CONNECTING CARS ON THE ROAD TO 5G

Cross-Industry Whitepaper Series: Empowering Our Connected World

June 2017

Executive Summary

The automobile industry has demonstrated significant innovation in the past decades, and over the last few years, the combination of vehicles and wireless communications has enabled automobiles to do new things. Examples include allowing smartphones to be synced wirelessly with dashboard systems, provide location tracking via GPS systems, and even offer the option of enhanced multimedia experiences. In some markets, it is also possible to reduce your insurance premiums by allowing firms to remotely monitor your driving style, creating a whole new level of personal service.

The modern automobile represents the natural extension of a mobile user's experience, but there is a difference in how much control a user has over this: with a car, there are many factors outside the driver's direct control that have an impact on that experience. Connected cars also place different levels of demand on mobile networks. Some estimates suggest that by 2020, each individual connected car will generate upwards of 4,000GB of data per day[1].

In-car connectivity has already become an important consideration for customers today. Nearly half of new car buyers who spend over 20 hours per week on the road say that they would switch car brands if it meant having improved connectivity features. The importance of connected car services will only continue to increase and these services are therefore a major area of focus for those in the transportation sector.

The number of vehicles on our streets is also increasing. It is important to assess the reliability of network connectivity so satisfaction with the user experience can be maintained and improved. Mobile network operators must carefully consider the changing and growing needs of consumers, with an eye on the future of connected vehicles, as well as implications for intelligent transportation systems.

While the ICT industry is focused on how to improve current cellular networks and prepare for the next generation of networks, it is increasingly important to better understand data consumption as consumer behaviour evolves – and this includes behaviour related to the use of mobile devices in vehicles.

Major players from the automotive and technology industries have stepped up connected car research activities over the last five years. Between 2010 and 2015, over 2,500 inventions relating to V2X (Vehicle-to-Everything) technologies were filed, while a further 22,000 patents relating to self-driving cars were also submitted during the same period[2].

Currently, every major automobile manufacturer is actively testing integral technologies for future connected vehicles. New players such as Tesla, Google, Apple, and Faraday Future are also investing heavily in this area. They could very well affect the auto industry in much the same way mobile network operators have been impacted by the arrival of over-the-top (OTT) applications. These new market entrants are a further sign of the potential of this new area; they will encourage more newcomers, and stimulate established players to respond.

With the ever-increasing ubiquity of mobile connectivity, the connected car could very well be the catalyst for mobile communication protocols to become integrated in our cities, and for future applications that will further transform our lives. As with smartphones, consumer demand could be the driving force behind the emergence of truly connected cars, requiring mobile network operators to evolve their communications networks to meet growing requirements.

In this whitepaper, we will describe the factors influencing the transformation of the automobile industry and the ICT industry, the mobile communication standards roadmap for vehicle-to-everything communications, and consumers' evolving requirements for car connectivity.

Connected Car Definitions

In the world of connected cars, as in many cutting-edge technologies and markets, there is the potential for confusion in the use of names and abbreviations. Broad concepts can get mixed up with specific technology approaches; technology approaches can be confused with standards or proprietary product names. In this paper the following terms are used:

V2N
Communication between vehicles and mobile network (via base stations)

V2V
Direct communications between vehicles, primarily for safety

V2I
Communication between vehicles and infrastructure such as traffic signals

V2P
Communication between vehicles and pedestrians (and cyclists)

V2X
Vehicle-to-everything (all the above)

C-V2X
Cellular V2X; a suite of technologies using features from the mobile industry's 3GPP standards to deliver V2X

802.11p/WAVE
An IEEE standard communication protocol developed from WiFi and used for transportation applications (WAVE stands for Wireless Access in Vehicular Environments)

DSRC
Dedicated Short Range Communications; a V2X technology focused on safety applications, using 802.11p/ WAVE in specific spectrum bands

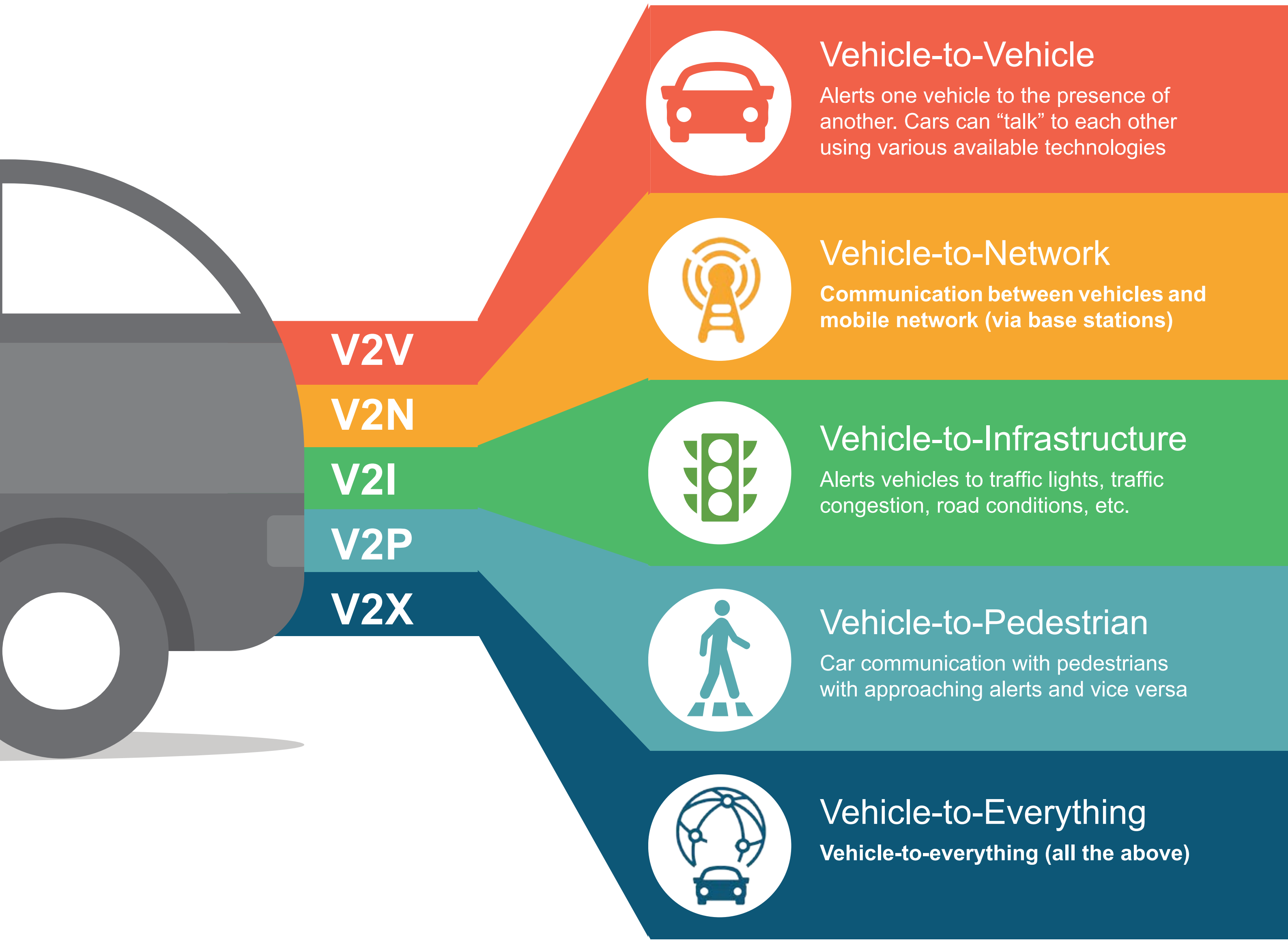
LTE-V2X
The current realization of C-V2X standardized in 3GPP

C-ITS G5
A European transportation communications standard based on 802.11p

The concept of vehicle-to-everything (V2X) communications was inspired by the idea that the car of the future would not only be an extension of a user's mobile communication experience, but would also satisfy the need for driving safety, reducing environmental impact, improving traffic management and maximizing the benefits of transportation for both commercial users as well as the general public. V2X can offer significant commercial opportunities for both the automobile and communication industries. This emerging innovative business has already attracted major investments from sectors including government, academia, manufacturing and logistics / supply chain management.

V2X enables vehicles to communicate with other vehicles, infrastructure and pedestrians. By using V2X communications, vehicles (more precisely drivers), receive real-time status information about surrounding vehicles, instructions from infrastructure and information about nearby pedestrians. Different types of pre-defined V2X cooperation and notification messages, containing vehicular speeds, movement direction and even route history, are exchanged between V2X transmitters and receivers. By analyzing the messages received, vehicles are then able to provide the corresponding notification or to alert drivers of possible impending danger and traffic congestion well in advance. The numerous advantages of this application include reducing the number of serious injuries and even fatalities that could result from vehicular collisions, reducing traffic congestion, and lowering fuel consumption as well as CO_2 emissions.

