CONNECTING VEHICLES
TODAY AND IN THE 5G ERA
WITH C-V2X (CELLULAR VEHICLE-TO-EVERYTHING)

www.gsma.com/automotive

C-V2X technology is set to revolutionise the mobility ecosystem and the way vehicles and drivers interact with the world, including vulnerable road users such as pedestrians and cyclists. It is an essential stepping stone for the ongoing digitization of transportation by providing real-time, highly reliable, and actionable information flows to enable road safety, traffic efficiency and environmental progress.
The auto and telecom industry – collaborating under 5GAA - supports the idea that 5G will further enable mission-critical enhanced V2X communications and be the ultimate platform to enable impactful C-ITS services.

Maxime Flament, CTO, 5GAA

Audi has demonstrated a novel C-V2X use case together with Ford, Ducati and Qualcomm Technologies. The four-way stop use case provides a glimpse of how cooperative driving will be possible with C-V2X in the future. Besides additional safety, C-V2X is designed to also improve comfort and efficiency, which can be applied to both current and future autonomous driving.

Anupam Malhotra, Director, Connected Vehicles & Data, Audi of America
[Wards Auto, January 2019]

Backed by a strong and diverse ecosystem of suppliers, C-V2X is commercially available and poised for widespread deployment in both vehicles and roadside infrastructure. Extensive testing and trials have demonstrated that C-V2X is consistently more reliable than alternative technologies - it is fast becoming the technology of choice for intelligent transport systems worldwide.

Jim Misener, Sr. Director and Product Management, Qualcomm Technologies, Inc.

Recent testing has shown the superior performance of C-V2X relevant to non-cellular ITS technology. Wi-Fi [...] has no relationship to existing cellular infrastructure, nor will it be compatible with 5G, which provides the best of both worlds: direct short-range communication in unlicensed bands and long-range communication with 4G and 5G. C-V2X also facilitates ad-hoc vehicle communication in situations with no cellular coverage.

Joakim Reiter, Group External Affairs Director, Vodafone
[from a joint statement by Joakim Reiter, Group External Affairs Director, Vodafone; Dr. Christoph Grote, Senior Vice President Electronics, BMW Group; Ulf Pehrsson, Vice President Government and Industry Relations, Ericsson, November 2018]

Executive Summary

The industry standard for vehicle communication, Cellular Vehicle-to-Everything (C-V2X) technology is commercially available globally today. Standardised by 3GPP, this 4G and 5G-based technology is designed to connect vehicles to each other, to roadside infrastructure, to pedestrians and cyclists, and to cloud-based services.

It promises to transform information and safety services on highways and within cities both by connecting individual vehicles and by enabling the development of cooperative intelligent transport systems (C-ITS) that reduce congestion and pollution and enhance travel. It can help cities to become smarter and support increasingly automated transport systems that are safer and more efficient than today's transport networks.

Why C-V2X?

Many automakers are adding C-V2X connectivity to their vehicles because it has several key advantages over DSRC[1] (a variant of Wi-Fi) and other technologies designed to enable vehicle-to-vehicle communications. C-V2X can:

- Provide levels of security, range, latency and reliability that have been proven to greatly exceed the capabilities of DSRC.
- Leverage the comprehensive coverage of secure and well-established LTE networks, reducing the amount of roadside infrastructure that needs to be installed and maintained by municipalities and highway agencies in both urban and rural areas.
- Enable highly reliable, real-time communication at high speeds and in high-density traffic.
- Support both short-range and long-range transmissions between vehicles and roadside infrastructure using one cost-effective module.
- Harness 5G networks to support fully autonomous driving, as well as being backwards compatible with 4G.
- Leverage the robust security built into cellular networks.

C-V2X builds upon the services already offered in the connected vehicle today, such as pay-as-you drive insurance, vehicle diagnostics, eCall and connected infotainment by adding critical safety features that allow the vehicle to share data in real time. C-V2X helps vehicles avoid accidents, work together on the road and even detect road hazards beyond the driver's field of vision.

[1] Dedicated Short Range Communications

C-V2X employs two complementary transmission modes:

1. **Short-range direct communications** between vehicles (V2V), between vehicles and infrastructure (V2I), and vehicles and other road users (V2P), such as cyclists and pedestrians. In this mode, C-V2X works independently of the cellular networks in dedicated ITS 5.9GHz spectrum.
2. **Long-range network communications (V2N),** in which C-V2X employs the conventional mobile network to enable a vehicle to receive information about road conditions and traffic in the area, beyond the driver's line of sight.

How C-V2X Is Changing Driving

C-V2X can be used in many different ways to improve road safety, while making more efficient use of transport networks and infrastructure. For example, it can support:

- **Collision avoidance:** Each vehicle on the road could use C-V2X to broadcast its identity, position, speed and direction. An on-board computer could combine that data with that from other vehicles to build its own real-time map of the immediate surroundings and alert the driver to any potential collisions.
- **Platooning:** The formation of a convoy in which the vehicles are much closer together than can be safely achieved with human drivers, making better use of road space, saving fuel and making the transport of goods more efficient.
- **Cooperative driving:** By sharing sensor data, vehicles can use C-V2X to work together to minimise the disruption caused by lane changes and sudden braking.
- **Queue warning:** Roadside infrastructure can use C-V2X to warn vehicles of queues or road works ahead of them, so they can slow down smoothly and avoid hard braking.
- **Supporting the emergency services:** C-V2X can be used to warn road-users about emergency vehicles on route to an incident.
- **Hazards ahead warning:** C-V2X can be used to extend a vehicle's electronic horizon, so it can detect hazards around a blind corner, obscured by fog or other obstructions, such as high vehicles or undulations in the landscape.
- **Increasingly autonomous driving:** Along with other sensors and communications systems, C-V2X will play an important role in enabling vehicles to become increasingly autonomous.
- **Collecting road tolls:** designed to reduce congestion and the impact of motor transport on the environment through reduced emissions.
- **Avoiding vulnerable road-users:** by detecting pedestrians and cyclists' smartphones, C-V2X will help vehicles to avoid other road users.

The Roadmap For Deployment

C-V2X has the support of mobile operators, leading mobile equipment makers and many automakers, including Audi, BMW, Daimler, Ford, Lexus, Nissan, PSA, SAIC and Tesla. Ford, for example, has committed to deploying C-V2X in all new U.S. vehicle models beginning in 2022, "pending a technology neutral regulatory environment." It also plans to begin deploying C-V2X technology in Ford vehicles in China in 2021.

In China, more than 20 trials and pilot C-V2X projects are taking place across 100km of roads in 10 provinces. China plans to install C-V2X on 90% of the country's highways by 2020, according to a strategic plan released by the National Development and Reform Commission, while 15 vehicle manufacturers have announced plans to roll-out cars supporting C-V2X for the Chinese market from the second half of 2020, according to the 5GAA, a cross industry consortia helping define 5G V2X communications.

