5G for Vehicular Applications

Public report

Project within Automotive Strategy Research and Innovation
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Content

1. Definitions

The following definitions are used to provide precise 5G Automotive application-specific requirements.

1. **End-to-end latency** (msec)
Maximum tolerable elapsed time from the instant a data packet is generated at the source application to the instant it is received by the destination application. If direct mode is used (PC5 transport), this is essentially the maximum tolerable air interface latency. If infrastructure mode is used (Uu transport), this includes the time needed for uplink, any necessary routing in the infrastructure, and downlink.

2. **Reliability** (10^{-x})
Maximum tolerable packet loss rate at the application layer (i.e., after HARQ, ARQ, etc.). A packet is considered lost if it is not received by the destination application within the maximum tolerable end-to-end latency for that application. For example, 10-5 means the application tolerates at most 1 in 100,000 packets not being successfully received within the maximum tolerable latency. This is sometimes expressed as a percentage (e.g., 99.999%) elsewhere.

3. **Data rate** (Mbit/s)
Minimum required bit rate for the application to function correctly.

4. **Communication range** (m)

Maximum distance between source and destination(s) of a radio transmission within which the application should achieve the specified reliability.

5. **Node mobility** (km/h)
Maximum relative speed under which the specified reliability should be achieved.

6. **Network density** (vehicles/km2)
Maximum number of vehicles per unit area under which the specified reliability should be achieved.

7. **Positioning accuracy** (cm)
Maximum positioning error tolerated by the application.

8. **Security**

Specific security features required by the application. These include user authentication, authenticity of data, and integrity of data, confidentiality, and user privacy.

2. Summary

A mobile communication system beyond 4G should support much higher mobile data volume per area, any more connected devices, much higher typical user data rate, longer user battery life for low power devices, and smaller end-to-end latency. Some of these challenges can be addressed with a denser base station deployment; however, this is not feasible from the cost or an energy perspective. Utilizing vehicles in a smarter way is therefore of great importance.

This project aims at researching and developing key 5G components to make 5G vehicular-friendly and thereby enable new vehicular-telecom business cases. 5G for vehicular applications aims at contributing to the specification of 5G to become a true enabler of V2X applications that today are not realizable due to the limitations of current communication networks.

3.Sammanfattning på svenska

Ett mobilt kommunikationssystem bortom 4G bör stödja mycket högre mobildatavolym per ytenhet, många fler anslutna enheter, mycket högre typisk datahastighet, längre batteritider för lågenergi utrustning och kortare fördröjningar. Några av dessa utmaningar kan hanteras med fler basstationer på samma yta, men detta är inte möjligt på grund av kostnaden eller från ett energiperspektiv. Att använda fordon på ett smartare sätt som en del av framtidens kommunikationssystem är därför av stor betydelse. Detta projekt syftar till att forska och utveckla 5G komponenter för att göra 5G fordonsvänligt och därmed göra det möjligt för nya affärsområden inom fordon-telekom.

Fokus i projektet ligger på enhet-till-enhet (D2D) kommunikation (en viktig komponent i 5G). D2D länkar kommer att erbjuda korta fördröjningar och pålitligt fordon-till-fordon (V2V) och fordon-till-väg infrastruktur (V2I) kommunikation. Länkarna kan användas för trafiksäkerhet samt allmänt informationsutbyte mellan fordon.

4.Background

Automotive safety services are focusing on improving safety of drivers and passengers as well as of vulnerable traffic participants such as pedestrians or bicyclists. To large extent, the safety of road depends on the interaction between road actors such as the vehicles, pedestrians, motorcycles and the awareness with the surrounding environment such as the road signs and traffic signals.

Vehicles can exchange information with other vehicles (V2V), with the roadside infrastructure (V2I), with a backend server (e.g., from a vehicle manufacturer or other mobility service providers) or with the Internet (V2N), with a pedestrian (V2P), etc. To refer to all these types of vehicular communication, the term Vehicle-to-Everything (V2X) has been proposed. Connected vehicle services have existed in the market for more than 10 years with the provision of automated crash notifications, vehicle breakdown notifications, traffic information and infotainment services, among others. Following the heels of these commercial deployments, eCall (emergency call) will be the first regulated service mandating all new vehicles to be connected to mobile communication networks and to be capable of geo-location by means of European Global Navigation Satellite System (E-GNSS / Galileo) receivers. Thus, eCall marks the beginning of the adoption of connected services on a larger scale.

