VEHICLE-TO-EVERYTHING COMMUNICATION

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Resume

With an increasing number of vehicles, there is a need for reliable and secure communication between subjects participating in the dynamic traffic environment. This kind of communication is called V2X (Vehicle-to-Everything). It can also contribute to higher level of autonomous driving. The V2X model operation is enabled by use of the newest technologies and standards, defined by 3GPP Organization. In this paper, a review of the V2X communication models, available technologies and standards are studied.

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1 Introduction

In the recent years, there has been a need for the V2X communication in the dynamic traffic environment. This communication ensures the safety and non-safety messages transmission. According to the subject, which is involved into communication, the last letter of the V2X model can change and define the models like:

- V2V (Vehicle-to-Vehicle) communication model
- V2I (Vehicle-to-Infrastructure) communication model
- V2N (Vehicle-to-Network) communication model
- V2P (Vehicle-to-Pedestrian) communication model.

Intelligent transport system

The first idea of monitoring the traffic was firstly formulated in Japan in the nineteen seventies. There was an intention to monitor the traffic information using telematics. It came to Europe in the nineteen eighties and there was the foundation of the ITS (Intelligent Transport System). The ITS supports the innovation services regarding the various traffic means and traffic management [1]. It helps to improve the safety and effectiveness of the traffic. This results in lower emissions. All the participants in the environment are the part of the ITS. Data generated by ITS system describe the real conditions on the road, traffic collision information or information about the planned journeys [2-3]. Seven groups of functionalities were defined, which should be covered by this system [3-4]:

- Travel and transportation management
- Travel demand management
- Public transportation operation
- Electronic payment
- Commercial vehicle operations
- Emergency management
- Advanced vehicle control and safety system.

The most known project, belonging to the ITS, is eCall [5], which enables to call emergency services in the European region in the case of accident.

There are also the organizations and partnerships, which define the conditions and standards for V2X, contributing to the ITS improvements. The most known is 3GPP (The 3rd Generation Partnership Project) Organization, founded in the year 1998 by the group of telecommunication associations [6]. This organization intended to create the standard for the 3rd generation of mobile telecommunication systems. Nowadays, it regularly works on releases, which define the supported technologies and functionalities for vehicular communication. Actually, they have been working on the Release 18 [6].