In the U.S., the Colorado Department of Transportation is testing C-V2X on a 90-mile stretch of the I-70 mountain highway, which has steep gradients, sharp bends and tunnels and is subject to extreme winter weather conditions. At CES 2019, Applied Information, which provides intelligent transportation infrastructure, said its C-V2X products have now been deployed in more than 500 U.S. cities, counties, school districts and states. The company provides cellular connections to traffic signals, school zone beacons, traffic control devices and emergency vehicles.

In Europe, Bosch, Huawei, and Vodafone Germany have successfully tested C-V2X on the A9 freeway in Bavaria, Germany, while Deutsche Telekom has announced C-V2X tests together with Skoda Auto in the Czech Republic as part of the European C-Roads project. Vodafone is also working with Continental to create a "digital safety-shield" for cyclists and pedestrians, using C-V2X direct communication and edge computing in the first 5G deployments. The 5G-ready tests are taking place under real-life conditions at Vodafone's 5G Mobility Lab in Aldenhoven, Germany.

> *"In China, more than 20 trials and pilot C-V2X projects are taking place across 100km of roads in 10 provinces."*

Further Enhancements with 5G

C-V2X can employ both 4G and 5G cellular connectivity. Indeed, it is the only V2X technology with a roadmap to 5G that upholds backward compatibility, while being able to capitalise on the greater bandwidth, low latency and high reliability of next generation networks.

In the 5G era, C-V2X will be able to support a range of advanced safety services, including very precise positioning and ranging to enable cooperative and automated driving, the delivery of local, dynamic maps based on camera and sensor data, and the very low latency connectivity necessary to enable high-density platooning. As 5G networks can support very large numbers of connections in a small area, individual vehicles will be able to capture more data about their immediate surroundings. Ultimately, C-V2X will play a pivotal role in enabling the deployment of fully autonomous vehicles, which will transform the way people travel.

> *"Ultimately, C-V2X will play a pivotal role in enabling the deployment of fully autonomous vehicles, which will transform the way people travel"*

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Introduction

The connected vehicle market continues to grow rapidly. Advances in mobile technologies are enabling drivers and passengers to benefit from increasingly sophisticated infotainment, navigation, safety and telematics services. As demand rises around the world, the connected vehicle market is one of the fastest growing segments of the Internet of Things, potentially generating application revenue of US$253 billion by 2025, according to Machina Research's forecasts, 2017.

Moreover, connected vehicles could generate major benefits for individuals and society as a whole. By 2025, connected cars could save 11,000 lives and lead to 260,000 fewer accidents, while avoiding 400,000 tonnes of CO2 emissions and saving 280 million hours of driving every year, according to automotive supplier Bosch, 2017.

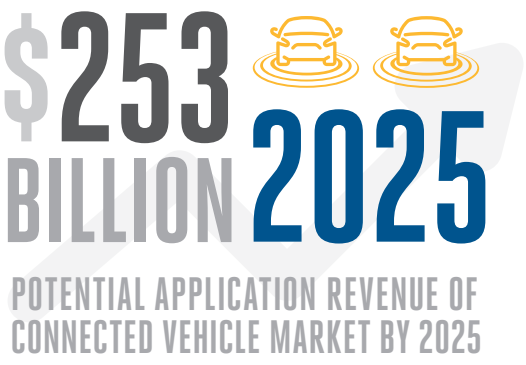
Cellular Vehicle-to-Everything (C-V2X) Technology

More than 800 mobile operators around the world have deployed networks that are compatible with the 3GPP standards, enabling them to benefit from global interoperability and economies of scale. In June 2017, 3GPP incorporated Cellular Vehicle-to-Everything (C-V2X) technology in Release 14 of its standards and the technology has evolved further with Release 15, which was finalised in June 2019. By harnessing LTE and 5G networks, this cellular technology is designed to deliver safety and information services to vehicles, paving the way for the development of cooperative intelligent transport systems (C-ITS) that reduce congestion and pollution, while making travel faster and more efficient.

This paper explains what C-V2X is, what it does, how it works, why it is important and why it is the best technology to enable communications between vehicles, roadside infrastructure and other road users. The paper is written as a guide for automakers, mobile operators, equipment vendors, policymakers and regulators.

The Role of the GSMA

The GSMA is working with mobile operators, automakers and suppliers, relevant industry associations and regulatory bodies to accelerate the growth of the connected vehicle market by agreeing a common approach to security, regulatory and infrastructure solutions. Only a standardised and collaborative approach can unlock the full potential of this market. The GSMA is consulting with global regulatory bodies to align the industry around a common approach to security and spectrum harmonisation.



Source: Machina Research

How Mobile Networks Can Improve Road Safety

The latest vehicles on the world's roads contain very advanced information and communications technologies, including on-board computers, a wide range of sensors and, in many cases, both short-range and wide area connectivity. Many new vehicles rely on cellular networks to deliver a broad range of infotainment and telematics services, including pay-as-you drive insurance, navigation and automated emergency calling. In particular, mobile networks are playing an increasingly important role in improving road safety and enhancing safety-critical systems on-board vehicles.

As well as making individual journeys safer, connected vehicles can deliver broader benefits for society by helping people to choose the most efficient form of transport and the quickest routes, while enabling the collection of automated road tolls designed to reduce congestion, carbon emissions and the impact of transport on the environment.

For the connected vehicle market to scale to its full potential, drivers need to trust the security and reliability of all components and layers of connected vehicles. Mobile operators have a long track record of deploying and managing secure, reliable and comprehensive end-to-end communication services and coverage. As experienced, trusted and licensed providers of connectivity, they are therefore best suited to meet the automotive industry's need for scalable, secure and proven solutions. Mobile operators can work with automakers and other stakeholders in the connected vehicle ecosystem to implement a proven and robust approach to cybersecurity.

Mobile operators bring a number of assets to this market, including:

- Broad coverage via existing cellular networks and mobile ecosystem support
- Extensive experience in deploying, managing, and maintaining complex communication systems
- Complementary services, such as navigation, pay-as-you-drive insurance and vehicle diagnostics
- Public key infrastructure (PKI) certificate management
- Data storage and data analytics

The Role of Cellular Vehicle-to-Everything (C-V2X)

The mobile industry body 3GPP has standardised a set of technologies specifically designed to enable communications between vehicles and roadside infrastructure. Known as Cellular Vehicle-to-Everything (C-V2X), these technologies can enhance safety and ultimately support autonomous driving by:

- Leveraging the comprehensive coverage of secure and already established LTE and future 5G networks
- Enabling highly reliable, real-time communication at high speeds and in high-density traffic
- Supporting short and long-range transmissions between vehicles, pedestrians, cyclists and roadside infrastructure

By providing real-time information on conditions beyond the driver's line of sight, C-V2X can work with other sensors on-board a vehicle to increase safety. The information captured by a C-V2X system can complement the data being captured by radar, lidar and ultrasonic systems that help the driver to keep the vehicle a safe distance from the vehicle in front and contend with bad weather conditions and low light situations. A vehicle's on-board computer can combine data received via C-V2X with information captured by on-board cameras to interpret road signs and objects. Moreover, GNSS systems pinpointing the vehicle's location on 3D and HD maps can be updated in real-time over a cellular network. The fusion of ever evolving and improving sensors and computational machine intelligence will ultimately emulate and then surpass the sensing and cognitive capabilities of human drivers.