Customers of connected cars are looking for personalized, contextual and efficient services that make mobility more secure, comfortable and easy. Telecom networks provide the connectivity between the car and the corresponding backend in which these services are running. These telecom networks together with the backend operations may be considered as a supportive business platform for the automotive industry, enabling an enhanced customer experience. Such a supportive business platform needs to ensure robust, secure and agile communications to guarantee the highest traffic safety, the most efficient operations and the best customer experience.

The use of wireless communications for the provision of automotive safety services has to satisfy more stringent QoS requirements in terms of latency and reliability than traditional services. Further requirements in terms of position accuracy and security aspects are also essential to enable its deployment. Current wireless communication systems such as the 4th generation of mobile communication standard known as LTE or the IEEE ITS-G5 specification based on the 802.11p standard cannot satisfy the requirements of the most demanding automotive safety services.

The cooperative awareness with the surrounding environment is built on the assumption that traffic actors can communicate with each other through a set of sensors such as the radars and video cameras. In this context, the use of wireless technologies in the communication, proximity-based detection, and the localization of the road actors have been studied. Multiple communications standards such as LTE and IEEE 802.11P have been investigated for their scalability and suitability of the automotive safety applications, but none of them have satisfied the challenging requirements for the challengeable QoS of cooperative automotive safety applications in terms of latency, scalability and reliability in case of high mobility and distance between devices.

5. Purpose, research questions and method

The focus of this project is on a second key component for vehicular 5G communications: direct device-to device (D2D) communication, i.e., communication between devices (e.g., smartphones) that goes directly between devices and not via any base stations. D2D links will, if properly designed, offer low-latency, reliable vehicle-to-vehicle (V2V) and vehicle-to-road infrastructure (V2I) communication. These links can be used for traffic safety as well as for general information sharing between vehicles (e.g., for infotainment, relaying to offer cellular coverage extension, or for non-safety machine-to-machine communication).

There are, however, a number of challenges that needs to be overcome
1. To be effective for traffic safety, the D2D links need to be operational also when there is limited or no network connectivity, i.e., when the vehicles are in areas of poor or no coverage of (fixed) base stations. In traditional cellular scenarios, this is not possible, as the base station is in charge of all communications to limit the interference between concurrent transmissions to an acceptable level. This calls for new medium access methods, i.e., methods for how to share the wireless medium among several transmitters, to:
A. provide timely access to the channel (to limit latency), and to
B. control interference such that the transmitted data is delivered to its destination with high probability.

2. The main mode of communication for traffic safety is broadcast to vehicles in the vicinity of the transmitting vehicle. This delivery mode is different from the traditional cellular unicast mode, i.e., when a data transmission is intended for a single receiver. In unicast, reliability is typically achieved with retransmission protocols: upon successful decoding of the data, the receiver sends an acknowledgement to the transmitter. If the transmitter does not receive an acknowledgement, it assumes that the data was lost and retransmits it. For broadcast, this approach is not attractive due to the excessive overhead implied by transmission of many acknowledgements. Furthermore, in traffic safety, vehicles might quickly move in and out of radio range, and a transmitter might therefore

not know which receivers to expect acknowledgements from. Hence, this calls for new methods to ensure reliability.

3. The 5G equipment that needs to be mounted in the vehicle includes antenna systems for backhauling, antenna systems for local transmission inside the vehicle passenger compartment (to offer 5G connectivity to the driver and passengers), antenna systems for transmission to 5G receivers in the vicinity (e.g., handheld devices and other vehicles), radio receiver and transmitter electronics, power cabling, and local wired transmission to vehicle systems (e.g., infotainment, active safety). Clearly, the form factor, power consumption, electromagnetic compatibility (EMC), electromagnetic exposure to customers (SAR values), and cost are issues that need to be controlled if 5G in vehicles are to be made a reality. This implies a close study of different hardware and software architectures. It is of particular interest to find a hardware structure that strikes a good balance between manufacturing cost and flexibility. The flexibility is needed reduce development cycles and to allow for hardware upgrades as the 5G standard evolves.

5G for Vehicular Applications has addressed the relevant use case classes and from those selected a relevant and suitable use case from each class to span the space of potential relevant futures to study.