Vehicle-to-Everything (V2X)



Connected Car Evolution and Market Disruption

Since the introduction of the first car phone over 30 years ago, automobiles seemed destined to be connected. However, the road to reach this connected status is slightly less obvious than for other devices, particularly smartphones. At its core, a smartphone is a telephone. But with the advent of technology advancements in digitization and mobility, what was once a device which was primarily used for voice communications has become an integral part of daily lives and is transforming societies and industries around the world.

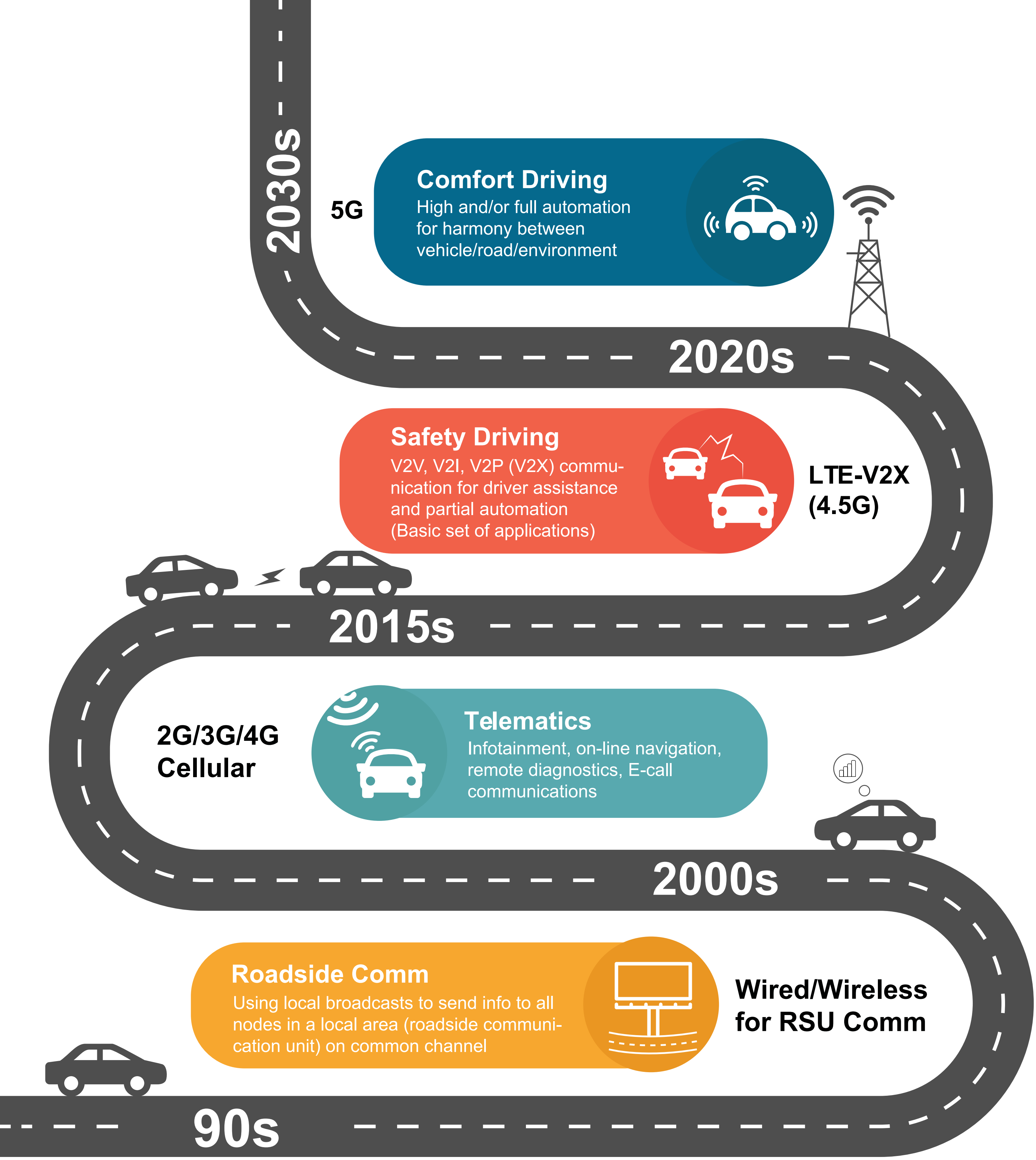
Automobiles have steadily become more "intelligent" over the last 20 years, albeit at a slower pace than telecom and IT products and services. The gradual adoption of technology can be explained by the marked difference in the lifecycle of cars compared to many other consumer goods. Smartphones, for example, are typically replaced every 18-24 months, whereas new cars have longer ownership periods – they are retained for an average of six years after they are purchased.

The integration of vehicles and connectivity can be traced back to high-end cars of the 1980s. These were fitted with physical car phones enabling business users to make calls on the move. As handheld mobile devices became prominent in the 1990s, in-car phones were phased out in favour of the first navigation-centric devices, which piggy-backed on GSM and GPRS networks to provide directions and traffic information.

In the last 5 to 10 years, smartphone usage has gone up dramatically, including in vehicles. Mobile applications such as GPS and music streaming have become common, and encourage the consumption of more data inside the vehicle. This type of usage can be adequately handled over a 3G connection, but increased use of satellite navigation applications with real-time updates on smart devices needs a data connection to load maps, and this often requires a 4G connection.

In 2017, every new car has the potential to be a "connected car" as infotainment services and software updates are provided via the Internet.

Another area of innovation over the last decade has been in the field of Advanced Driving Assisted Systems (ADAS), which are crucial to improving the in-car experience. Lane changing, assisted braking and cruise control systems are already on the market, and these technologies are evolving at a rapid pace. One of the most recent and prominent examples is Tesla's Autopilot feature[3]. While this is still in beta mode, it already provides a limited amount of hands-free driving and is being continuously refined with over-the-air updates.



Connected Car Communication Technology Evolution

How Connected Cars Will Disrupt The Market

Between 2015 and 2020, nearly 184 million connected cars will be produced, according to Gartner[4]. The industry consensus is that we still have some way to go before we see mass production or adoption of autonomous cars, but that the technological developments available today will move us closer to that objective. Sales of autonomous cars is expected to reach 21 million units in 2035, with the number of autonomous cars sold globally reaching 76 million units through 2035[5]. Connected and self-driving vehicles will have a profound impact on many industries, particularly in automotive, telecoms, logistics and insurance.

The more intelligent cars become, the greater the need there is for them to incorporate cellular connectivity as standard. A report from Allied Market Research suggests that the global connected car market may generate revenues of $141 billion in total by 2020[6].

Consumer expectations and buying behaviours are contributing to change. Today, consumers are likely to prioritize access to service over ownership – the proliferation of on-demand services such as Netflix, Amazon Prime, Spotify and even productivity software such as Office 365 shows how much the world is moving to a subscription economy. Giving customers access to such services in their vehicles opens up new ways for service providers to reach and support their audience.

This will become a big business that McKinsey defines as the “automotive revenue pool”. The company predicts that diversification towards on-demand mobility and data-driven services could create up to $1.5 trillion in additional revenue potential for auto manufacturers as the car becomes not just a vehicle but also a platform for other services[7].

General Motors is a prominent example of a manufacturer willing to make a change. The US firm made a bold statement at the beginning of 2016 by announcing it had invested $500 million in the car sharing service Lyft. The partnership will see the development of on-demand autonomous vehicles, the creation of rental hubs, and the introduction of personalized services[8].

Of the many potential benefits derived from connected cars the most important is increased road safety. Currently, the World Health Organization (WHO) estimates that 1.25 million people are killed in road traffic accidents every year and 90 per cent of these accidents are caused by human error[9]. The industry is certain that effective car-to-car communication can reduce those figures significantly by safely identifying and avoiding risk. That is not the only positive here: fully automated cars will also increase road utilization rates, lower fuel consumption and ultimately reduce CO_2 emissions[10]. Researchers have even suggested that using automated cars on motorways could reduce the transportation energy consumption by up to 25 percent[11].

Connected cars and the automated cars of the future are going to be hugely beneficial in terms of productivity as well. Morgan Stanley estimates that in the US alone, drivers spend a total of 75 billion hours behind the wheel each year[12]. By automating daily commutes, citizens will be free to work on projects, take calls, or even have a nap to ensure they are refreshed. Analysts predict the automation of these journeys will add approximately $507 billion to the US economy[13].

For millions of connected cars to co-exist on the road simultaneously, cars will need a deeper understanding of their surrounding environment, and will need to integrate advanced technology to make intelligent decisions. This will be made possible through the introduction of vehicle-to-everything (V2X) communication technology. V2X technology enables cars to communicate with each other as well as to share information with the city’s smart infrastructure, highways, data centers, mobile network infrastructure, mobile devices and even pedestrians, in real-time.