How C-V2X is Changing Driving

C-V2X can be used in many different ways to improve road safety, while making more efficient use of transport networks and infrastructure. This section gives examples of the many scenarios in which C-V2X can help to enhance safety.

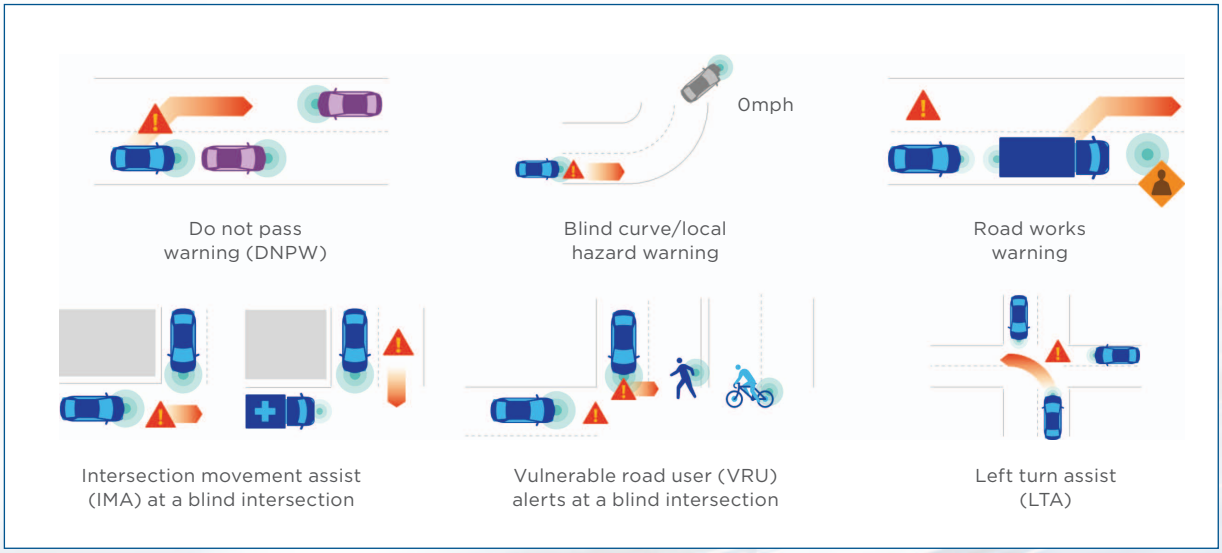
Collision avoidance: Each vehicle on the road can use C-V2X to broadcast its identity, position, speed and direction. An on-board computer can combine that data with that from other vehicles to build its own real-time map of the immediate surroundings and determine whether any other vehicles (including those out of the driver's sight) are on a potential collision trajectory. The vehicles involved can then take evasive action, such as braking or accelerating, that will enable a collision to be avoided. In cases where a human driver is about to cause an accident, the information collected by C-V2X can be used to over-ride the manual controls. For

example, if a driver is about to pull out at a junction into the path of another vehicle, the on-board computer can automatically apply the brakes and prevent the car moving forward.

Platooning: refers to the formation of a convoy in which the vehicles are much closer together than can be safely achieved with human drivers. Such automated convoys make better use of road space, save fuel and make the transport of goods more efficient. C-V2X can be used to enable communications between up to three vehicles in the platoon, so that they all slow down or speed up simultaneously. And C-V2X could also be used to signal the presence of the platoon to other vehicles and roadside infrastructure. Platoons will be flexible in that they will typically be established on a motorway, then broken up when a vehicle leaves the motorway. For platoons of more than three vehicles, relaying information between vehicles takes too long to enable synchronous braking. Therefore, platoons of more than three vehicles will also need to make use of the low latency cellular network infrastructure that will be deployed with 5G.

Co-operative driving: Vehicles can use C-V2X to work together to make the best use of the available road space and minimise the disruption caused by lane changes and sudden braking. C-V2X can be used to convey intent to other road users. For example, once a vehicle has overtaken another vehicle, the most efficient way to re-enter a slower lane during periods of dense traffic, is for the vehicle in front of it to accelerate slightly, and for the following car to slow down slightly to make sufficient space for the merging car. The same process can also be used to smooth a vehicle's entry on to a busy motorway.

Queue warning: Roadside infrastructure can also use C-V2X to warn vehicles of queues or road works ahead of them, so they can slow down smoothly and avoid hard braking. More broadly, the roadside infrastructure can use C-V2X to help vehicles retain a consistent speed and reduce the number of so-called phantom traffic jams caused by the ripple effect caused by sudden braking and lane changes on motorways. Traffic lights can advise oncoming vehicles about when they will turn green or red, so the car can adjust its speed accordingly.

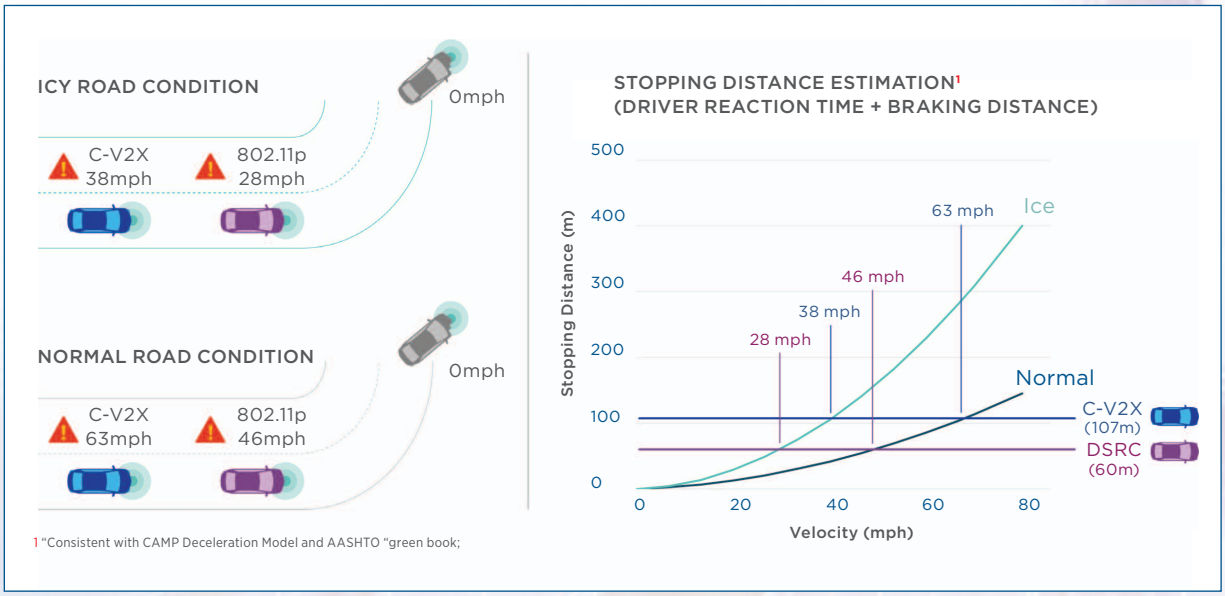


Source: Qualcomm

Protecting vulnerable road users: Vehicles equipped with C-V2X systems will in future be able to detect the smartphones of pedestrians and cyclists, enabling them to avoid collisions with these vulnerable road users. When a smartphone detects it is on or near a road, it could use C-V2X to continually broadcast a signal to warn nearby connected vehicles of its presence.