1- Automated Driving

In a critical traffic situation, the leader and the ego vehicles are driving in close proximity to each other, a sudden obstacle appears in front of the leader and only the leader vehicle detects the obstacle due to the limitation of line-of-sight of the ego vehicle. In this situation, both drivers in the leader and the ego vehicles will stop suddenly. Utilizing the low rate MTC sensory data being delivered from the leader vehicle, the driver in ego vehicle will perform a lane change to avoid the obstacle collision.

This means that the vehicles are expected to take over the complete driving task until now manageable by the human driver under all environmental situations and with the highest reliability. In order to achieve the vision of fully autonomous driving, several key capabilities need to be implemented in the vehicles and taking into consideration the significant driving scene complexity that might be encountered in the future.

The vehicle should be able to center itself within the lane and control its trajectory and speed by performing automated steering interventions and combined lateral and longitudinal motion control. In order to make reliable decisions on the best appropriate actions for any possible situation encountered in road traffic, the vehicle is required to perform a continuous surround sensing in order to maintain a complete awareness of its environment. This is achieved through a combination of data from multiple sensors, e.g.

radar, video sensors, etc., that are necessary for generating a complete and reliable model for the vehicle environmental. This process of sensor data fusion is known as perception. The local sensor information are usually complemented by information from other vehicles, roadside infrastructure or back-end server using wireless communications. In particular using sensor data shared by other vehicles is beneficial for extending the vehicle field of view and resulting in a 360 degree reliable environment model. In addition to the environment perception, the automated vehicle requires up-to-date and high definition map information including road descriptions and context information provided from an online server and enabling the vehicle to navigate intelligently through all type of environments.
This will result in alternative sources of information that create a form of redundancy which helps increasing the reliability of the automated driving system.

As part of the automated driving tasks, the vehicle should be able to automatically change lanes when appropriate. For this, the interaction with the surrounding and the cooperation with other vehicles in the vicinity will become more and more relevant for performing join maneuver decisions that enhances the safety and helps the vehicle getting through difficult traffic situations.

In addition to cooperation with other vehicles, the interaction with other vulnerable road users (e.g. pedestrians, bicycles, motorcycles) helps increasing the road safety and reduces the traffic accidents through early notifications about potential collisions and their avoidances with appropriate actuation system maneuvers. For this an accurate localization of both vehicles and vulnerable road users is one major key enabling technology that needs to be developed.

Finally, another potential form for bringing the autonomous driving into reality is the remote driving. This could be for example realized by having an operator remotely monitoring and controlling the vehicle from a distance (e.g. via a server on the cloud) in order to intervene if necessary and hence increasing the road safety and efficiency.
The analysis of the autonomous driving needs described in this section will constitute the basis for the use cases selection within the 5G for Vehicular Applications.

2-Vulnerable Road Users Detection

In intelligent transport systems ,the cooperation between vehicles and vulnerable road users, e.g. pedestrians and cyclists is employed, through their mobile devices, such as smartphone and tablets, will be an important key element to improve traffic safety. The intelligent transport systems will rely on timely and reliable exchange of information. The idea is therefore to collect safety-relevant information directly from the vulnerable road users (VRU). This can be achieved by exploiting the information from an existing and very powerful sensor that almost everyone carries in their pocket today: a mobile phone. Information is exchanged between the VRU device and the vehicles in order to warn the driver and the VRU about the presence of each other in order to actively initiate the necessary actions to avoid an accident.

3-Emergency Brake Warning

Current V2X communication technologies are not suitable for the exchange of sensor data of the vehicle. Higher automation level will require lower latency and higher reliability since the reaction time of the driver is removed from the equation.

6. Objective

The objective was to develop a profile of the 5G technology that comprises the requirements and features needed to be studied in the area of active safety and transport systems, e.g., what vehicle safety features will be considered, the time needed for driver to get a traffic safety warning (e.g., hazardous road warnings), and warning messages frequency. The project has provided feedback to the vehicular and telecom industries about 5G technology automotive integration aspects.

7. Results and deliverables

Autonomous Driving

Automated driving systems require highly resolved and dynamic maps to maneuver the vehicles safely, in particular as a means to provide decimeter localization which is not achieved by typical consumer-grade satellite navigation equipment. As the resolution of current 2D maps coupled with inaccurate position information is not sufficient, high resolution and real-time maps, also called dynamic High Definition (HD) maps, become indispensable [1]. Figure 2 shows an example of an HD map generated with a LiDAR (Light Detection and Ranging) sensor, which is used to monitor the car surroundings and display the same as a high-resolution and real-time point cloud.