The information provided via these interactions will be essential in allowing future connected and self-driving cars to navigate to their intended destination efficiently and safely. The continuous flow of information will also help to maintain “swarm intelligence”, which can be used to train fleets of cars and ensure they are using the safest and most efficient routes possible – something that is of great interest to the logistics industry, and more widely: shared autonomous vehicles have the potential to dramatically reduce costs.

Traditional vehicle operating cost per mile today	Shared autonomous vehicles operating cost per mile in 2040	Pooled shared autonomous vehicles operating cost per mile in 2040
US¢66	US¢29	US¢12

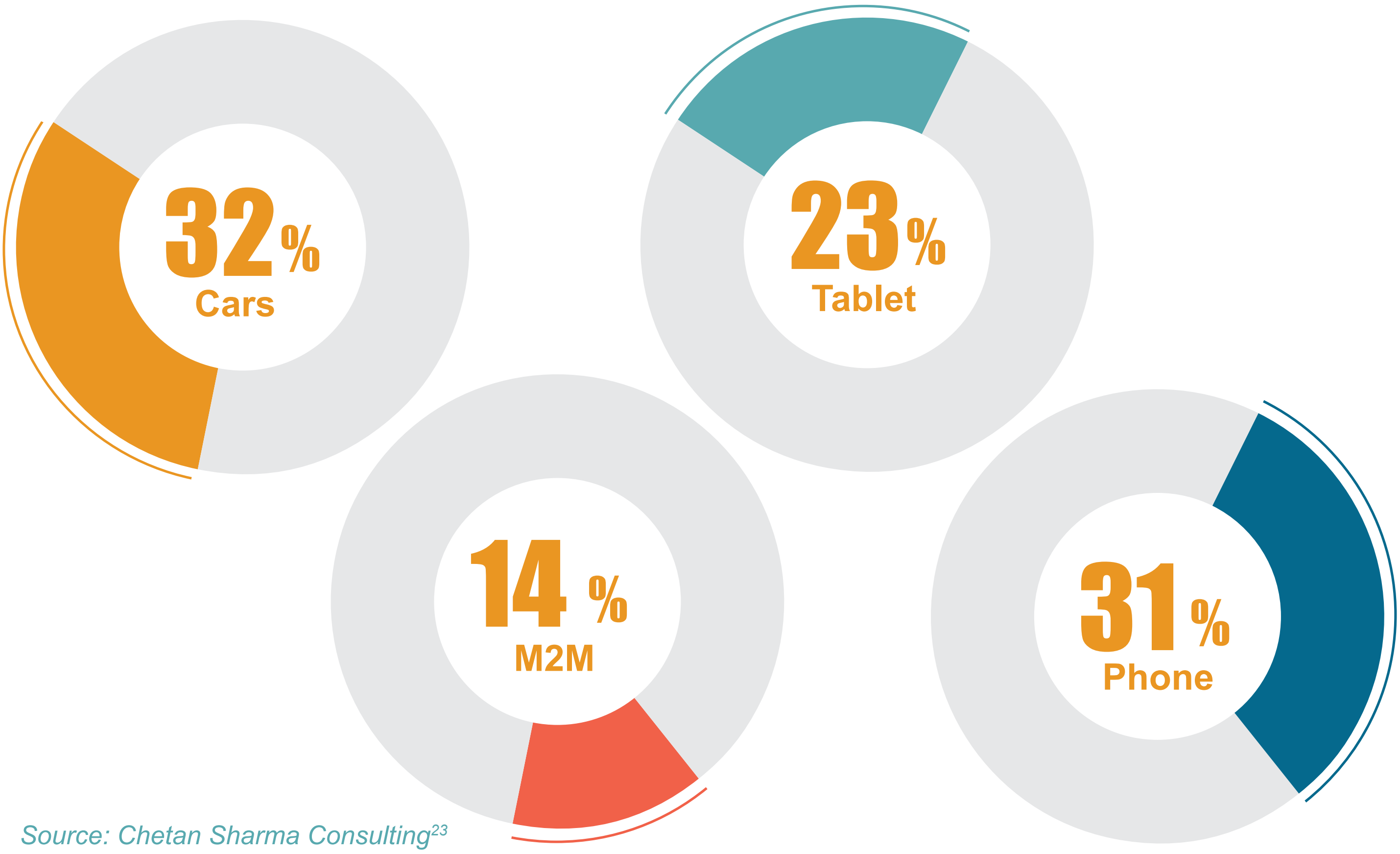
Source: Barclays Research Insights[14]

Connected Cars Are Profoundly Influencing The ICT Industry

According to McKinsey, the term "connected car" is already one of the most intensely debated buzzwords in 2016[15]. Gartner's Technology Hype Cycle positions "autonomous vehicles" at the peak of inflated expectations just between the "internet of things" and "advanced analytics"[16].

Over the past decades, the auto industry has evolved at a somewhat slower pace than telecommunications and IT, as product differentiation has moved gradually from power and size towards more comfort and security features. But the automobile itself is one of the most important purchases for the average household, and is considered much more significant than cellular or fixed Internet telecommunications both at an individual and macroeconomic point of view.

More cars than phones were connected to cell service in Q1



Source: Chetan Sharma Consulting[23]

What makes the automobile interesting for mobile communications is the simple fact that it is an enclosed environment capable of transporting a person or persons from one place to another. There are striking parallels between a person using a smartphone and a person driving a car and there have been several attempts by both industries to integrate the experiences. So far, the most common uses of telecommunications in an automobile are hands-free calling and mapping / direction applications. Both applications can be performed directly with a suitable smartphone and do not require full integration of automobile and telecommunications.

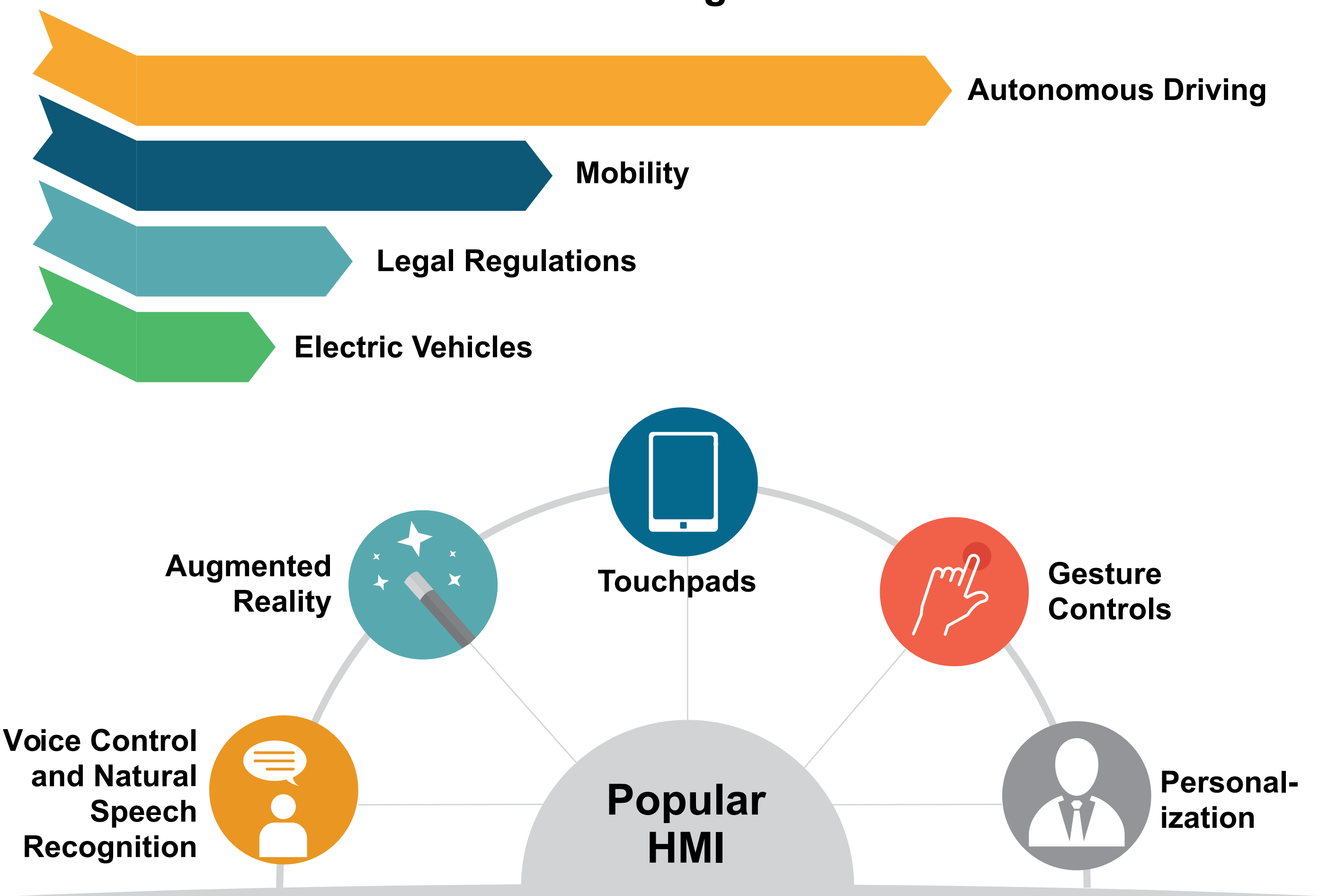
The evolution of the mobile telecom industry as technologies have changed has been more profound than the auto industry's evolution in recent years, and has required changes to what were once traditional business models. Mobile network operators continuously strive to expand the coverage of their network by performing network upgrades generally on an annual basis. Standardization runs ahead with a new release by the 3GPP around once every 18 months, while the introduction of new features and latest technologies by network equipment suppliers generally happens on a quarterly basis. Consumers keep their smartphones for an average period of 18 months.

