COMMUNICATIONS NETWORKS FOR CONNECTED CARS

Key topics we will discuss in this paper include:

> Impact of 'connected cars' in the global automotive market
> Multiple applications for connected cars
> Options to deliver communications for connected cars
> A close look at different communications approaches

HUAWEI

INTRODUCTION

"Connected car" has become one of the buzzwords of the last few years as the potential for combining the automotive and ICT industries becomes clearer. It's important to understand what the car can be connected to, and how these different connections an create opportunities for services and applications.

Connecting the car to the passenger creates an infotainment opportunity including multimedia, and when GPS data is added, enables mapping and direction applications. Connecting to the cloud opens up telematics applications, including the potential to change the way insurance services are delivered, or cars are maintained. Connecting to other cars if done with a technology that enables acknowledgement of the message) enables fuel-efficiency and safety applications. Connecting to transport and other infrastructure also provides for better traffic management. The term for all of these connections together is V2X – vehicle-to-everything.

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[1]. 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.

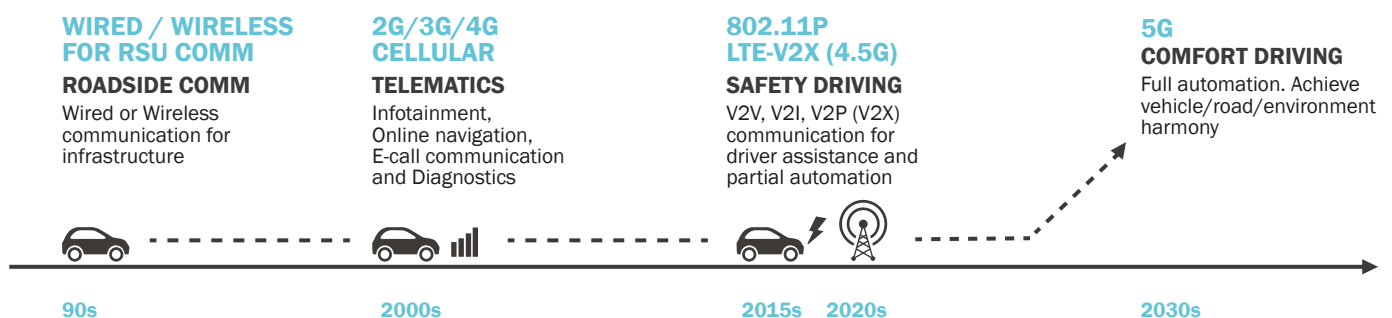In 2016, every new car has the potential to be a "connected car" as infotainment services and software updates are provided via the Internet, and increasing numbers of vehicles are being fitted with lane changing, assisted braking and cruise control systems. Tesla's Autopilot feature, currently in beta mode, already provides a limited amount of hands-free driving and is being continuously refined with over-the-air updates[2].

Between 2015 and 2020 nearly 184 million new connected cars will be produced, according to analyst company Gartner[3]. 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. The self-driving market is expected to reach critical mass within 15 to 20 years. By the end of 2035, 76 million cars will be in circulation worldwide[4]. 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 bn in total by 2020[5].

This paper looks at some example connected car applications, and the networks that will enable them – now, in the next five years, and further into the future.

CONNECTED CAR TECHNOLOGY EVOLUTION

WIRED / WIRELESS FOR RSU COMM	2G/3G/4G CELLULAR	802.11P LTE-V2X (4.5G)	5G
ROADSIDE COMM	**TELEMATICS**	**SAFETY DRIVING**	**COMFORT DRIVING**
Wired or Wireless communication for infrastructure	Infotainment, Online navigation, E-call communication and Diagnostics	V2V, V2I, V2P (V2X) communication for driver assistance and partial automation	Full automation. Achieve vehicle/road/environment harmony
90s	2000s	2015s 2020s	2030s

1 - http://images.info.science.thomsonreuters.biz/Web/ThomsonReutersScience/%7B86ccb67a-e45a-4c3a-8513-5350b39929de%7D_tr-automotive-report-2016_final.pdf
2 - https://www.tesla.com/presskit/autopilot#autopilot
3 - http://www.gartner.com/newsroom/id/3460018
4 - IHS Markit — https://www.ihs.com/expertise/research-analysis.html; http://www.autofocus.ca/news-events/news/76-million-autonomous-cars-will-be-on-roads-by-2035-experts
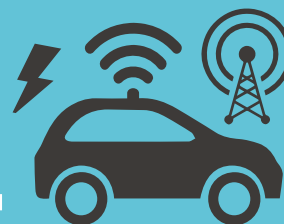5 - https://www.alliedmarketresearch.com/connected-car-market

