5G	5th Generation
ACC	Adaptive Cruise Control
D2D	Device-to-Device
DSRC	Dedicated Short-Range Communication
eMBMS	evolved Multimedia Broadcast Multicast Service
eNB	evolved Node B
ETSI	European Telecommunications Standards Institute
IEEE	Institute of Electrical and Electronics Engineers
LiDAR	Light Detection and Ranging
LTE	Long-Term Evolution
MAC	Medium Access Control
MBMS	Multimedia Broadcast Multicast Service
NHTSA	National Highway Traffic Safety Administration
PHY	Physical
ProSe	Proximity Services
RSU	Road Side Unit
UE	User Equipment
USDOT	U.S. Department of Transportation
V2I	Vehicle-to-Infrastructure
V2N	Vehicle-to-Network
V2P	Vehicle-to-Pedestrian
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything

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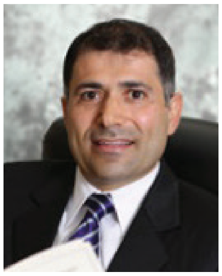

Esmael Dinan is founder and CEO of Ofinno Technologies. He has over twenty years of research and development experience in technology firms such as WorldCom, Bechtel Communications, Sprint, and Clearwire. He led research and development projects in various areas of wireless and wireline networking technologies, such as LTE Advanced, Evolved Packet Core, 5G New Radio, and 5G Core Networks. He is an inventor in over six hundred granted or pending patent applications. He received his PhD in Electrical Engineering from George Mason University, Fairfax, Virginia in 2001.

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