While transitioning from 2G to 3G and 4G, mobile network operators have provided more minutes of use, higher speeds and more data volumes as the average revenue per user reached a plateau and began to decline. Advances in new technology have resulted in lower margins for mobile network operators, and new 5G networks will deliver even lower revenue per bit than previous networks, but they will open doors to new revenue streams, delivered in different ways, particularly from vertical sectors such as automotive, industrial and healthcare.

Disruption To The Automobile Sector

In contrast to the telecoms sector, the automotive industry works on longer replacement cycles. The development phase of a new car model takes about 8 years. Once introduced into the market, this model line will be sold for about 8 years with a major redesign scheduled at mid-term. Because of this lengthy development cycle, some of the human-machine interface (HMI; see graphic) and infotainment features originally integrated during the development phase are almost out of date when they hit the market since technology evolves at a faster pace than the vehicle design.

Trends Influencing Vehicle HMI [17]



Compare car manufacturers' in-car navigation systems with the latest smartphones. They both offer the same basic capabilities, yet using a smartphone for in-car navigation is only a fraction of the cost, or even free. Furthermore, the technologies integrated in the latest smartphone are more advanced than the latest in-car models in most cases. There seems to be an urgent need for auto manufacturers to adjust their business models by integrating electronics and software so that new technologies are upgraded over the lifetime of their products. Today, people commonly use smartphones for in-car navigation rather than the factory-installed systems, even in high-class luxury models, and especially if the car is over 3 years old.

One area in which the auto industry has seen a lot of changes is mapping. High definition maps are crucial for advanced driving assistance: carmakers Audi, BMW and Daimler-Benz acquired mapping company HERE from Nokia, recognizing this fact. The technology powering HERE is based on a cloud-computing model. Car maker Tesla also uses cloud computing as each of its cars continuously sends information to the cloud. If a car were to encounter adverse road conditions and react to compensate, information related to the car's response could be automatically sent to the cloud, allowing another car to change its suspension and stability settings accordingly. With gigabytes of data being constantly transmitted to and from the cloud, real-time information about traffic, road conditions and other parameters then become readily available.

Prompted by innovations like these, the automotive industry is beginning to change a business model that has remained stable for over a century.

Business Models To Realize The Value Of Connecting Cars

A study by McKinsey indicated that car manufacturers make most of their margins from the initial purchase of a vehicle[18]. This represents 52% of the overall life cycle revenue, while connectivity features and related services are estimated at 4% of the initial purchase price. Additionally, the manufacturers collect another 6% from the sale of spare parts and maintenance services, and 24% for various operational expenditures. Insurance on the car comes in at around 14%. The initial purchase of the car generates the bulk of the revenue for automakers. But this is about to change.

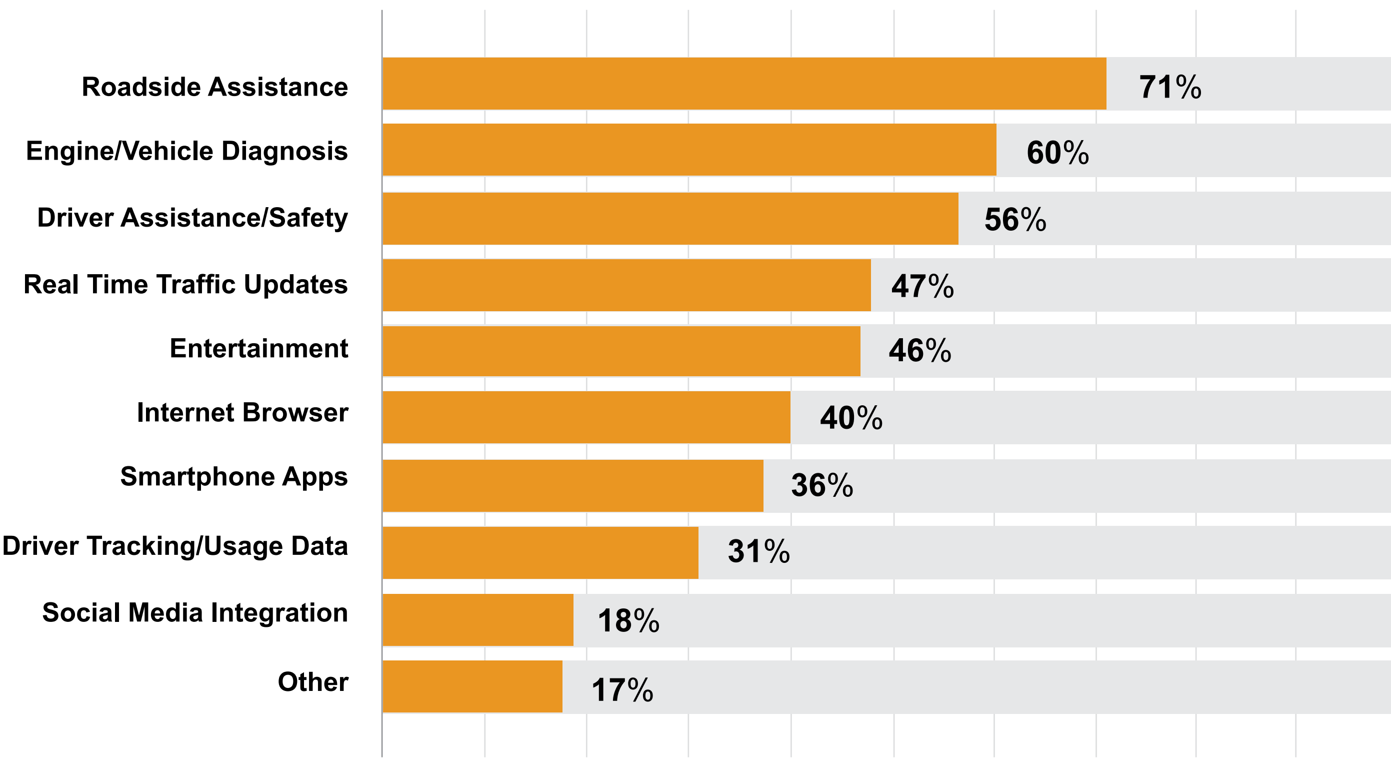
A significant finding of McKinsey's research is that an average of 37% of new car buyers said they would switch to another car brand were it to offer better connectivity features[19]. Previous McKinsey studies show that this number is higher for those who spend over 20 hours per week in their car.

Consumers already understand the value of connectivity for cars in areas relating to driving, maintenance and insurance. For instance:

- Displaying the average and instant fuel consumption has influenced certain drivers to adapt their driving style to effectively reduce consumption
- Adaptive maintenance, which automatically schedules a service appointment through self-analysis of the data provided by sensors and cloud, enables a more efficient preventive maintenance service
- Telematics-based tailored insurance tariffs such as pay-as-you-drive, or pay-how-you-drive, are being introduced, based on insurance "black box" units that many drivers are now familiar with.

A survey by Ipsos identified those connected services that were of most interest to consumers.