KEY DATA

2,500 INVENTIONS

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

184 MILLION CARS

Between 2015 and 2020, nearly 184 million connected cars will be produced, according to analyst company Gartner

141 BILLION

A report from Allied Market Research suggests that the global connected car market may generate revenues of $141 bn in total by 2020

76 MILLION

The self-driving market is expected to reach critical mass within 15 to 20 years. By the end of 2035, 76 million cars will be in circulation worldwide

270 NETWORKS

Commercial deployments of 5G are expected to begin in the next five years, and by 2025, approximately 270 networks worldwide are expected to have full 5G capabilities
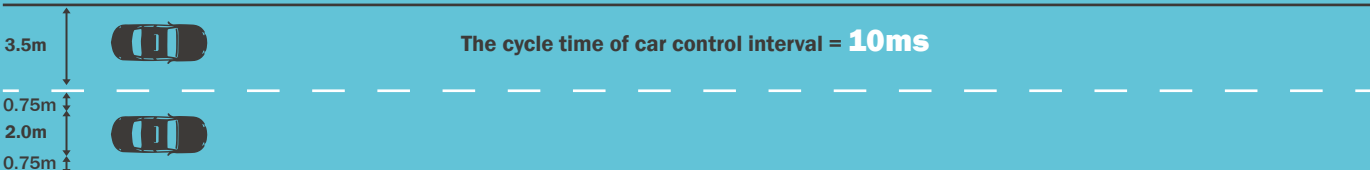
4,000 GB

Some estimates suggest that by 2020, each individual connected car will generate upwards of 4,000GB of data per day

CONNECTED CAR APPLICATIONS

PART 1

There are very many connected car applications, but it is helpful to look at some examples and assess the demands that will place on communications networks.

An early use case is infotainment: connection directly to the car can overcome some limitations of using smartphones in vehicles, such as the shielding of the metal structure inhibiting network performance. An integrated LTE module with an active antenna can significantly improve the user experience. Looking beyond the provision of infotainment, there are other types of use cases requiring advanced mobile connections, illustrated in the table.

USE CASE	DESCRIPTION	NETWORK REQUIREMENTS
Communication Oriented		
Cooperative Driving	Driving can be cooperative in many ways. An illustrative test case is automated lane merging to maximize road capacity. 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. For emergency trajectory planning, every vehicle broadcasts its identity, position, speed and direction and uses that data to build its own map and determine whether any other vehicle is on a potential collision trajectory.	The three involved cars need to communicate with very low latency, and acknowledge receipt of any messages. This will required 5G.

Assumption: Speed=144km/h, Trajectory tolerance= 40cm (longitudinal), 10cm (lateral), Positioning accuracy= 2cm (Differential - GPS)

3.5m | The cycle time of car control interval = **10ms**

0.75m
2.0m
0.75m

EVERY 10ms CAR POSITION MUST BE CONTROLLED BY CAR ROBOTS (STEERING, ACCELERATOR, BRAKE)

Platooning	Linking trucks or cars automatically in a convoy of vehicles that are much closer together than can be safely achieved with human drivers, to save fuel and make the transport of goods more efficient. Platoons are expected to be flexible – being established on motorways, then broken up when a vehicle leaves the motorway.	Platoons of 2 or 3 vehicles can be established using sensors and direct communication between immediate neighbors. For longer platoons, propagation of messages takes too long. Braking must be synchronous, requiring low-latency network communications. For platoons of more than 3 cars, 5G will be needed.

CONNECTED CAR APPLICATIONS

PART 2

USE CASE	DESCRIPTION	NETWORK REQUIREMENTS
Tele-operated / Remote Driving	A vehicle is driven by someone in a remote location, rather than someone in the vehicle. The vehicle is still driven by a person – it is not automated. This could potentially be used to deliver a premium concierge service to enable someone to participate in a conference or to work while on a journey, or 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.	Requires a high-reliability 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. This will require 5G.

