Vehicular communication

Theory

Increasing density of road traffic (cars, motorbikes, public transportation, or logistics) leads to higher requirements on driver's capabilities to safely reach the designed destination. Communication of the users or devices is constantly evolving with the vision of everything (humans and devices) being connected. This opened a possibility of vehicular communication, which is a part of Intelligent Transport Systems (ITS). The vehicular communication enables communication of vehicles to infrastructure for communication such as receiving traffic density information, but nowadays it includes direct communication between vehicles for informing vehicles about unexpected obstacles on the road or about braking. These functionalities can reduce number of accidents by providing fast and targeted information. Furthermore, the vehicular communication is one of the technologies necessary for autonomous driving. Nevertheless, even with autonomous driving, vehicular communication will be necessary for providing passengers with entertainment.

The vehicular communication consists of multiple types of communications, all under name Vehicle to X (V2X), where X represents the other end of communication. Types of communication, as shown in Figure *1*, are:

- Vehicle to Infrastructure (V2I) – communication with traffic lights or roadside infrastructure.
    - Providing traffic signal/light priority, emergency vehicle warning.
- Vehicle to Vehicle (V2V)/Vehicular Ad Hoc Networks (VANET) – communication between vehicles. Can be also done via assistance of UAVs.
    - Collision avoidance systems, braking information, traffic jam, blind spot warning, lane change assist.
- Vehicle to Network (V2N) – communication with the network.
    - Real-time traffic/routing, cloud services, green light optimization.
- Vehicle to Pedestrian (V2P) – communication with pedestrians.
    - Safety alerts to pedestrians, cyclists.

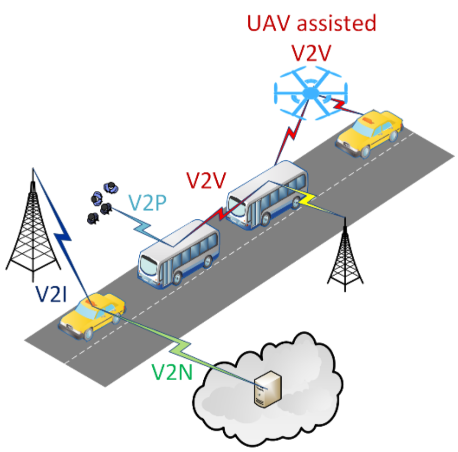

Figure 1. Types of Vehicular communication.

The vehicular communication is divided into Wireless LAN (WLAN) and cellular based technologies. Both technologies have the same goal but exploit a different approach. The Wireless LAN based were introduced in 2012 by standardization of IEEE 802.11p, which have special function channels, shown in Figure *2*. The 802.11p is basis for Dedicated Short-Range Communication (DSCR) in the USA that exploits Wireless Access in Vehicular Environment (WAVE) and Cooperative – Intelligent Transportation System (C-ITS) in Europe that exploits Intelligent Transportation System - G5 (ITS-G5). The IEEE 802.11p has been designed specifically for automotive to provide bidirectional communication for short to medium distances. Its physical layer is based on IEEE 802.11a. The IEEE 802.11p enables communication without need to establish Basic Service Set (BSS), as vehicles communicate within the same Basic service set identifiers (BSSID). The evolution of the IEEE 802.11p is the IEEE 802.11bd that doubles the range of the IEEE 802.11p and enables communication of vehicles with speeds up to 500 km/h (IEEE 802.11p only up to 200 km/h). The physical layer of the IEEE 802.11bd is based on IEEE 802.11ac and improves performance via exploitation of midambles, that are exploited for channel estimation within frames. They are like preambles (send at the beginning of the frame) but are send within frames.

CH 172 5 860 MHz	CH 174 5 870 MHz	CH 176 5 880 MHz	CH 178 5 890 MHz	CH 180 5 900 MHz	CH 182 5 910 MHz	CH 184 5 920 MHz
Accident avoidance safety of life	Service channels		Control channel	Service channels		High power long range

Figure 2. Channel structure of 802.11p.

The cellular based technologies for vehicular communication are standardized by 3GPP, with initial standardization exploiting LTE in 3GPP release 14 in 2014, known as LTE-V2X. The LTE-V2X is based on Device to Device (D2D) communication for Proximity Services (ProSe), and as a such exploit sidelink channels. The sidelink channels[1] are:

- Sidelink synchronization signal (SLSS) - providing synchronization with and id SLSSID that identifies master device that provides synchronization
    - Primary sidelink synchronization signals (PSSS)
    - Secondary sidelink synchronization signals (SSSS)
- Physical sidelink broadcast channel (PSBCH) - carrying Master Information Block
- Physical sidelink control channel (PSCCH) - carrying sidelink control information (SCI) also known as scheduling assignment (SA)
- Physical sidelink shared channel (PSSCH) - carrying user data
- Demodulation reference signal (DMRS)

For purposes of V2V, a dedicated interface PC5[2] has been introduced, addressing high speed (up to 250 km/h) and high density of vehicles. However, with 3GPP release 16, the 5G mobile networks providing NR V2X, with their ultra-reliable low latency communication capabilities can provide superior performance in comparison to LTE-V2X. The cellular NR V2X communication is envisioned to exploit mmWaves, as it can provide short-lived high data rate connection for V2I or high-speed low latency V2V communication.