Supporting the emergency services: Police cars, ambulances, fire engines and other emergency vehicles can use C-V2X to warn other vehicles on their routes to clear the road, so they can pass through quickly. The C-V2X connectivity can also adjust traffic lights so that the emergency vehicles can travel through junctions without having to slow for crossing vehicles.

Hazards ahead warning: C-V2X can be used to extend a vehicle's electronic horizon, so it can detect hazards around a blind corner, obscured by fog or other obstructions, such as high vehicles or undulations in the landscape. Roadside signs can use C-V2X to broadcast hazard warnings to each vehicle on a particular stretch of road. Moreover, a vehicle can use C-V2X to send salient data captured by its sensors, such as ice on the road, to other vehicles travelling behind it. If a vehicle is braking hard, it can use C-V2X to transmit a warning to the vehicles behind it.



1 "Consistent with CAMP Deceleration Model and AASHTO "green book;

Source: Qualcomm

Increasingly autonomous driving: Along with other sensors and communications systems, C-V2X will play an important role in enabling vehicles to become increasingly autonomous. For example, C-V2X can be used to give advance warnings of changes in traffic conditions so that the on-board computer can make better decisions on when to change lanes, accelerate or slow down. As 5G networks spread, C-V2X will harness this low latency, highly reliable connectivity to further support autonomous driving, by giving the vehicle comprehensive real-time information about the roads ahead of it.

The Advantages of C-V2X

C-V2X has several major advantages over other vehicle connectivity solutions for each of the key stakeholders in this sector.

For automakers: Combining secure wide area and short-range connectivity in one technology, C-V2X is a versatile and cost-effective solution for automakers looking to improve road safety. For example, an automaker using C-V2X can install a single connectivity module in a vehicle to support both secure communications with the Internet and cloud-based systems, and direct communications with nearby vehicles, infrastructure and road-users. As well as leveraging the security built into cellular networks, the automaker can benefit from the massive economies of scale in the 4G mobile ecosystem, in which a large and diverse group of chipset, module and equipment makers all comply with the 3GPP standards. In essence, C-V2X has the support of a large, innovative and competitive supply chain.

Robust Global C-2VX Ecosystem is Ready

9150 Modules

- WNC
- Quectel
- ZTE
- LG
- LG Innotek
- Telit
- SIMCom

Commercial ready module in 2018

RSU vendors

- US : Savari, Kapsch Commsignia, McCain
- EU: Swarco, Lacroix, Aximum, Marben
- China: Nebulalink, Genevict, Neusoft
- RoW: Cohda, Cybercom, Oki

16+ RSU products slated. Commercial ready in Q1 2019

Tier1s/OBU vendors

- Bosch
- Ficosa
- Cohda
- Valeo
- Savari
- Marben
- Continental
- LG Electronics
- Nebula
- Commsignia
- Genevict

10+ OBU suppliers slated. Commercial ready in Q1 2019

System Integrators

- Sasken
  - Integration & Support
- Thundersoft (China)
  - Integration & Support

Global foot print to support system integration

Source: Qualcomm

For road operators: As the ITS band uses high frequency spectrum (5.9 GHz), in which radio signals have a limited range, providing extensive connectivity coverage is challenging for road operators. However, C-V2X allows for direct communications in the 5.9 GHz band to be supplemented with cellular communications using lower frequencies in which radio signals travel further. The net result is high service availability and reliability. Moreover, in future, C-V2X will enable road operators to also harness the millimetre waves that will be used by 5G mobile networks for high volume data transfer, and low latency wide area network support for assisted driving. In essence, harnessing the existing cellular infrastructure will reduce the amount of roadside infrastructure that will need to be installed and maintained by municipalities and highway agencies in both urban and rural areas. That would free up funds for other purposes, such as the training of road agency personnel and highway maintenance.

For mobile operators: To keep deployment costs down, mobile operators can harness their existing cellular infrastructure to support the rollout of C-V2X connectivity. The synergies between the roadside infrastructure and the conventional cellular infrastructure can generate significant economic benefits. Firstly, the operators' base stations can work with roadside infrastructure to provide the comprehensive coverage required to create cooperative intelligent transport systems (C-ITS). At the same time, operators' commercial cellular networks can also provide backhaul to link the roadside infrastructure to the cloud. As C-V2X is based on a variant of 4G, it is compatible with existing LTE base stations, enabling rapid deployment.

The Technical Advantages of C-V2X

C-V2X has a number of technical advantages over DSRC/802.11p (a variant of Wi-Fi), as summarised in the graphic below.

C-2VX Technical Advantages Over IEEE 802.11p (ITS-G5 or DSRC)

	C-V2X: PC5	802.11p	C-V2X: PC5 ADVANTAGE
Synchronization	Synchronous	Asynchronous	Spectral Efficiency. Synchronization enables time division multiplexing (TDM) and lowers channel access overhead.
Resource Multiplexing Across Vehicles	FDM and Time Division Multiplexing (TDM) Possible	TDM Only	Frequency Division Multiplexing allows for larger link budget and therefore longer range - or more reliable performance at the same range
Channel Coding	Turbo	Convolutional	Coding gain from turbo codes leads to longer range - or more reliable performance at the same range.
Retransmission	Hybrid Automatic Repeat Request (HARDQ)	No HARQ	Leads to longer range - or more reliable performance at the same range.
Waveform	SC-FDM	OFDM	Allows for more transmit power with the same power amplifier. Leads to longer range - or more reliable performance at the same range.
Resource Selection	Semi-persistent transmission with relative energy-based selection.	Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA)	Optimizes resource selection with selection of close to 'best' resource with no contention overheads. By contrast 802.11p protocol selects the first "good enough" resource and requires contention overhead.

Source: 5GAA

Together, these advantages equate to a significantly higher link budget and system performance, enabling range, Doppler (speed) and reliability advantages over DSRC. C-V2X has a higher spectral efficiency, enabling it to serve more road users within a given chunk of spectrum. Hence, C-V2X can provide higher levels of safety to more road users than alternative technologies.