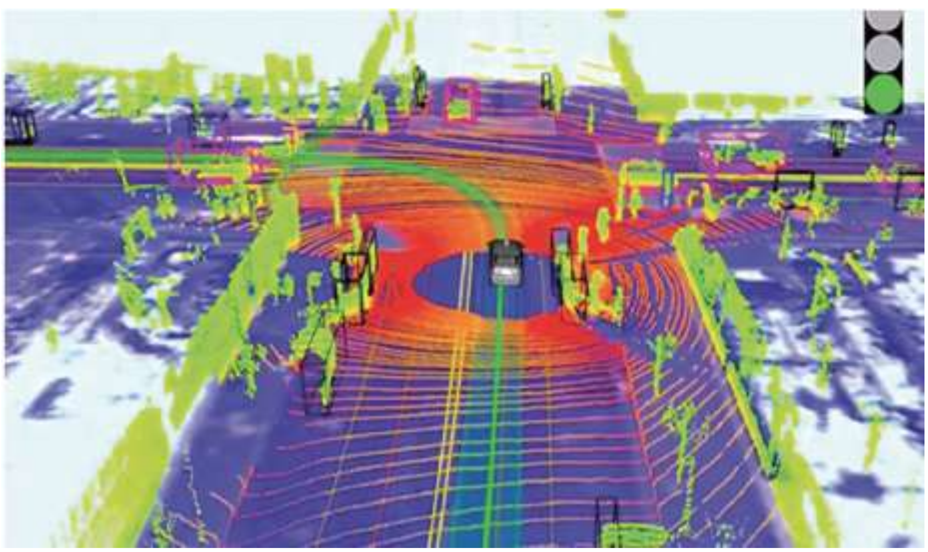

Figure 1 HD Map for Autonomous Driving

It is estimated in [1] that the total data volume of such an HD map collected for the duration of one hour is about 1 TB, which corresponds to a 2.2 Gbps data output for this type of sensor. Even though the final values depend on the resolution of the actual HD map, an estimation of 1 Gbps appears reasonable as a typical data rate requirement for exchanging HD map information via V2V/V2X links.

It is expected that even though the final values depend on the resolution of the actual HD map, an estimation of 1 Gbps, end-to-end latency of less than 10 msec per link and a communication range of 150-300 m appears reasonable as a typical data rate requirement for exchanging HD map information via V2V/V2X links. This situation nominates the mmWave technique as the only possible way to provide such data rates for autonomous driving.

Cooperative perception is realized by exchanging sensor data between vehicles and Roadside Units (RSUs) and is necessary in order to widen or enhance the visibility area of HD maps in [2, 3]. It is estimated that 100 meters as a braking distance (including a safety increment distance) for the emergency stop of a generic sedan car at 70 km/h, which can be seen as the maximum speed in urban city environments

This concept allows a more accurate localization of objects and more important, due to the bird's eye view that can be derived from sensor fusion, prevents that objects remain not visible and undetected, due to the ego-perspective of the sensors mounted on the vehicle. This external object detection capability is particularly critical for a safe realization of automated driving in complex urban environments. The communication range supported by a cooperative perception system can be determined by the braking distance of vehicles.

MmWave Module integration in 5G car Modules

A block diagram of On-board unity OBU and Road Side Unit (RSU) messages processing systems is shown in figure 2, where the difference between an OBU and a RSU is solely the automated driving unit. The OBU/RSU receives via mmWave V2V/V2X links the HD maps from surrounding OBU/RSUs and fuses them with its own HD sensor data in the HD map processing unit. This process is called cooperative perception. This combined HD map with its widened visibility area is used for automated driving decisions and in addition is transferred to neighboring OBU/RSUs. However, before transmitting the fused HD map, the HD map processing unit selects the area of interest (or control resolution of HD map area by area) dependent on the location of receiver OBU/RSUs to avoid exponential increase of data rate. The OBU/RSU is a unification of mmWave and MEC, since the HD map processing unit is considered as MEC to compute cooperative perception at the edge of the network.