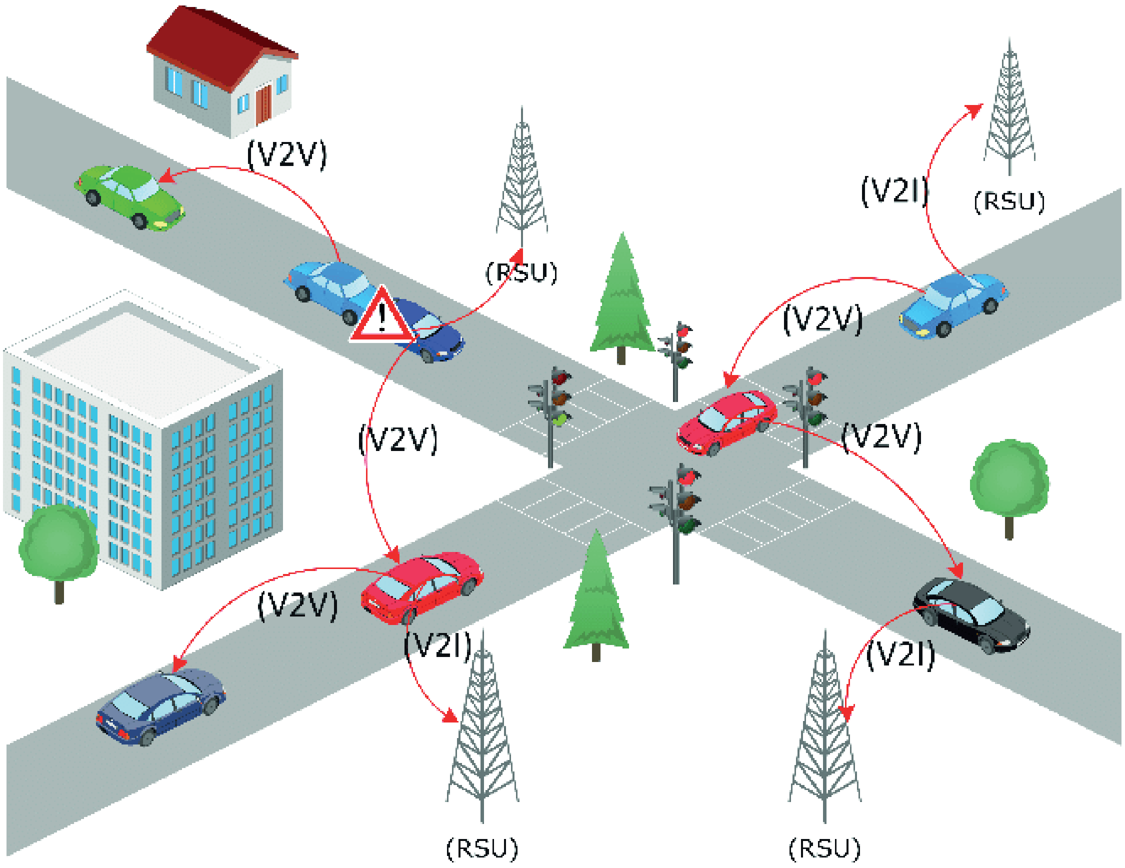

***Figure 1** The VANET environment with OBU and RSU units [14]*

VANET network and its components

The ITS operates in the vehicular network called VANET (Vehicular-Ad-Hoc-Network), which belongs to the subgroup of MANET (Mobile-Ad-Hoc-Network) networks. It is the network without the fixed infrastructure. That means, the communication between nodes is established spontaneously. The node can be any entity (vehicle, infrastructure, device) situated in this environment. The connection between nodes is enabled by the control units, like OBU (On-Board Unit) and RSU (Road-Side Unit). Both could be used like routers. An example of the VANET environment can be seen in Figure 1. Topology, created in the VANET network, is characterized by frequent changes and self-organization due to the high speeds of nodes. The connection is short and dependent on actual transport conditions [7-12].

VANET enables four communication types, unicast, multicast, geocast and broadcast. By unicast communication, the data packets are sent directly from source node to destination node. The multicast communication enables the group addressing of packets to nodes, which are located in the signal range of source node. By the geocast communication, the packets are sent to the nodes in geographical region. If the packets are received by the node from another geographical region, the data are damaged by the control electronics. By the broadcast communication, the data are sent from the source node to all the nodes in the network [9].

As it was mentioned, units OBU and RSU enable communication between the nodes in the network. The unit OBU is the hardware device integrated in the vehicle, together with another huge number of control units, creating the vehicle topology. It is used to establish the wireless communication. The received data are processed by this unit and resend to other units through the vehicular buses or to other nodes in the network [13]. The data sources are also obtained by vehicular telematics and vehicular technologies, like Head-up display, cameras or sensors. In addition to the received data, the OBU unit is able to transmit data, processed by vehicle itself.

The RSU unit is the hardware device equipped with the processor and antenna. It is able to establish wireless communication. However, it is equipped with the wire communication interface, as well. There are two types of these systems, static transport systems and smart transport systems. The first one works with the data from central systems, like information about weather or work on the road. The second one works with the actual data from the traffic system, obtained from cameras or from other nodes. As they are able to work like router, both can processed received data. The