DSRC uses a low-bandwidth 5.9GHz radio channel to transmit data at 3-27Mbps over a distance of 150 meters to 1 kilometre, between vehicles moving at up to 260 km/h. But in practice, DSRC's actual transmission distance and data bandwidth are likely to be on the low to middle parts of those ranges.[2]

By comparison, C-V2X uses the same 5.9GHz radio channel as DSRC, but also offers both low bandwidth and higher bandwidth options for transmitting more data with superior range, reliability, and latency.

In September 2018, 5GAA tested the maximum range at which C-V2X and DSRC could achieve 90% reliability. As the table below shows, the reliable range of C-V2X is far superior to that of DSRC.

Test Procedure	Range at 90% Reliability	
	DSRC	CV2X
Line-of-Sight (LOS) Range	675m	1175m
Non-Line-of-Sight (NLOS) Blocker (5GAA)	125m	425m
Non-Line-of-Sight (NLOS) Blocker (CAMP)	400m (200m)[1]	>1350m (625m)
Non-Line-of-Sight (NLOS) Intersection	375m	875m
Co-existence with Wi-Fi 80 MHz Bandwidth in UNII-3	300m (75m)	625m
Co-existing of V2X with Adjacent DSRC Carrier	400m (100m)	1050m

Source: 5GAA

[2] Source: http://www.iaeng.org/publication/WCECS2014/WCECS2014_pp691-698.pdf

In December 2018[3], trials in Japan by Continental, Ericsson, Nissan, NTT DOCOMO, OKI and Qualcomm Technologies, found that C-V2X delivered a mean latency of 20 milliseconds for direct communication and nearly error-free communication at distances up to 1.2km. The trial involved test vehicles passing each other at speeds of up to 110 km/h. Qualcomm says 5G C-V2X will support "lossless data transfers" between vehicles traveling at up to 500km/h, even at distances of over 450 meters.

More broadly, ad hoc networks relying solely on direct communications between vehicles can become inefficient if the number of hops becomes significant, due to the protocol overhead. A practical limit tends to be five hops. However, if there is an active antenna system located in the front and rear of a car, the number of hops can be doubled.

As well as offering superior direct communications, C-V2X offers a higher degree of security than DSRC for all operating modes. Mobile operators secure all traffic travelling to and from their networks, which can be supplemented with Public Key Infrastructure (PKI) encryption services.

In tests carried out between March and September 2018, the 5GAA compared the performance of C-V2X and DSRC for the reliable delivery of safety messages broadcast between vehicles. 5GAA says the tests found that C-V2X significantly outperformed DSCR in range and reliability, especially in challenging conditions (see graphic).

Reliability	**Lab** Cabled Tx and Rx Tests	C-V2X better
	Field Line-of-Sight (LOS) Range Tests	C-V2X better
	Field Non-Line-of-Sight (LOS) Range Tests	C-V2X better
Interference	**Lab** Cabled Test with Simulated Co-Channel Interference	C-V2X better
	Lab Cabled Near-Far Test	Pass
	Field Co-existence with Wi-Fi 80 MHz Bandwidth in UNII-3	C-V2X better
	Field Co-existing of V2X with Adjacent DSRC Carrier	Pass
Congestion	**Lab** Cabled Congestion Control	Pass

[3] Source: https://www.greencarcongress.com/2018/12/20181214-cv2xjapan.html

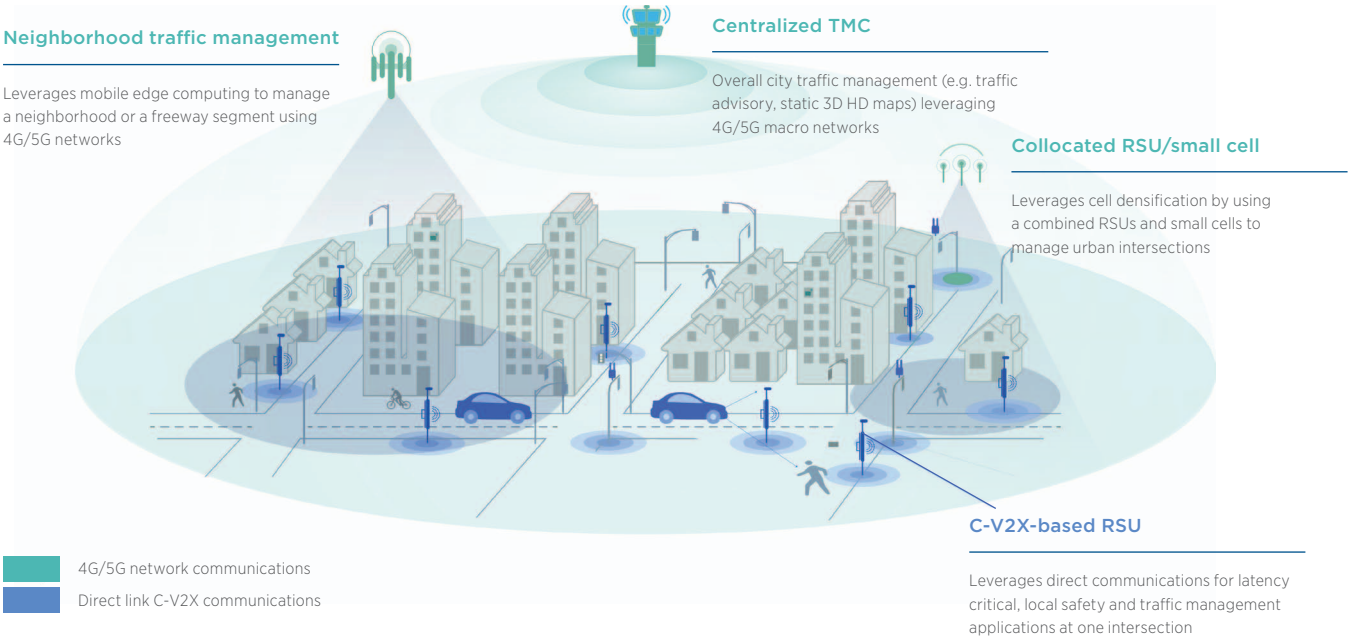
How C-V2X Works

An advanced technology that draws on the capabilities of 4G and 5G cellular networks, C-V2X can support a wider range of capabilities than earlier dedicated vehicle connectivity solutions, which are generally based on a Wi-Fi variant, known as DSRC/802.11p.

C-V2X employs two complementary transmission modes to enable a very broad range of driving safety features. These modes are:

1. Short-range direct communications between vehicles (V2V), between vehicles and infrastructure (V2I), and vehicles and other road users, such as cyclists and pedestrians (V2P). In this mode, C-V2X operates in the 5.9 GHz frequency band – the ITS (intelligent transport system) spectrum that has been identified and harmonised internationally for safety purposes. In this mode, C-V2X works independently of the cellular networks.