USE CASE	DESCRIPTION	NETWORK REQUIREMENTS

Environmental Data Processing Use Cases

| USE CASE	DESCRIPTION	NETWORK REQUIREMENTS
See-through, Sensor sharing / Camera sharing	Sharing of sensor data and camera images between vehicles, enabling cars to effectively "see through" other vehicles 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.	Requires perfect synchronization of high definition video streams; time alignment is crucial, so very low latency networks are needed. This will require 5G.
Augmented Reality Mapping	Building high definition 3D maps. Camera information would be overlaid on to existing digital models of the surrounding environment. Images from stereo cameras in multiple vehicles would be uploaded into the cloud and multiple images would be overlaid in a collaborative oversampling approach to create a very sharp 3D image of the landscape. The 3D image could include also infra-red details. This augmented reality mapping approach is expected to produce much better maps than existing services, and cars could compare the 3D model with reality to identify differences between the stored model and the real-time image (to identify pedestrians, animals, cars, motorcycles, and details like the changing surface of a street).	Requires real-time, non-stop transmission of video from the car, and timely receipt of the centralized map data at the car to enable comparisons. High throughput networks would be required, for instance to enable time synchronization of images. This will require 5G.

Applications Enabled by Cloud Computing

USE CASE	DESCRIPTION	NETWORK REQUIREMENTS
Telematics, Mobility Profiles, Insurance, and Theft Prevention	There are many ways to exploit vehicle mobility data, even in anonymous form. For instance, TomTom is augmenting its traffic maps by using data about movement speeds reported by its devices. By analyzing where speeds are significantly slower than the local speed limit, it can identify traffic jams. Insurance companies also collect mobility data and offer the option to install a telematics device that reports driving styles, speeds and locations. Data is collected in the cloud and analyzed, and used to determine the risk of insuring each driver, and individuals' insurance premiums. For theft prevention, it is straightforward to track where a vehicle is, and who is driving it, and pass this information to the cloud for analysis. Where permitted, it is only a small step from these applications to correlate data and determine where people work, live and shop, and sell them appropriate services using that information.	Network requirements vary by specific application, but in many instance, these use cases can be realized with today's cellular networks as there are no very demanding latency or throughput requirements.

WAYS TO DELIVER COMMUNICATIONS FOR CONNECTED CARS

PART 1

Different types of communications are needed between vehicles and other vehicles, transport infrastructure, cloud-based and other applications, and even pedestrians or cyclists. These are generally abbreviated as follows:
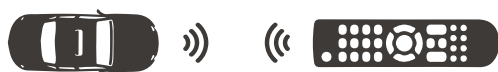
V2A

Interaction between vehicles and remote applications (vehicle monitoring, information, mapping systems etc)

V2V
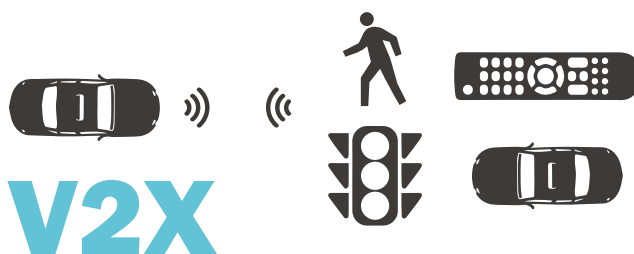
Vehicle-to-vehicle (direct communications between vehicles, primarily for safety)

V2I

Interaction between vehicles and infrastructure such as traffic signals

V2P

Interaction between vehicles and pedestrians (and cyclists)

V2X

Vehicle-to-everything (all of the above)

The information delivered by V2X technologies will be essential in allowing future connected and self-driving (autonomous) cars to navigate to their intended destinations efficiently and safely. It's important to understand the huge volume of data that connected cars will be transmitting and receiving, as this places very great demands on network capacity. Some estimates suggest that by 2020, each individual connected car will generate upwards of 4,000GB of data per day[6].

WAYS TO DELIVER COMMUNICATIONS FOR CONNECTED CARS

PART 2

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.

• **In-Car Sensors.** 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, mix with other companies or legacy systems and services.

• **Current Cellular Networks**. As we saw earlier, current cellular networks have already enabled many connected car applications, but infrastructures limit applications 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 Quality of Service (QoS). If cellular networks are used, they must deliver on every one of these requirements while also supporting other mobile connections.