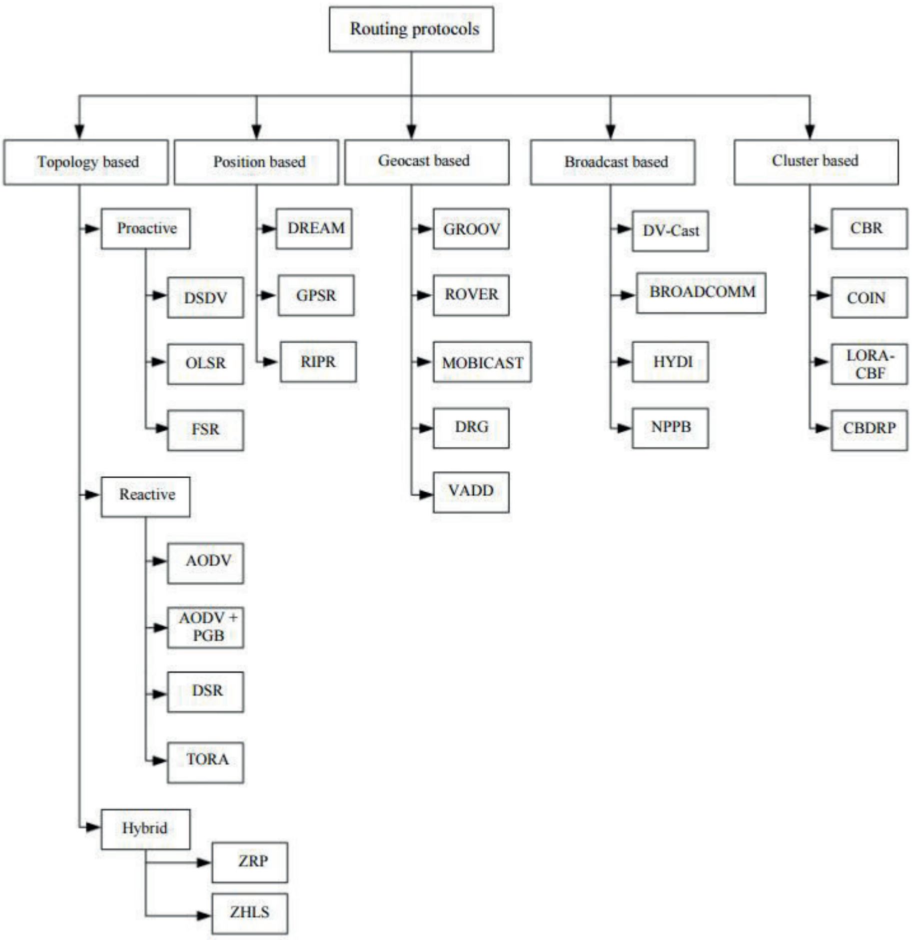

Figure 2 *Routing protocols [16]*

RSU units are normally located near to the main roads, highways, or gas stations [11, 13].

Routing protocols

As the topology of the VANET network is characterized by the frequent changes [15], there is a need for optimal creation of communication channels between the source and destination node. The optimal communication channel can be found using routing protocols, which could be classified like [9, 16-18]:

- Topology routing protocols: The idea of topology routing protocols is to find the shortest path between the source and destination node. Information related to route is stored into the routing table. According to the updating time, protocols are further divided into proactive, reactive and hybrid protocols [11].
- Position routing protocols: These protocols are based on the vehicle position or location from sources such as maps or GPS [16]. There is no need to maintain the topology information.
- Cluster routing protocols: Vehicles with similar characteristics, like velocity or direction can create a cluster with one cluster head. Cluster head is responsible for the communication with other clusters creating virtual infrastructure [11]. In the case of inside communication, the direct path is used.
- Geocast routing protocols: The information is forwarded between the nodes in the same geographical area. The packets are sent from source nodes to nodes in the same zone.
- Broadcast routing protocols: The information is shared between vehicles, which are outside the range of the source node [17]. It means that there is a flooding of information, shared via the nodes in the network. The information is related to emergency situations, road conditions or safety situations.
- Forwarding routing protocols: The information is transmitted via multiple hops between the nodes. This way is useful when the requested information is only in the interest of a few nodes [9].
- Beaconing routing protocols: This mechanism enables to store information, which are not time dependent and rebroadcast that with other incoming message.
- Delay-tolerant routing protocols: This scheme is used when the traffic density is low and the end-to-end routing is not possible, for example at nights.

In Figure 2, are shown the routing protocols mentioned above, which can also be classified into more subgroups.

Table 1 Service requirements for V2X use cases [20-22]

Service type	V2X applications	Description	Datarate [Mbps]		Latency [ms]	Comm. range [m]
			V2V	V2I		
Automated driving related services	Platooning	SAE J3016 Level 4/5 Platooning	65	50	20	80-350
Automated driving related services	Advanced driving	SAE J3016 Level 4/5 Automated driving	53	50	100	360-700
Safety related services	Extended driving	Collision warning	1000*	-	3*	50-1000
Automated driving related services Safety related services	Remote driving	V2X Data transfer	-	DL[1]:1 UL[2]:25	5	1000+

*- exclusive selection

[1]- Downlink, [2]- Uplink

Autonomous driving

With the increasing number of vehicles and used technologies enabling the vehicular communication, there is also the intention to increase the level of autonomous driving. In 2014, the levels were defined in the standard SAE J3016 [19] by the Society of Automobile Engineers (SAE). There are six of these levels:

- Level 0 - manual driving (No driver assistance systems.): The driver is fully responsible and permanently carries out all the aspects of the driving tasks.
- Level 1 - driver assistance (The system will perform one of the driving tasks.): The driver can delegate steering or accelerating/braking to the system.
- Level 2 - partial automation (The driver must permanently monitor the system.): The system will perform some of the driving tasks.
- Level 3 - conditional automation (In certain situations, the driver can turn attention away from the road, but must always be ready to take full control again.): The system can autonomously control the vehicle on defined routes.
- Level 4 - high automation (The driver can transfer complete control to the system and dedicate to other activities. However, he can take control at any time if he wishes.): The system is able to perform all the driving tasks.
- Level 5 - full automation (No driver needed): The system controls the vehicle autonomously under all the conditions.