2. Long-range network communications, in which C-V2X employs the conventional mobile network to enable the vehicle to receive information about road conditions and traffic in the area, beyond the driver's line of sight. In this mode, C-V2X operates in spectrum that has been licensed to mobile operators to provide connectivity to their customers.



Source: Qualcomm

Direct Communications

The ITS 5.9 GHz spectrum band has been set aside by governments worldwide to enable vehicles to talk to each other using dedicated frequencies that won't be subject to interference. Using this band, C-V2X can support direct low latency connections over short distances, without the involvement of the cellular network. Like DSRC, C-V2X employs the global navigation satellite system (GNSS) to determine the position of the vehicle and to synchronize communications between vehicles and with roadside infrastructure. In this mode, no SIM card is required, as the vehicle doesn't need to connect to the cellular network. The vehicle and its driver remain anonymous, as no cellular subscription is required for direct safety communications. C-V2X and DSRC can co-exist in the ITS spectrum by employing different channels within the 5.9 GHz band, but testing[4] by the 5GAA has found that C-V2X is significantly more reliable. Just 10MHz of spectrum in the 5.9GHz band is required to support basic safety services, while 70MHz could support advanced safety services, such as sharing large amounts of data collected by on-vehicle sensors.

Network Communications

C-V2X can also support vehicle-to-network (V2N) applications delivered over commercially-licensed cellular spectrum. This mode can be used to provide network assistance for safety-related features, as well as commercial services, requiring the involvement of a mobile operator, providing access to cloud-based data or information. This mode also enables C-V2X to harness the data security and privacy of mobile networks. Time-critical services can be supported by edge computing – the deployment of computer servers and data analytics on the edge of the network. By contrast, DSRC is only designed to support direct communications between vehicles and between vehicles and road-side infrastructure.

Both deployable today and future-proof, C-V2X is versatile enough to support both today's use cases, and those of tomorrow. Compatible with 4G and 5G cellular networks, it is intended to be both scalable and interoperable. C-V2X can also support advanced driver assistance systems (ADAS) where vehicles can cooperate, coordinate and share information collected by sensors, and ultimately, connected automated driving (CAD).

[4] Source: https://5gaa.org/wp-content/uploads/2018/11/P-180106-V2X-Functional-and-Performance-Test-Report_Final_051118.pdf

The Roadmap for Deployment

C-V2X has widespread support within the mobile and automotive industries. The 5GAA, a cross industry consortia to help define 5G V2X communications, is a strong supporter of C-V2X. Audi, BMW, Daimler, Ford, Honda, Jaguar Land Rover, Nissan, SAIC Motor, Toyota and Volkswagen are among its members, along with most of the world's leading mobile operators and their equipment suppliers.

China Leads the Way

China is at the forefront of the deployment of C-V2X[5]. There are more than 20 trials and pilot projects taking place across 100km of roads in 10 provinces. In Wuxi, in eastern Jiangsu province, where C-V2X already covers 170 square km of urban land, China Mobile and supplier Huawei plan to nearly double that coverage to 400 intersections by the end of 2019. With more than two million vehicles in circulation, Wuxi processes around 1.6 PB (petabyte) of traffic data each day on average, with communication delays varying between 20 and 50 milliseconds, according to China Mobile.

As it explores business models for C-V2X, China Mobile intends to begin sharing the traffic data with automakers for use on on-board platforms this year. Huawei has demonstrated 19 potential usage applications so far including emergency brake warnings from nearby vehicles, and a parking assist.

Some 15 vehicle manufacturers have announced plans to roll out cars supporting C-V2X for the Chinese market from the second half of 2020, according to the 5GAA. Moreover, BMW China has teamed up with China Unicom to test autonomous cars using 5G networks. The 5GAA says 15 chipset/modules vendors are committed to support C-V2X for the Chinese market, while 35 manufacturers are able to provide C-V2X infrastructure hardware or software.

"5GAA is instrumental in supporting the implementation of C-V2X technology in different parts of the world including China. The momentum in China reflects the fact that C-V2X is the verified, mature and preferred future proof technology for connected vehicles," said Luke Ibbetson, 5GAA Board Member and Vodafone Group's Head of Research and Development.

Australia – Improving Road Safety

Australia's first on-road trials of C-V2X are underway in Victoria as part of the state government's Towards Zero programme to improve road safety[6]. The Advanced Connected Vehicles Victoria (ACV2)

[5] Source: https://technode.com/2019/06/28/china-wuxi-v2x-2019/
[6] Source: https://www.premier.vic.gov.au/connected-vehicle-trial-hits-the-road-in-australian-first/

project is led by mobile operator Telstra and automaker Lexus Australia. Having tested C-V2X on controlled tracks, on-road testing is now taking place on metropolitan and regional roads in the state. The trial is testing connected vehicle safety systems, including emergency braking alerts, in-vehicle speed limit compliance warnings, right-turn assist for vulnerable road users, and warnings when surrounding vehicles are likely to violate a red light.

Victoria's Minister for Roads, Jaala Pulford, says: "We're trialling cutting-edge technology like this to make our roads safer into the future. Victoria is leading the nation in connected and automated vehicles; this technology will be critical in making roads safer not only here, but across Australia."

The U.S. – Growing Momentum

Ford has committed to deploying C-V2X in all new U.S. vehicle models beginning in 2022, "pending a technology neutral regulatory environment." In its Sustainability Report 2018/19, Ford said that every new car it makes "in the United States will soon be able to tap into a wireless network and "talk" directly to other vehicles, pedestrians and infrastructure, helping to make our streets safer and less congested." It also plans to begin deploying C-V2X technology in Ford vehicles in China in 2021.

At the CES 2019 event in January, chipset maker Qualcomm demonstrated its C-V2X platform with Audi and Ford vehicles, as well as Ducati motorcycles[7]. The demos included vehicle-to-vehicle, vehicle-to-pedestrian and vehicle-to-infrastructure safety scenarios: The V2V use case featured the "intersection movement assist" scenario, which is designed to avoid angle collisions at intersections, while the V2P scenario showed how C-V2X can be used to protect vulnerable road users, including pedestrians and bicyclists. The V2I use case featured the "work zone warning" scenario, which is designed to provide drivers with advanced warning of road construction ahead, allowing them to manoeuvre in a safe manner.

Meanwhile, the Colorado Department of Transportation is testing C-V2X on a 90 mile stretch of the I-70 mountain highway[8], which has steep gradients, sharp bends and tunnels and is subject to extreme winter weather conditions.

At CES 2019, Applied Information, which provides intelligent transportation infrastructure, said[9] its C-V2X products have now been deployed in more than 500 U.S. cities, counties, school districts and states. The company provides cellular connections to traffic signals, school zone beacons, traffic control devices and emergency vehicles. Overall, Applied Information has deployed its current C-V2X technology in more than 10,000 devices.