Must Have Services[20]

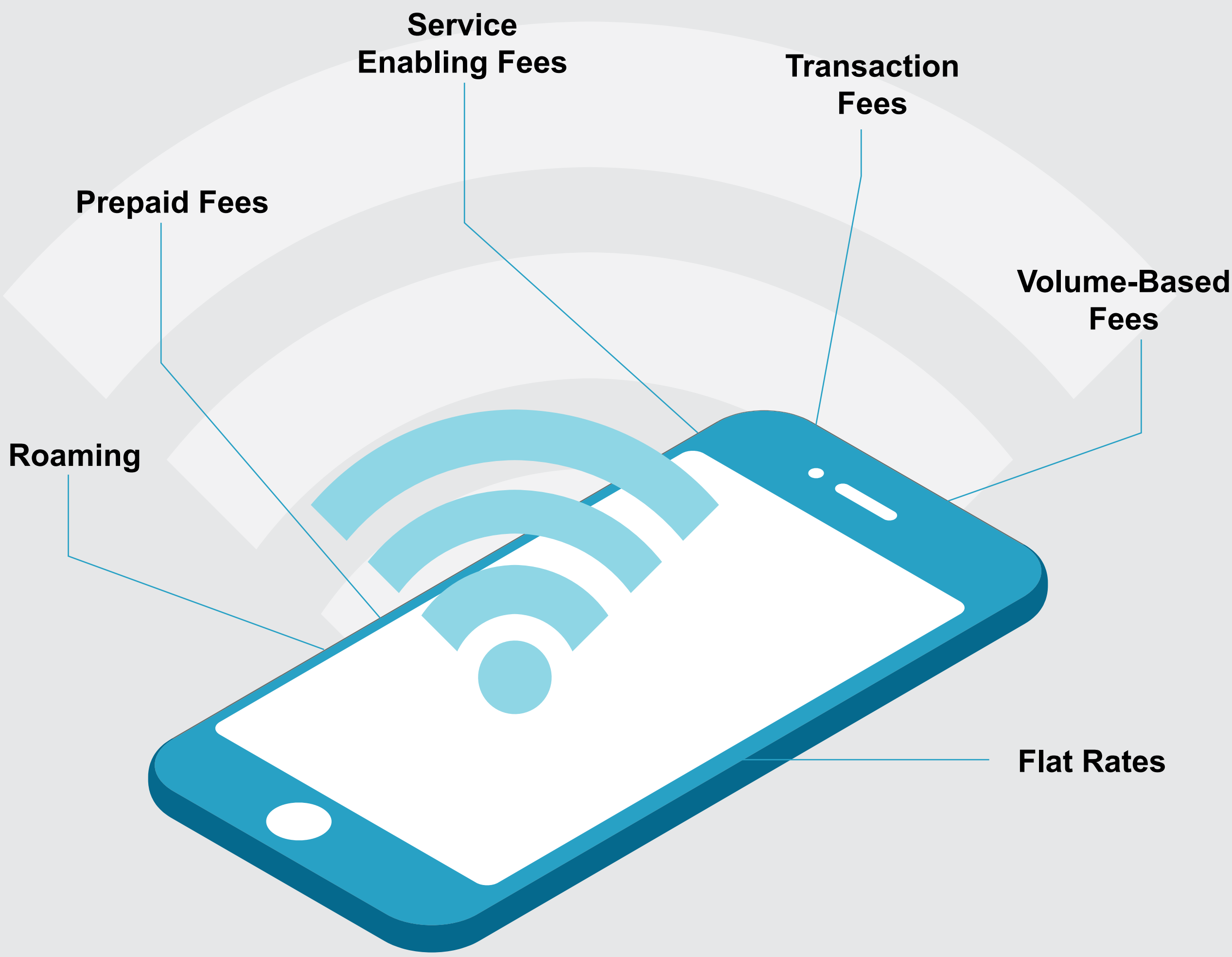


There are wider trends affecting how consumers interact with vehicles, too. For instance, in urban societies all over the world, car sharing and car pooling are gaining in popularity, and Uber and others are shaking up the traditional taxi business in many countries.

Auto makers must learn to monetize connectivity and respond to other changes that are disrupting their industry. Early applications indicate the type of business models that can be used, and example business models are compared in the box.

Comparison of Business Models (Using Germany as an Example)

Mobile Broadband Model
In Germany there are around 80 million inhabitants, spending about 25 EUR per month (ARPU) on mobile broadband services, giving total revenues of 24 billion EUR per year. This revenue is captured in several ways:



Underpinning these revenue lines are complex charging, billing and customer care systems, authentication processes, proxies and gateways. Vertical-market services might introduce other, indirect billing options.

Car Insurance Model
The German car insurance market generated revenues of 25.2 billion EUR in 2015, with spend on damage of 21.9 billion EUR. Car insurance companies now offer specific rates for drivers accepting a black box that records their driving behaviour. Drivers with a “defensive” (cautious, safe) driving style will get a bonus; others will continue to pay the normal rate. It is to be expected that the normal rate will increase. The model is intended to incentivize poor drivers to change behaviour and lower the risk of accidents.

Connectivity Developments

The 5G Vision And The "Innovation Gap"

5G network technologies, which are being developed by the telecoms industry now, will be key enablers of innovative applications in the auto industry. By delivering ultra-low latency of 1ms, having capacity for 1 million connections per square kilometre and providing 99.999 per cent reliability, 5G will boost the safety and efficiency of future connected cars and help spur the development of self-driving cars.

> **"[On] a 4G network, a self-driving car travelling at 100 km/h will continue to move 1.4 metres from detecting a failure to applying the brakes. This can be the difference between life and death. On a 5G network, the same car will move just 2.8 centimetres, and this is comparable with the standard of Anti-lock Braking Systems (ABS)"**
>
> ***Ken Hu,***
> *Deputy Chairman of the Board, Huawei*

The automobile industry has very stringent performance requirements and demands adherence to very detailed specifications, and will also need assurance about continuity of quality of service and clearly defined pricing models so that innovations can be widely accepted and adopted. Consumer demand will speed up the process by which the automotive and ICT industries develop workable, safe, reliable solutions based on 5G.

Huawei and its partners have conducted numerous field trials related to 5G connectivity. These have already yielded average speeds of 3.6Gbit/s using 100MHz of bandwidth — almost 10 times the speed of 4G. Commercial deployments of 5G are expected to begin in the next five years, and by 2025, GSA predicts approximately 270 networks worldwide are expected to have full 5G capabilities[21].

There has been a global surge in research and development activities surrounding 5G and there is a heightened expectation that the mass adoption of 5G communications will be the catalyst that will inspire new services and applications in many industries – not just telecoms and automotive. But until 5G arrives, many connected car use cases will be met by C-V2X technologies such as LTE-V2X.

Whilst 5G promises new innovations and applications for the automobile industry, it is not quite around the corner. The big auto industry players are planning for 5G being commercially viable in 2022, with mass-market adoption following afterwards. This leaves the auto industry with a connectivity "innovation gap" of at least half a decade. Moreover, there is some concern that current available technologies will require a complete overhaul or a massive upgrade to accommodate latency and bandwidth challenges for real-time applications. This issue is addressed by LTE-V2X which presents a clear evolutionary path from 4.5G to 5G through 3GPP standardization.

For any connected car application, even the most advanced, functional safety is key since the lives of the driver, the passengers and the pedestrians depend on it. As such, solutions enabled through a mixture of sensor and communication technologies are preferred and, in many cases, even essential. In any case, the communication links need to be robust against congestion over the air.

Currently deployed communication infrastructures limit applications for connected cars to functions such as GPS navigation and traffic information. Providing infotainment, telematics, safety and other advanced functions requires a reliable, secure, low-latency communication system capable of handling multiple connections in a variety of different scenarios with guaranteed QoS. The use of cellular networks would be a viable option which could deliver on every one of these requirements while also supporting other mobile connections. Ideally, what is needed is a flexible and dedicated solution for proposed scenarios for vehicle communication, rather than separate technologies used for specific applications. The automobile industry therefore needs a readily available communication standard which can satisfy all scenarios and is also able to bridge the gap to 5G. This is where the LTE-V2X standard can have a tremendous impact.

Technical specifications

3GPP standardization

Standardization is essential to maximizing interoperability, safety and quality as well as global compatibility. The V2X feature has been introduced into Release 14 of the 3GPP standard (the standards-setting body for the mobile telecoms industry) and the initial version of LTE-V2X was completed in September 2016. Further enhancements to support additional V2X operational scenarios leveraging the cellular infrastructure, also for inclusion in Release 14, became available in March 2017. As part of Release 14, 3GPP is also working on V2X network architecture and security based on the current evolved packet core network.

From the RAN point of view, V2V/I/P communications are supported on the PC5 interface at 5.9GHz. For such communications, additional DMRS symbols for each sub-frame were added to handle the high Doppler associated with relative speeds of up to 500km/h and at high frequency (e.g., 5.9GHz ITS spectrum). 3GPP enhanced the radio resource allocation mechanism to improve the system-level performance with high vehicle density while meeting the stringent latency requirements of V2V/I/P. Also, GNSS-based synchronization was introduced for both in-coverage and out-of-coverage cases.