V2X use cases and service requirements

Regarding to the V2X model, there are three groups of vehicle related services [20]. The first group, safety-related services, works with the real-time safety messages to decrease the risk of car accident. The second group, non-safety related services, makes the traffic flow effective. The last group, automated driving-related services, intends to increase the level of autonomous driving.

For each of the mentioned cases, there are requirements for quality of service [20-22]. These services mainly depend on maximal end-to-end latency and communication range. Very low latency (less than 10 ms) is required for V2X applications like collision warning or remote driving. As the communication range is also very important in these cases, the minimal one, which is needed to support some of the services, is 50 meters. The higher, the better, is the main requirement in these cases [21].

2 The V2X technology based on DSRC

There are several protocols and standards defining the communication between the nodes in VANET network, like WAVE protocol for North America and ETSI ITS protocol for Europe. Both define the standardization for the DSRC (Dedicated short-range communications). DSRC establish the communication via the OBU and RSU units [23-25].

WAVE protocol

This protocol is defined in the standard IEEE 1609 for the safety wireless communication. The communication model can be described with ISO/OSI model divided into four layers, as it can be seen in Figure 3.

Physical layer

Physical layer of the WAVE protocol is defined in the standard IEEE 802.11p. It supports different data rates using OFDM mechanism. The 75 MHz bandwidth in 5.9 GHz spectrum is divided into 7 smaller operation channels, each of 10 MHz bandwidth [2]. The channel 178 is the control one, channels 174, 176, 180 and 181 are used like service channels. Channels 184 and 172 are reserved for the future use. There was the channel

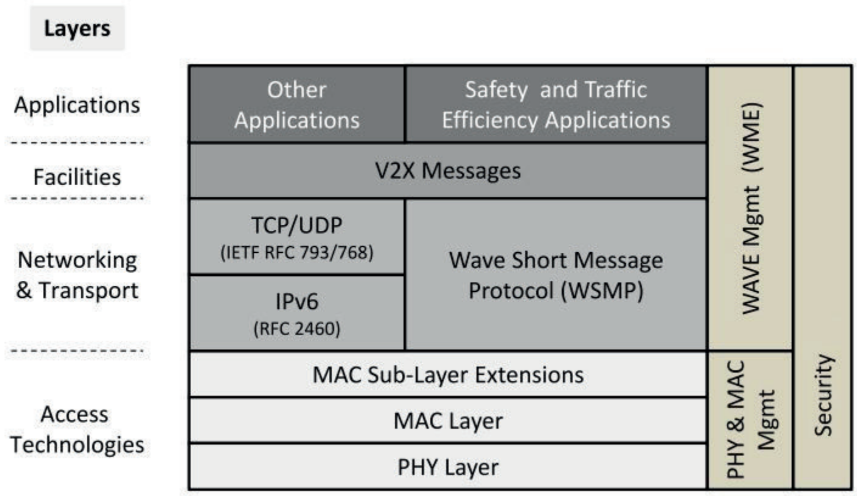

Figure 3 *Communication model for WAVE protocol [2]*

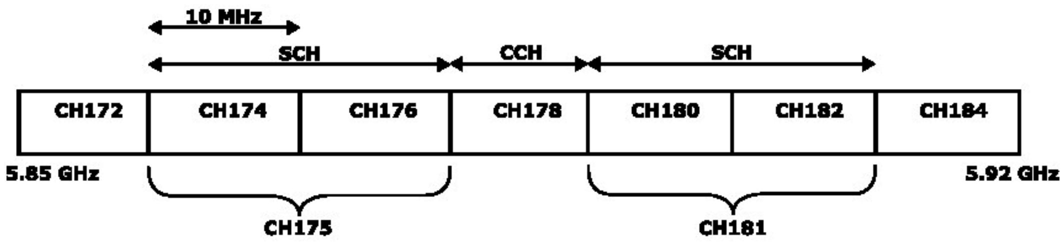

Figure 4 *WAVE frequency band [26]*

revision, which merged the channels 174 and 176 into the channel 175 and the channels 180 and 182 into the channel 181 [26]. The mentioned spectrum can be seen in Figure 4.

By devices with more than one physical layer, it is possible to use the control channel and minimal one service channel. By devices with one physical layer, there is a switch between the control and service channel. In this case, the devices are synchronized for monitoring and use the control channel [2].

MAC layer

The MAC layer of WAVE protocol is defined in the standard IEEE 1609.4. A typical reference model consists of two planes, data and management [27]. Data plane provides data service to the upper layer for incoming and outgoing data. Management plane provides synchronization and channel availability. The MAC sublayer provides channel switching for devices with parallel switching operation between the control and service channels [27].