Europe – Widespread Support

In Europe, Bosch, Huawei, and Vodafone Germany have successfully tested C-V2X on the A9 freeway in Bavaria, Germany[10]. They used a pre-standard 5G network in combination with Bosch's Adaptive Cruise Control (ACC) driver-assistance system. In a similar vein, Deutsche Telekom has announced C-V2X tests together with Skoda Auto in Czech as part of the European C-Roads project[11]. Vodafone is also working with Continental to create a "digital safety-shield" for cyclists and pedestrians, using C-V2X direct communication and edge computing

[7] Source: https://www.qualcomm.com/news/releases/2019/01/07/audi-ducati-and-ford-host-live-interactive-demos-las-vegas-using-c-v2x
[8] Source: https://coloradosun.com/2018/12/26/colorado-internet-roads-x-technology/
[9] Source: https://www.businesswire.com/news/home/20190110005376/en/C-V2X-Infrastructure-Technology-Applied-Information-Deployed-500
[10] Source: https://www.huawei.com/en/press-events/news/2018/3/Huawei-Vodafone-Bosch-Smart-Cars
[11] Source: https://www.prnewswire.co.uk/news-releases/automotive-c-v2x-ready-to-roll-out-globally-says-5gaa-at-this-year-s-mwc-barcelona-859235053.html

in the first 5G deployments[12]. The 5G-ready tests are taking place under real-life conditions at Vodafone's 5G Mobility Lab in Aldenhoven, Germany.

At MWC Barcelona 2019, 5GAA members Telefónica, Ericsson, Ficosa and Seat demonstrated 5G connected car use cases supported by C-V2X direct communication for safer driving in a city (e.g. detection of cyclists when turning right or of a pedestrian at a zebra crossing)[13]. Meanwhile, Rohde & Schwarz is working with automotive electronics specialist Vector on a C-V2X end-to-end application layer test solution to verify safety-critical V2X scenarios[14]. The companies' integrated test platform was showcased at MWC19 Barcelona.

How Will 5G Change C-V2X?

C-V2X is designed to be fully compatible with 5G, meaning investments in infrastructure and modules today won't be made obsolete for a long time to come. C-V2X technology is being further refined and its capabilities expanded with each new release of the 3GPP standards.

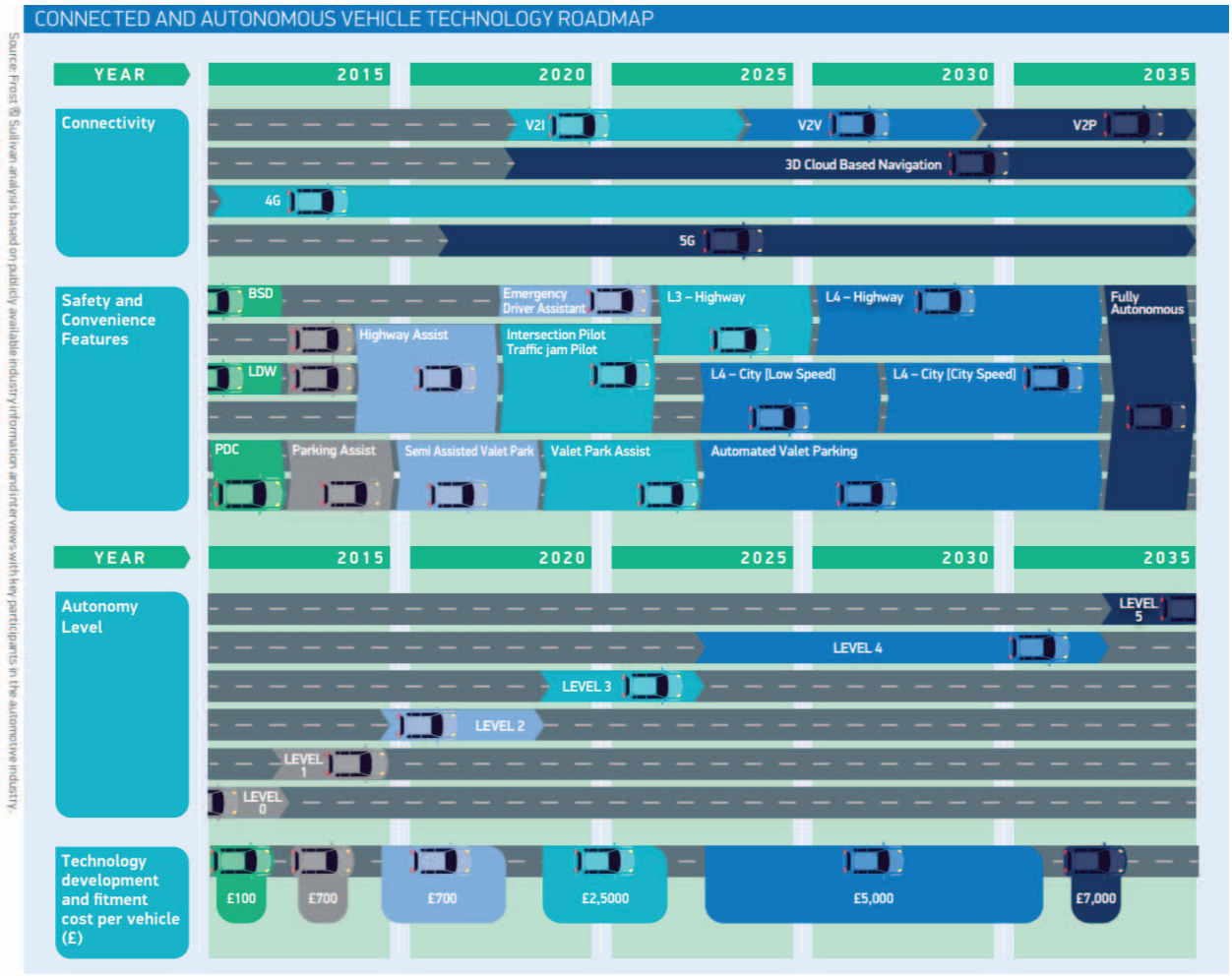
The ongoing deployment of commercial 5G networks is enhancing C-V2X in several different ways. With 5G, C-V2X is able to support:

- Very precise positioning and ranging to support cooperative and automated driving and ultimately autonomous vehicles
- High throughput and low latency connectivity to enable the exchange of raw or processed data gathered through local sensors or live video images
- High throughput to build local, dynamic maps based on camera and sensor data; which can then be distributed at street intersections. For example, C-V2X could be used to supply a driver or an on-board computer with a bird's eye view of an intersection or see-through capability when driving behind a truck
- Very low latency and high reliability to support high-density platooning

Moreover, 5G is able to support very large numbers of simultaneous connections in a small geographic area, enabling each vehicle to gather more information about its immediate surroundings.

Developed by research firm Frost & Sullivan, the diagram below shows how the evolution of C-V2X connectivity will support new safety and convenience features, and increasingly autonomous cars.