V2N communications are supported through the Uu interface in bands licensed to mobile network operators (e.g., 800, 1800, 2600 MHz). In this scenario, the vehicle will transmit messages to the network base stations through the Uu interface on the uplink. If the messages need to be transmitted to other vehicles, the network base stations can broadcast these through the Uu on the downlink by means of SC-PTM or eMBMS. 3GPP will specify a mechanism for enabling E-UTRAN to select between PC5 and Uu for transport of messages between vehicles when the vehicles are within network coverage.

Available Technologies

There are some technologies available that can already deliver aspects of V2X communications. Some, such as IEEE 802.11p, have been around for several years, but have not been used commercially and cannot deliver the features needed for safety applications due to deferred transmissions when congestion occurs over the air. Innovations in mobile connectivity have also delivered new technologies such as the recently trialled and standardized LTE-V2X solution.

There are many advantages associated with using LTE-V2X technology as a foundation for V2X communications. LTE-V2X is based on a variant of 4G; it can connect vehicles to the cellular network (V2N) and support V2X communications effectively and reliably. The solution is low cost as it uses only one chipset, and it can be rapidly deployed as it is compatible with existing base stations.

LTE-V2X has been extensively trialled by Huawei and its partners. At the Zhangzhou Test Zone, Huawei, China Mobile's Zhejiang Branch, and SAIC Motor Corporation are testing LTE-V2X for everything from intelligent traffic lights to V2V communications on a 5km stretch of road. The aim is to determine how to deploy this technology to increase road efficiency and safety and to create a roadmap for the rollout of V2V communications in the near future.

In July 2016, Deutsche Telecom announced it had upgraded its infrastructure with LTE-V2X hardware from Huawei to support field trials. Audi and Toyota have been testing cars on the digital A9 motorway test bed near Ingolstadt, Germany, and will provide feedback to further enhance the LTE-V2X standard. And in September 2016, Huawei simulated real-life driving scenarios by performing live LTE-V2X trials at the G20 Summit in Hangzhou.

How Technologies Compare

Although connecting automobiles is rapidly becoming mainstream there are still questions about where and what to connect, and what for. There are several options and scenarios.

The most natural way to evolve cars is to add more sensors, radar systems and cameras to the vehicle itself and not worry about connecting those devices to a network. This is the preferred option of some premium car manufacturers because it is independent of infrastructure, radio coverage, or interaction with other companies or legacy systems and services. This approach can provide the user with visibility from a few metres to around 100 metres (with line-of-sight) and is limited to the gap between the vehicle and the ones in front and behind.

But if sensors and other equipment are to be connected via a network, the primary question is "how do IEEE 802.11p, LTE-V2X and 5G measure up against each other?" The best way to answer this is to perform a thorough comparative evaluation of these technologies, and point out the advantages of each one of them. The table below presents some key facts.

	802.11p	LTE-V2X	5G
Coverage	100s of metres	V2N: same as cellular network V2V/I/P: 100s of meters	Cellular and direct communication (ad hoc*)
Frequency band	ITS spectrum 5.9 GHz	V2N: Mobile spectrum V2V/I/P: ITS spectrum (e.g. 5.9 GHz)	V2N: Mobile spectrum V2V/I/P: ITS spectrum
Channel bankwidth	10 MHz	V2N : same as cellular network V2V/I/P: 10/20MHz	Up to 100 MHz (perhaps greater)
Robustness Doppler / Delay	Good Doppler compensation, good robustness to delay spread for short packets, potential issues for long packets due to short coherence time of V2X channels	Medium Doppler and good delay compensation	High. New waveform supporting highly dispersive channels in time and frequency
Maturity of standards	Several years of availability but few commercial deployments	Standardised in Q1, 2017	Will be standardised in 2020
Targeted use cases	Day 1 Only broadcasting	Day 1, 2 Release 14 Direct and/or network-assisted broadcasting communication	All Day 1, 2, 3 cases including cooperative and autonomous driving, real-time protocol with acknowledgment
Services			
Emergency breaking	Yes	Yes	Yes
Assisted driving	Some	Some	Yes
Latency and reliability for autonomous driving	Limited 100 ms 90% reception	Limited 100 ms 90% reception	1 ms 99.999% hard real time

**Ad hoc communication is a term used within the IEEE community for networks that are established and released. In this context, it refers to, say, a group of cars (not necessarily all travelling in the same direction) forming a group for a limited time, to communicate between themselves. The idea is fundamentally different from broadcasting, as used in IEEE 802.11p, where there is no acknowledgement of messages.*

It is likely that in practice, the best-performing solution may be a communication system combining sensors and cameras, complemented by a high-definition mapping system, which in turn receives real-time updates over cellular networks, and direct car-to-car communication with ad hoc network functions.

The requirements for direct car-to-car communications vary from one device to another because of factors associated with mobility, such as driving speeds and channel characteristics. Ad hoc networks can become quite inefficient if the number of hops becomes significant, due to protocol overhead. A practical limit might be five hops. If there is an active antenna system located in the front and rear of a car, the number of hops can be doubled. In this respect, cellular networks constitute a feasible option as they can support a combination of centralized (network-assisted) and decentralized (ad hoc) radio resource management resulting in much more efficient communications.

The next section looks in more detail at how different communications technologies match some of the connected car use cases that are being developed.

Mapping Use Cases To Existing And Future Technologies

Proposed intelligent transport systems (ITS) include a variety of innovative applications that will require advanced network connectivity, and for which in-built mobile connections supporting LTE-V2X and 5G will be most suited.

An obvious use case for the connected car is infotainment. The use of smart phones in cars faces limitations – for instance the shielding of the metal structure can inhibit network performance. In contrast an integrated LTE module with an active antenna can significantly improve the user experience.

Looking beyond the provision of entertainment, though, there are three less obvious groups of use cases that will be better supported with more advanced mobile connections:

- Communication-oriented use cases
- Environmental data processing
- Applications enabled by cloud computing

These are discussed in more detail below.

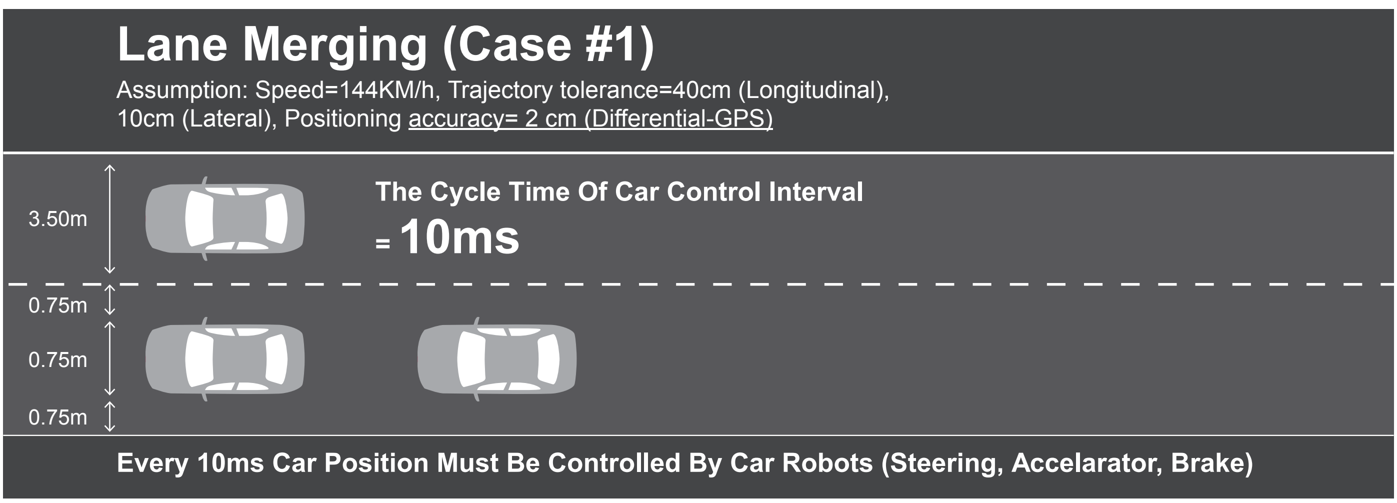
Communication-Oriented Use Cases

Cooperative Driving

Cooperative driving is one of the intermediate technologies being developed as innovators work to create fully autonomous vehicles. Driving can be co-operative in many ways. One of the illustrative test cases for this technology is automated lane merging to maximize the overall capacity of the road. For an overtaking vehicle to most efficiently re-enter a slower lane during periods of dense traffic, it is ideal for any vehicle in front of it to accelerate slightly, and for the following car to slow down to make sufficient space for the merging car. The same process is also desirable when a vehicle enters on to a dense motorway.

To perform this kind of function the three involved cars need to communicate, and the communication process cannot afford to be slow – they need very low latency. Systems based on IEEE802.11p use a broadcast method of enabling vehicle-to-vehicle communications and there is no acknowledgement of receipt of any messages, so its applicability for this use case is limited.