[1] ETSI, "LTE; 5G; Overall description of Radio Access Network (RAN) aspects for Vehicle-to-everything (V2X) based on LTE and NR (3GPP TR 37.985 version 16.0.0 Release 16)", 2020.
[2] https://www.3gpp.org/news-events/3gpp-news/1798-v2x_r14

Furthermore, with even higher communication frequencies, Vehicular Visible Light communication (VVLC) in terahertz frequencies can be exploited. The VVLC can be implemented with minor vehicle cost increase, as the Light Emitting Diodes (LEDs) are frequently exploited for vehicle lights, and parking cameras are exploited as well.

The communication messages, for passing information between vehicles, infrastructure, network, or pedestrians are (only few examples):

- Cooperative Awareness Messages (CAM) or Basic Safety Message (BSM) with information of presence, positions as well as basic status of communicating ITS stations to neighbouring ITS stations.
- Decentralised Environmental Notification Messages (DENM) providing alerts to road users of the detected events.
- Signal Phase and Timing Message (SPAT) message primarily used to communicate the intersection status to vehicles approaching an intersection
- In Vehicle Information Message (IVI) message conveying information about infrastructure-based traffic services (traffic light state, future state predictions, speed advice, etc.).

No matter, which communication technology is exploited for V2X, it must be in line with communication requirements for various operations, such as:

- Cooperative awareness: warning and increase of environmental awareness (e.g., Emergency Vehicle Warning, emergency electronic brake light, etc.).
- Cooperative sensing: exchange of sensor data (e.g., raw sensor data) and object information that increase vehicles environmental perception.
- Cooperative maneuver: includes use cases for the coordination of the trajectories among vehicles, e.g., lane change, platooning, or cooperative intersection control.
- Vulnerable Road User (VRU): notification of pedestrians, cyclists etc.
- Traffic efficiency: update of routes and dynamic digital map update; for example, signal phase and timing, green light optimal speed advisory, etc.
- Teleoperated driving enables operation of a vehicle by a remote driver.

The requirements for the mentioned operations are presented in Table 1.

Table 1. Communication requirements[3].

Use Case	V2X mode	E2E latency (ms)	Reliability (%)	Data rate (kbps)	Communication range
Cooperative awareness	V2V/V2I	100 - 1 000	90-95	5 - 96	Short to medium
Cooperative sensing	V2V/V2I	3 - 1 000	>95	5 - 25 000	Short
Cooperative maneuvering	V2V/V2I	<3	>99	10 - 500	Short to medium
Vulnerable road user	V2P	100 - 1 000	95	5 - 10	Short
Traffic efficiency	V2N/V2I	>1 000	<90	10 - 2 000	Long
Remote Driving	V2N	5 - 20	>99	>25 000	Long

[3] Boban, M., Kousaridas, A., Manolakis, K., Eichinger, J. and Xu, W., 2017. Use cases, requirements, and design considerations for 5g v2x. *arXiv preprint arXiv:1712.01754*

The standardization and implementation process differ by the country, due to different spectrum allocation of existing technologies, such as radio, television, mobile networks, etc. The different channel allocation, and parameters are shown in Table *2*.

Table 2. Comparison of vehicular technologies around the world.

Item	USA	EU	Korea	Japan
Frequency band (GHz)	5.855~5.925GHz (7 CH)	5.855~5.925GHz (7 CH)	5.855~5.925GHz (7 CH)	700MHz (1 CH)
Channel bandwidth	10MHz, 20MHz	10MHz	10MHz	10MHz
Data rate (Mbit/s)	3 - 54	3 - 27	3 - 27	3 - 18

Comparison of LTE-V2X and IEEE 802.11p performance in terms of Packet Reception Ratio (denoting ratio of successfully received packets), as shown in Table 3, shows the LTE-V2X outperforming the IEEE 802.11p for longer distance, but providing similar results for distances below 100 m, where most of the communication will occur. Furthermore, the IEEE 802.11p is already being deployed and thus a combination of both technologies (with addition of 5G-V2X when ready) seems to be promising solution for vehicular communication.

Table 3. Comparison of LTE-V2X and IEEE 802.11p[4].

	FREEWAY: ABSOLUTE SPEED 140 KM/H		**URBAN: ABSOLUTE SPEED 60 KM/H**	
DISTANCE	**LTE-V2X**	**IEEE 802.11p**	**LTE-V2X**	**IEEE 802.11p**
100 M	99.9 %	98.9 %	78.6 %	67.0 %
200 M	98.5 %	91.2 %	42.2 %	33.9 %
300 M	95.5 %	33.2 %	13.8 %	2.6 %
DISTANCE TO ACHIEVE 90 %	360 m	210 m	80 m	60m

[4] Zhao, L., Fang, J., Hu, J., Li, Y., Lin, L., Shi, Y. and Li, C., 2018, June. The Performance Comparison of LTE-V2X and IEEE 802.11 p. In *2018 IEEE 87th Vehicular Technology Conference (VTC Spring)* (pp. 1-5). IEEE.