[12] Source: https://www.prnewswire.co.uk/news-releases/automotive-c-v2x-ready-to-roll-out-globally-says-5gaa-at-this-year-s-mwc-barcelona-859235053.html
[13] Source: https://www.prnewswire.co.uk/news-releases/automotive-c-v2x-ready-to-roll-out-globally-says-5gaa-at-this-year-s-mwc-barcelona-859235053.html
[14] Source: https://www.prnewswire.co.uk/news-releases/automotive-c-v2x-ready-to-roll-out-globally-says-5gaa-at-this-year-s-mwc-barcelona-859235053.html



Source: Frost & Sullivan, 2019

Additional Spectrum Requirements

The International Telecommunication Union (ITU) is considering allocating more spectrum to road safety applications. ITU-R Working Party 5A is further developing spectrum requirements and studies at the national, regional and global level that will support existing and future use cases envisaged for road safety and traffic efficiency applications. These applications are likely to require spectrum beyond the currently harmonized 5.875-5.905 GHz, comprising at least the 5.905-5.925 GHz band. Additionally, 5GAA advocates that sharing with unlicensed Radio Local Area Networks (RLANs) at 5.855-5.875 GHz should be considered, provided ITS spectrum is adequately protected.

The GSMA is participating in and consulting with global regulatory bodies to align the industry around a common approach to spectrum harmonization.

Conclusions

For road operators, automakers and mobile operators, C-V2X offers multiple technical and economic advantages over other dedicated vehicle connectivity technologies. Unlike the alternatives, C-V2X can support a very broad range of use cases spanning safety, navigation and integrated transport systems. One of the main advantages of using a cellular system is that it can address all V2X applications in an end-to-end manner with the same technology. That makes it very scalable and future-proof. Moreover, as part of the 3GPP standards family, C-V2X has the support of a broad and global ecosystem, while providing a clear evolution path from LTE to 5G. As experienced, trusted and licensed providers of an already established network infrastructure, mobile operators are well-placed to meet the automotive industry's need for secure, reliable, proven and scalable solutions.

Indeed, C-V2X has widespread support among automakers, mobile operators and equipment suppliers. Now that C-V2X technology has been standardised, it is being commercialised by vehicle manufacturers and mobile operators, working with road operators and municipalities around the world. C-V2X systems are beginning to go live in China, Asia-Pacific, Europe and North America.

As a matter of urgency, governments and public agencies need to ensure that there are no regulatory barriers preventing the widespread adoption of C-V2X. Rather than mandating the use of a specific technology in the spectrum bands dedicated to road safety, policymakers should allow stakeholders to select the most efficient and effective option to meet their needs. With a flexible and future-proof regulatory framework, C-V2X will help to transform road transport, delivering numerous socio-economic and environmental benefits along the way.

Ultimately, C-V2X will transform highways and cities by underpinning a cooperative intelligent transport system (C-ITS) that reduces congestion and pollution, improve safety and efficiency, and provides a better quality of life for all citizens.

By 2025, Connected Cars Will

Save **11,000** LIVES

Lead to **260,000** fewer **ACCIDENTS**

Avoid **400,000** tonnes of CO_2 **EMISSIONS**

Create a potential application **REVENUE** of **$253** BILLION

Save **280** MILLION hours of **DRIVING** every year

“Cellular networks have a coverage that is impossible for any alternative technology to achieve. This also includes devices like smartphones that are in everybody’s pockets these days. This means that already today C-ITS applications can be deployed on the cellular devices [...] Infrastructure and further investments in the cellular platform will be far more efficient in increasing traffic safety and saving lives. Advanced traffic solutions are also envisaged for the further evolution of cellular, towards 5G.”

Ulf Pehrsson, Vice President Government and Industry Relations, Ericsson
[Ericsson statement, November 2018]

“With plans to roll out 5G cellular networks underway, C-V2X can complement the sensors of self-driving cars. While these vehicles will be fully capable of operating without C-V2X, the technology could add to its comprehensive view from the LiDAR, radar and camera sensors. For instance, if emergency vehicles were equipped with C-V2X transmitters, they could notify self-driving vehicles that may be on their route so the vehicles pull over or reroute in plenty of time. Self-driving vehicles could even get real-time updates on road conditions that affect their routes.”

Don Butler, Executive Director, Ford Connected Vehicle Platform and Product
[Ford blog post, February 2019]

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Jaala Pulford, Victoria’s Minister for Roads
[Victoria State Government news release, June 2019]

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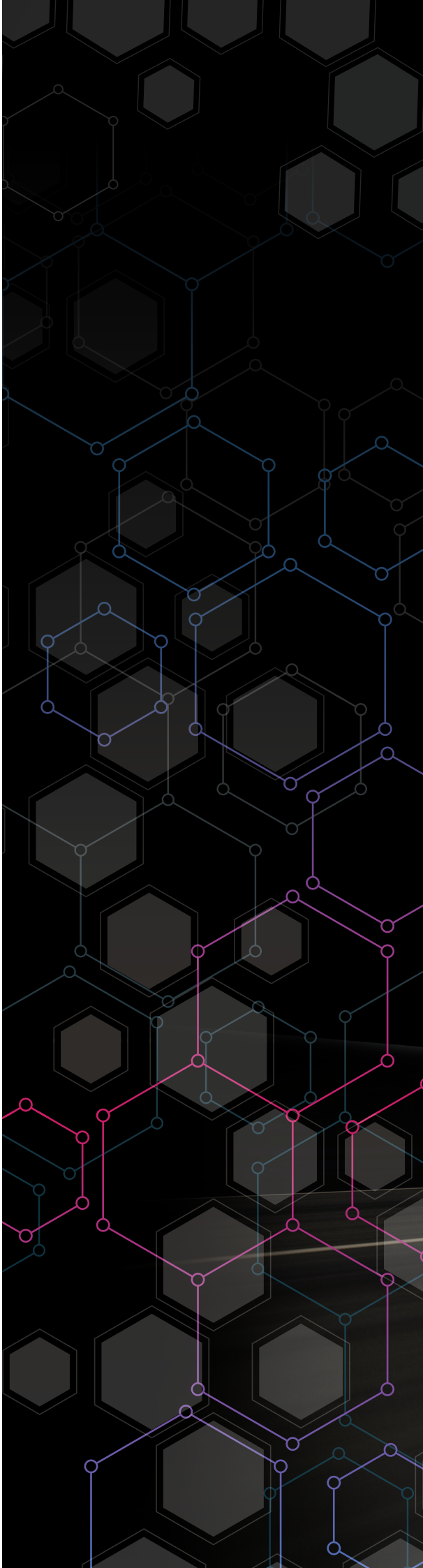
Luke Ibbetson, 5GAA Board Member and Vodafone Group’s Head of Research and Development
[5GAA statement at MWC Shanghai June 2019]

For more information please visit:
www.gsma.com/IoT



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