• **802.11p/WAVE (DSRC)**. 802.11p is 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) is a V2X technology focused on safety applications, using 802.11p/ WAVE in specific spectrum bands. C-ITS G5 is a European transportation communications standard based on 802.11p. DSRC technologies have been around for many years, but have not been widely deployed.

• **C-V2X (LTE-V)**. LTE-V is a specific set of features proposed for standardization within 3GPP to deliver C-V2X (cellular V2X), a suite of technologies using features from the mobile industry's 3GPP standards to deliver V2X. It is based on a variant of 4G, uses only one chipset, and can be rapidly deployed as it is compatible with existing base stations. LTE-V has been extensively trialed by Huawei and partners including China Mobile, SAIC Motor Corporation, Deutsche Telecom, Audi and Toyota. In September 2016, Huawei simulated real-life driving scenarios by performing live LTE-V trials at the G20 Summit in Hangzhou.

• **5G**. 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 kilometer 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. 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 LTE. Commercial deployments of 5G are expected to begin in the next five years, and by 2025, approximately 270 networks worldwide are expected to have full 5G capabilities.

"[On] a 4G network, a self-driving car travelling at 100 km/h will continue to move 1.4 meters 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 centimeters, and this is comparable with the standard of Anti-lock Braking Systems (ABS)"

- Ken Hu, Deputy Chairman of the Board, Huawei

COMPARISON OF COMMUNICATIONS APPROACHES

If sensors and other equipment are to be connected via a network, the primary question is "how do IEEE 802.11p, LTE-V and 5G measure up against each other?" The best way to answer this is to perform a thorough comparative evaluation of these infrastructure technologies, and point out the advantages each of them brings over and above unconnected sensors.

The table below presents some key facts.

	VEHICLE-BASED SENSORS	802.11P	LTE-V	5G Ad Hoc*
Range	10s of meters	100s of meters	Cellular + sidelink	Cellular + 5 hops
Frequency Band	N/A	5.9 GHz	700, 1800, 2600	Tbc
Bandwidth	N/A	30 MHz (in the EU)	20 MHz	< 100 MHz
Coverage	N/A	Medium	High	Very high
Robustness Doppler / Delay	N/A	High due to large carrier spacing	Medium. Doppler effects need to be compensated at the receiver. This leads to inefficiency	High. New waveform supporting highly dispersive channels in time and frequency
Interference	N/A	Limited to low interference levels	Sidelink causes UL interference	Cellular and ad hoc in parallel
Maturity	Available	SAE J2735: BSM IEEE 1609.X IEEE 802.11p	2019	Starting 2020 General adoption 2025
Protocol Type	N/A	CAM DENM	ProSec, Day1&2	Day 1,2,3
SERVICES				
Self-parking	Yes	N/A	N/A	N/A
Emergency Braking	Yes	Yes	Yes	Yes
Lane Merging	No	No	No	Yes
Assisted Driving	Limited	Same	Same	Yes
Autonomous Driving	Limited	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 having 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 become quite inefficient if the number of hops becomes significant, due to protocol overhead. A practical limit would 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.)

Huawei's view is that 5G promises new innovations and applications for the automobile industry, but that it is not quite around the corner, and the auto industry will have a connectivity "innovation gap" that is best filled with LTE-V – a flexible and dedicated solution for future vehicle communication.

KEY TAKEAWAYS

01 Connected cars are the subject of immense R&D effort, and the potential market is huge: 184 million connected carscould be produced by 2020.

02 Any cellular technology for cars faces challenging requirements for coverage.

03 Many use cases have been developed; some of them can be realized with today's technologies. While using in-car sensors, 802.11p and LTE-V networks can meet some requirements, only 5G provides the reliability to satisfy functional safety requirements.

04 5G networks will not be widely enough deployed for automotive applications for many years.

05 802.11p technology for DSRC has been available for over 10 years and has been extensively tested around the world but it is not in commercial use as it cannot deliver all the features needed.

06 A comparison of current proposed technologies for V2X (vehicle-to-everything) communications suggests that LTE-V is the best choice.

07 LTE-V technology is being trialed extensively by major automobile makers, network operators and equipment vendors.

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