Both 802.11p and LTE-V2X can use broadcasting for emergency trajectory planning. In this scenario, every vehicle broadcasts its identity, position, speed and direction. Every vehicle uses that data to build its own map and determine whether any other vehicle is on a potential collision trajectory. However, as soon as reliable communications are needed that can be accomplished with no more than a 10ms round trip delay, 5G technology will be needed.



Platooning

The idea of platooning is to link trucks or cars automatically in a convoy of vehicles that are much closer together than can be safely achieved with human drivers. The aim of creating a platoon is to save fuel, and to make the transport of goods more efficient. One German project (Gigaliner) tried to emulate these aims by using very long trucks. Platoons are expected to be more flexible, however, because platoons can be established on motorways, but then broken up when a vehicle needs to leave the motorway and move on to a secondary road.

Platoons made up of two or three trucks can be established using sensors and communication between the vehicles based on existing communication technologies. In this scenario, each truck communicates with its immediate neighbor. This configuration does not work so effectively for longer platoons because propagation of messages takes too long. Braking must be synchronous: you cannot assume that the lighter trucks with the better brakes will be located at the rear of the platoon. Where longer platoons are required, technologies such as LTE-V2X can deliver an advantage because they offer deterministic communications, with 5G providing enhanced platooning through much reduced latency.

Tele-Operated / Remote Driving

In the case of tele-operated driving a vehicle is driven by someone in a remote location, rather than someone in the car. The vehicle is still driven by a person – it is not automated.

This sort of configuration could potentially be used to deliver a premium concierge service, to enable someone to participate in a conference or do some work while on a journey. It could also be used to support a taxi service, or to help a person without a driving licence, or when they are ill, intoxicated, or otherwise unfit to drive.

To make this service work it is necessary to have a perfect radio link with full round trip delay below 10 ms. This is fast enough that instructions can be received and acted upon by the systems just as quickly as the human eye can perceive change. 5G networks will be needed.

Environmental Data Processing Use Cases

See-Through, Sensor Sharing / Camera Sharing

Future vehicles are expected to be able to share sensor data and camera images, even enabling cars to effectively “see through” other cars and trucks in front of them. A heads-up display (HUD) or augmented reality display on the driver’s windshield would combine what a driver can see, with what the vehicles in front can see. This requires perfect synchronization of high definition video streams, and time alignment is crucial.

Relevant work is underway at the IEEE to create standards for time sensitive networking (TSN) based on Ethernet. Ultimately only 5G networks will be able to deliver the bandwidth or the latency performance required to support this kind of feature.

Augmented Reality Mapping

Moving beyond “see through” technology, innovators are researching ways to build high-definition 3D maps out of stereo pictures derived from advanced dash cams. In this scenario 3D camera information would be overlaid on to existing digital models of the surrounding environment.

Imagery from stereo dash cams in multiple vehicles would be uploaded into the cloud. Multiple images can be overlaid (in a collaborative oversampling approach) to create a very sharp 3D image of the landscape (using the same sort of process employed by cameras which overlay 3 to 5 images to create one ‘perfect’ image). The 3D image is not necessarily limited to the spectrum of visible light but can include also infra-red. This augmented reality mapping approach is expected to produce much better maps than existing services such as Google Street View.

Once the 3D image of the world has been created, a car can compare that 3D model with reality to identify differences between the stored model and the real-time image. Items that can be identified include pedestrians, animals, cars, motorcycles, and details like the changing surface of a street.

This approach would not require real-time, non-stop transmission of video from the car, but would require timely receipt of the centralized map data at the car to enable comparisons. 5G networks would be required to meet the required data rates, and enable time synchronization of images. Elektrobit Automotive has proposed something similar, but its system would use the latest high-end cameras instead of collaborative oversampling.

Applications Enabled by Cloud Computing

Telematics, Mobility Profiles, Insurance, and Theft Prevention

Businesses are increasingly sophisticated users of analytics tools to interrogate large and multiple sets of data (big data) to improve their activities. Data sets typically used are purchase history, geographical data and social profile information. Location-based services have also been introduced, although widespread use of mobility data is restricted in some jurisdictions due to concerns about protection of personal data. Nevertheless, there is a huge opportunity to be gained from exploiting mobility data – even in anonymous form. One innovator doing this is TomTom. It is augmenting its traffic maps by using data about movement speeds reported by its devices, and by analyzing where speeds are significantly slower than the local speed limit, it can identify traffic jams.

Insurance companies are also collecting mobility data. They already offer the option to install a telematics device which reports back on driving styles, speeds and locations. This data is collected in the cloud and analyzed, and then used to determine the risk of insuring each driver, and hence the level of that individual's insurance premium.

Theft prevention is another application that will take advantage of cloud-based storage of data and advanced analytics. As the future connected car will be continuously exchanging data with the cloud (including its location), it will be quite simple to track where the car is, and who is driving it.

Where permitted, it is only a small step from the TomTom, insurance and anti-theft approaches to correlate data to figure out where people work, where they live and where they shop; and to sell them appropriate services using that information.

Overcoming The Challenges

Before connected cars, and later, automated connected cars can become widespread, manufacturers, mobile network operators, and regulators must overcome several significant challenges.

Coverage and Take-up

Probably the biggest challenges for any mobile communications technology are to provide sufficient geographic coverage, and to reach critical mass in terms of actively used commercial terminals so that the service becomes commercially and economically viable. It is the ability of cellular mobile technologies to provide national coverage for "network assisted" V2X communications which sets them apart from other ITS technologies.

As described earlier, LTE-V2X supports V2N communications using existing mobile bands (e.g., 800, 1800, 2600 MHz) for coverage, and V2V/I/P communications using the core 5.9 GHz ITS band. 5G is being considered to provide coverage initially in bands such as 700, 1400 and 3600, in addition to very high data rates at bands above 24 GHz.

In the past operators employed a fall back mechanism. In locations where faster technologies (such as LTE or 3G) were not available, slower technologies (such as 3G or 2G) were used. Consequently, the newer technology was deployed in zones (typically busy urban areas) where immediate cash flow could be generated for further investments. In contrast to these classic deployment strategies for mobile networks, connected car applications require coverage to be provided first for roads and motorways, including those in rural areas.

National administrations are increasingly aware of the need for a high quality of coverage along transport routes. This is evident in the recent 5G Action Plan of the European Commission which sets the objective of "Ensuring that every Member State will identify at least one major city to be '5G enabled' by the end of 2020 and that all urban areas and major terrestrial transport paths have uninterrupted 5G coverage by 2025."

Finally, as mentioned previously, cars are replaced on average much less frequently than smartphones. This leads to a much slower rate of adoption for new technologies introduced by manufacturers. This is demonstrated by the rates of adoption of ABS, air bag technology, and GPS. It takes years to achieve high penetration within the global installed base. Traditionally, the latest technologies were almost always initially reserved for high-end models or offered at a premium price. But mounting pressure from the increased speed of innovation and from overall market demand has forced automakers to introduce the latest innovations across their model lineups. In the case of Mercedes-Benz, for example, the company has reduced its prototype production period from 18 months down to 10 months, and plans to introduce breakthrough technologies coinciding with their earliest model debuts.

Security

Safety is a priority concern for carmakers, and in the context of connected cars creates challenges for both automotive manufacturers and their partners such as network operators. Of particular interest is data security. This will need to be addressed before connected cars (and later, autonomous connected cars) achieve mainstream acceptance. McKinsey estimates that 54 per cent of consumers are afraid that connected cars can be hacked and manipulated[22]. It's easy to see why. Car manufacturers are promoting connected cars as 'personal assistants' on wheels. Cars will know everything about you, including your name, age, address, daily schedules and frequented locations. They will be a virtual goldmine of information, and are expected to become a prime target for hackers looking to find and to exploit confidential information.