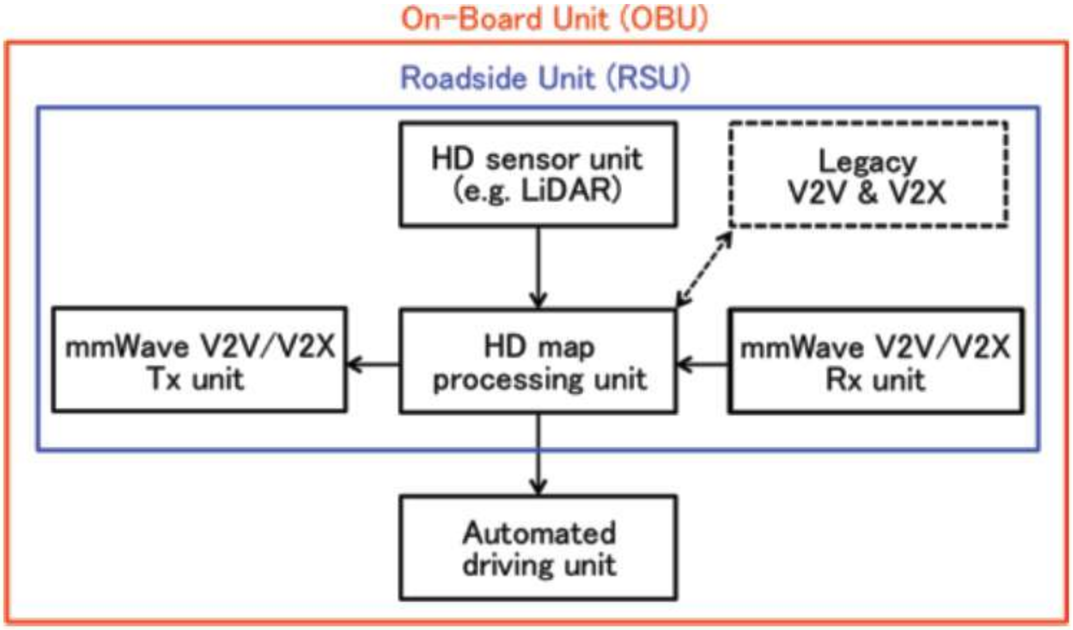

Figure 2 Block Diagram of Road Side Unit and On-Board Unit Processing system

It is expected that the described V2V/V2X system using the mmWave will play an important role in Intelligent Transport Systems (ITS) in addition to 700 MHz and 5.9 GHz frequency bands. Figure 3 shows an example of a system architecture for mmWave based V2V/V2X to realize a real-time exchange of HD maps between On-Board Unit (OBUs) mounted in vehicles and RSUs.

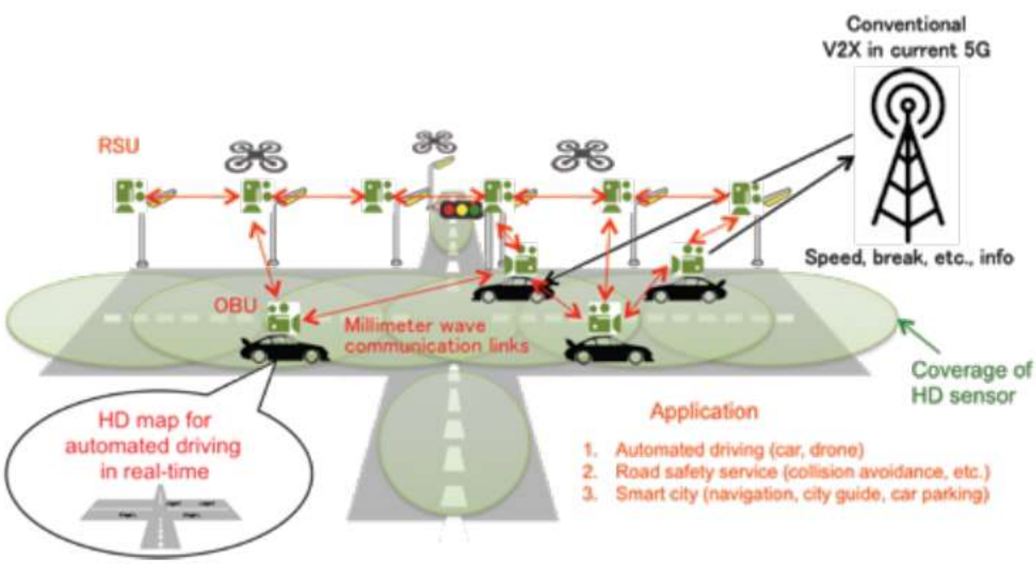

Figure 3 mmWave Based V2x/V2v To exchange HD maps

Vulnerable Road User Detection

Vehicles periodically announce their presence and position. VRUs (pedestrians, cyclists, etc., carrying a mobile device) discover vehicles in proximity and begin announcing themselves. The VRU mobile device may trigger a loud warning sound, vibration, flashing light, etc., in case of imminent danger. Vehicles in proximity of an announcing VRU incorporate the received information into their Local Dynamic Map (LDM) and potentially notify both the driver and the VRU if a vulnerability situation is detected as illustrated in figure 4.