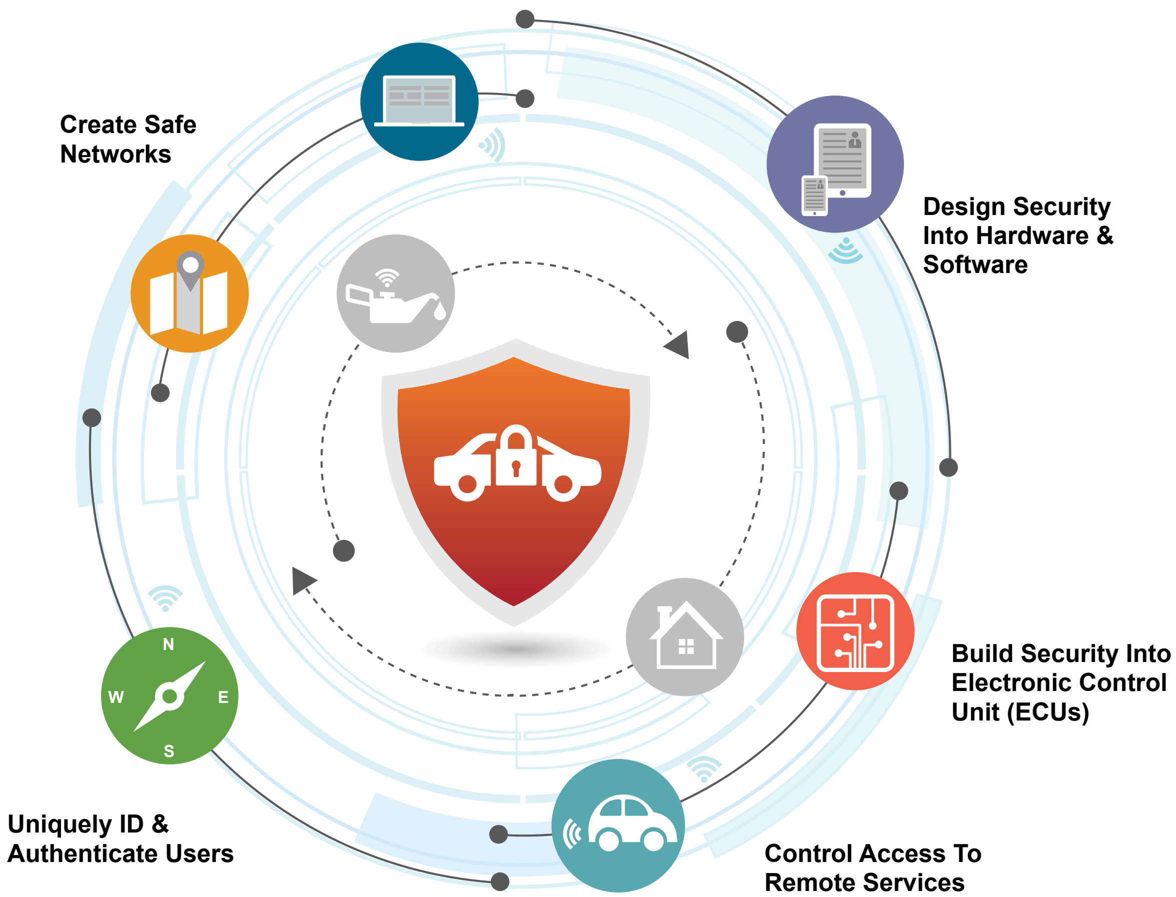
MAJOR VULNERABILITIES

Communication Channels	Threat
RFID Keys	Car can be immobilized
Keyless Entry	Jammers block alarms & access car
Tyre Pressure Monitoring	Can be hacked
Bluetooth	Malicious software

In-Car Hacking	Threat
USB ports	Software malware
Infotainment Interfaces	ECU system vulnerabilities
OBD II ports	Access to key auto controls

Remote Hacking	Threat
Cellular/ Telematics	Access to internal units and ECU
Dedicated Short-Range Comm	Malicious inputs to other cars
Wi-Fi	Opens vulnerability to OBD II port

HOW DO WE SECURE OUR CARS?



Early evidence already suggests that in-car operating systems will be a weak link. In 2015, white hat hackers exposed a flaw in the Jeep Cherokee's 'Connect' infotainment system. They demonstrated that the car could be hijacked while moving, resulting in a recall of 1.4 million vehicles. Vulnerabilities in various other models such as the Tesla Model X have subsequently been publicized, foreshadowing the challenges on the horizon.

Legal/Regulatory Issues

Even once the coverage, penetration and security hurdles have been overcome, there will be additional challenges. Governments around the world need to finalize legal and regulatory frameworks, identify safety standards and be ready to enforce them. Cities will need to reassess the planning and management of traffic flows. Automobile manufacturers and network operators need to agree on industry-wide standards and establish successful business models.

Given these challenges, bringing the concept of connected cars to reality requires several key groups of players to combine their expertise. Recognizing this, Huawei is committed to working with both traditional car manufacturers and market disruptors to provide the wireless communication solutions that will enhance the connected car experience. Based on current progress as well as network capacity growth around the world, it may even be possible that we see self-driving cars on the road before 2030.

Conclusion

The automobile and ICT industries are converging to create new consumer experiences and new ways of working. The car and other vehicles are increasingly connected – to each other, to networks and infrastructure, to pedestrians and others - in ways that enable changes in how people move, work and spend their time. New business models are emerging as a result of this increasing connectivity.

It is not yet clear what types of connections will be used for different purposes within the vehicle, and with other devices: there are some existing technologies which can deliver only part of the comprehensive V2X connectivity picture and have not been widely deployed.

Cellular network technology is evolving fast, with the standardized LTE-V2X likely to deliver much of what the connected car industry requires. A little way into the future, 5G networks will arrive to deliver the remaining functionality – opening up the prospect of autonomous vehicles.

The ICT and automotive sectors cannot wait for 5G: consumers recognize the value of good connectivity and will look for it when they next buy a vehicle. Use cases for many V2X applications can be delivered with LTE-V2X, and LTE-V2X provides a step on the road to a 5G-enabled connected autonomous car future. While currently available in-car sensor technologies as well as communications technologies can deliver some V2X needs, ultimately only 5G will provide the reliability to satisfy fully autonomous driving applications and stringent functional safety requirements.

1. http://www.intel.eu/content/www/eu/en/it-managers/autonamous-cars.html
2. http://images.info.science.thomsonreuters.biz/Web/ThomsonReutersScience/%7B86ccb67a-e45a-4c3a-8513-5350b39929de%7D_tr-automotive-report-2016_final.pdf
3. https://www.tesla.com/presskit/autopilot#autopilot
4. http://www.gartner.com/newsroom/id/3460018
5. IHS Markit — https://www.ihs.com/expertise/research-analysis.html; http://readwrite.com/2016/06/15/millions-self-driving-cars-expected-global-roads-2035-tl4/
6. https://www.alliedmarketresearch.com/connected-car-market
7. http://www.mckinsey.com/industries/high-tech/our-insights/disruptive-trends-that-will-transform-the-auto-industry
8. http://media.gm.com/media/us/en/gm/news.detail.html/content/Pages/news/us/en/2016/Jan/0104-lyft.html
9. WHO —http://www.who.int/gho/road_safety/mortality/traffic_deaths_number/en
10. http://www.vtpi.org/avip.pdf
11.Will self-driving cars reduce energy — http://www.businessgreen.com/bg/feature/2448937/will-self-driving-cars-reduce-energy-use-and-make-travel-better-for-the-environment
12. Morgan Stanley: Autonomous cars: The Future is Now http://www.morganstanley.com/articles/autonomous-cars-the-future-is-now
13. http://www.morganstanley.com/articles/autonomous-cars-the-future-is-now
14. https://www.investmentbank.barclays.com/content/dam/barclayspublic/docs/investment-bank/global-insights/barclays-disruptive-mobility-pdf-120115-459kb.pdf
15. https://www.mckinsey.de/files/mck_connected_car_report.pdf
16. http://www.gartner.com/newsroom/id/3412017
17. http://www.automotive-iq.com/consumer-electronics/white-papers/infographic-the-top-5-trends-in-automotive-hmi
18. http://www.mckinsey.com/industries/automotive-and-assembly/our-insights/connected-car-automotive-value-chain-unbound
19. http://www.mckinsey.com/~/media/mckinsey/industries/automotive%20and%20assembly/our%20insights/how%20carmakers%20can%20compete%20for%20the%20connected%20consumer/competing_for_the_connected_customer.ashx
20. http://innovationpov.com/connected-car/
21. http://old.gsacom.com/gsm_3g/info_papers.php4
22. http://www.cintas.com/ready/the-workplace-today/connected-cars-the-opportunities-and-risks-driving-a-trend
23. http://www.chetansharma.com/usmarketupdateq12016.htm

Co-Authors:

YongQiang Gao
Manager, V2X Research & Standard
Huawei Technologies

Artur Wachtel
Deputy Director, European Wireless Marketing
Huawei Technologies

Chief Contributor and Editor-in-Chief:

Hidetaka Shiraishi
Industry Innovation Relations
Huawei Wireless Branding

NOTICE
The product, service, or feature that you purchase should be restricted by the Huawei commercial contract and the clauses in the contract. All or a part of products, services, or features described in this document may not be purchased or used. Every effort has been made in the preparation of this document to ensure the accuracy of the contents, but the statements, information, and recommendations in this document do not constitute a warranty of any kind, expressed or implied. The information in this document is subject to change without notice. Every effort has been made in the preparation of this document to ensure the accuracy of the contents, but the statements, information, and recommendations in this document do not constitute a warranty of any kind, expressed or implied.