Figure 4 Vulnerable Road User Detection

One of the most critical issues with this use case is a reliable localization of the VRUs. Combining several positioning techniques – including satellite and natively integrated in 5G – should be able to increase the accuracy of the positioning, especially the relative positioning to vehicles in all environments (urban and rural). This use case mainly requires highly accurate localization. For vulnerable road users, the positioning error needs to be less than 10 cm for a 1 m width pedestrian/bike lane. Relative localization must be supported by 5G.

Cooperative Collision Avoidance

Inattention/distraction is a growing concern in the traffic environment. The loss of forward road vision in combination with an unexpected event will normally result in an accident. Modern vehicles are equipped with a variety of sensors including cameras and radars that initiate an emergency braking warning which also includes an early collision warning If a critical traffic situation is detected (.i.e., slow or stopped traffic ahead as shown in figure 5), in a try to focus the drivers' attention towards the traffic in front of the vehicle. Nevertheless, the range of such sensors is quite limited and insufficient for the recognition of most hazards on the road. In this context, combining the information gather by multiple vehicles, however, leads to an extended perception horizon reaching far beyond the limited field of view of a single vehicle or its driver. This would enable drivers and systems for autonomous driving to recognize hazards in advance and take preventive actions much earlier, but requires cooperation (i.e., information exchange) between the traffic participants. This could be achieved through device-to-device communication that will come up with a novel solution to meet the stringent QoS requirements for traffic safety.

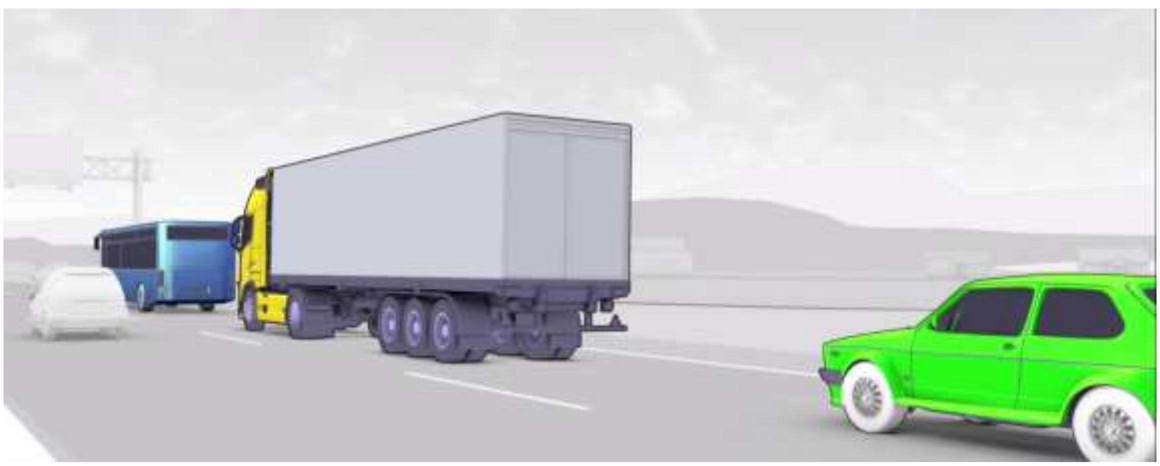

Figure 5 Emergency Break Warning

In a critical driving situation, trajectories have to be exchanged, rated and agreed upon in order to avoid a collision. This handshake must be completed within 100 msec and shall not fail with a probability higher than 10-5. Upon agreement, during the execution phase, lateral and longitudinal controllers need status updates within their 10 msec cycle time. The status information is used by each vehicle to update its trajectory and inform its controllers (in case of minor deviations from the agreed trajectory) or cancel the maneuver (in case of major deviations). A status message shall be received within 10 msec with a probability of 99.9% (packet loss rate of 10-3).

Frequency Band for Automotive 5G

The 5G for vehicular Applications has studied in depth the 24, and 60 GHz bands as potential mmWave frequency bands. The V2X/V2V communicating is possible on these two bands, and high data rate was achieved in 60 GHz bands which was around 4Gbps compared to 2.2 Gbps in the 24 GHz band.

The most challenges with the 60 GHz band was the data rate is minimized with high velocities. In addition, Received signal strength degrades very much when there is a vehicle between the TX/RX even at short range. Sometimes signals pass through the windows and degradation is not very high. The loss is RSSI is often close to 20dB, which is a lot and must be considered when designing system as shown in figure 6.

Figure 6 TX/RX experiment for 24/60 GHz Band

It is expected that the frequency bands to be used for V2V/V2X shall fulfill certain requirements, such as 1) have a bandwidth more than 1 GHz in order to exchange HD map information, 2) work internationally and regardless of country borders and regulatory bodies, namely use International Mobile Telecommunications (IMT) bands, 3) should be license-based to avoid unnecessary interference, and 4) should work standalone when Public Land Mobile Networks (PLMNs) are unavailable. Based on the above mentioned criteria, this report nominates four candidates for mmWave V2V/V2X: (1) 31.8 – 33.4 GHz, (2) 40.5 – 42.5 GHz, (3) 47.0 – 50.2 GHz, and (4) 66.0 – 71.0 GHz. Although band (4) is recently regulated for unlicensed use in US, it is kept as a candidate because real applications in this band are still open to practical markets. The 28 GHz band is another candidate from the viewpoint of device availability, though the bandwidth is limited to 400 MHz per channel in US and there is no harmonization in the world. We have not selected the 71.0 – 76.0 GHz and 81.0 – 86.0 GHz bands to avoid interference with existing or future backhaul / fronthaul networks using these frequency bands.

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Table 1 Frequency candidates for 5G and beyond selected in the four different organizations.

8. Dissemination and publications

8.1Dissemination

How are the project results planned to be used and disseminated?	Mark with X	Comment
Increase knowledge in the field	X	Volvo cars is continuously developing new electrical platform architectures to develop concept vehicles that promote new safety features and traffic awareness. This new platform is planned to go through VCC product development system, which comprises several vehicles designs. The results from this project shall be used to transfer the knowledge and expertise to the first car program on the new platform.
Be passed on to other advanced technological development projects	X	The project results has complemented and created synergies with other on-going and planned 5G activities
Be passed on to product development projects	X	
Introduced on the market		The developed prototype was used for research and development only; however, many of the 5G concepts will be translated to functional requirements when putting 5G modems in production. The developed prototype has examined the possibility to software-defined modems for wireless backhaul targeted towards 5G systems. An essential part in this project was to breakdown system requirements to hardware requirements for a flexible platform.
Used in investigations / regulatory / licensing / political decisions	X	

The project was a good input to H2020 research and development program with the EU commission. The most related project was 5GCAR. https://5gcar.eu/

8.2Publications

Power Control for Broadcast V2V Communications with Adjacent Carrier interference Effects" is presented in "IEEE International Conference on Communication (ICC)" held in Kuala Lumpur, May, 2016.

9. Conclusions and future research

Future connected cars need Ultra-fast E2E delays, ultra-reliable links, and accurate positioning 3D systems in real-time manner. In addition, High mobility, Interference-Controlled D2D links, Radio resource management, and Ultra-Secured connections are need to secure the requirements of the automotive use cases for the 5G.

The KPIs provided above must be achieved under different physical circumstances – such as distance and relative velocity of transmitting and receiving vehicles, vehicle density and offered load per vehicle – depending on the scenario. For example, it may be relatively easy to achieve 10 msec latency with 99.999% reliability when vehicles are 10 meters away, traveling in the same direction at the same speed in an otherwise empty street. It will be much more challenging to achieve such targets if the vehicles are 500 meters away, traveling fast in opposite directions in a crowded street where they need to share the wireless channel with many other vehicles.

10. Participating parties and contact persons

The Executive Group (EG) is comprised by:

- Muthanna Abdulhussein, Volvo Cars Corporation (project manager)
- Erik Ström, Chalmers
- Fredrik Harrysson, Ericsson
- Andreas Wolfgang, Qamcom

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