WSMP protocol

The WSMP (WAVE Short Message Protocol) protocol allows applications to control features and parameters of physical layer [28]. It can be a number of a channel or receiver's MAC address. It is designed to have the minimal size.

BSM

The BSM (Basic Safety Message) protocol defines safety related messages, which are periodically sent by source node [29]. The destination nodes are all the entities in the signal range.

ETSI ITS Protocol

This protocol is similar to WAVE, just defined for the geographical region of Europe. In Figure 5, is shown the communication model described by ISO/OSI model divided into four layers, network and transport layer, access, application and facility layer.

Physical and MAC layer

Physical and MAC layer are defined by IEEE 802.11p standard. It is also called ITS-G5. It works in two frequency bands, 5 GHz using the OFDM mechanism. In the second case, communication works in the range of 5.9 GHz divided into smaller operation channels named from A to D. Version A works with the frequency of 30 MHz for safety messages, version B with the frequency of 20 MHz for non-safety messages and version C works

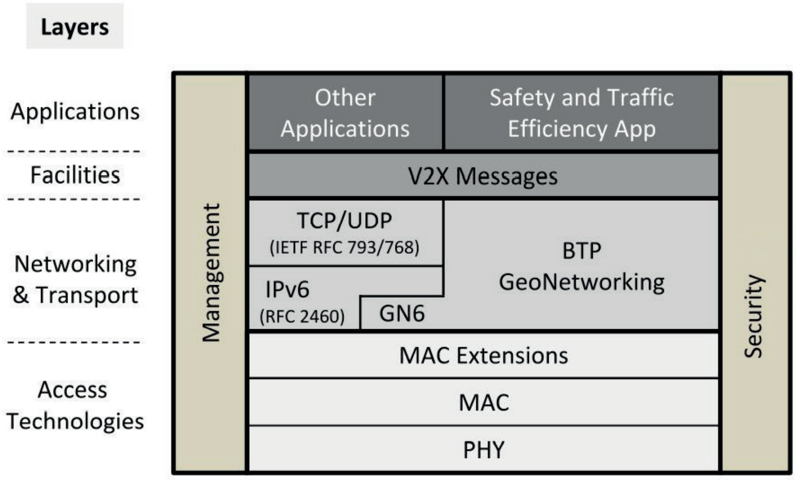

Figure 5 *Communication model for the ETSI ITS protocol [2]*

in the frequency band for radio access [2, 30].

GeoNetworking protocol

This protocol uses geographical coordinates for transmitting the safety related data. All the nodes, located in the geographical region of the source node, are able to receive the data. After processing the information, they forward the message in the range of the region.

CAM

The CAM (Cooperative Awareness Message) is safety related message with information about vehicle state, like position, direction or velocity. It is periodically sent by source node to destination nodes in the network to proceed the critical traffic situations [31-32].

DENM

DENM (Distributed Environmental Notification Message) messages are classified as safety related. They operate in the geographical region, which the source node is located in [32]. They are sent in the case of any change, not periodically.

Standard IEEE 802.11p

Standard IEEE 802.11p is based on its forwarder IEEE 802.11a for the WLAN network. In the traffic environment, it supports the communication between moving nodes up to the speed of 252 kmph, as it is seen in Table 2. Latency time is 100 ms and the communication range is about 1000 m. The transmission reliability is just 78% due to the noise effects [33-34].

Physical layer uses the OFDM (Orthogonal Frequency Division Multiplexing). The main difference is the carrier spacing and bandwidth, which are reduced by the factor of two (10 MHz of bandwidth and 156.25 kHz sub-carrier spacing). It uses BCC (Binary Convolutional Coding), which loses its capability to recover defect messages when the modulation and coding schemas are extended in a high communication range (more than 50 m) [14, 33, 35].

MAC layer uses EDCA (Enhanced Distributed Channel Access) method. This method uses CSMA/CA (Carrier Sense Multiple Accesses with Collision Avoidance) with no exponential back-off and no message acknowledgement [33].

Standard IEEE 802.11bd

Standard IEEE 802.11bd is based on the standard IEEE 802.11ac (Wifi 5). The standard "bd" is able to support double performance of "p" version. Regarding to the latency and communication range, one can expect the values < 100 ms and > 1000 m [33]. It supports the communication up to the speed of 500 kmph with double communication range of IEEE 802.11p. The used bandwidth channel is 20 MHz [14]. According to [33], the transmission reliability is just 88%.

The MCS (Modulation and Coding Scheme) profile enables to reach 256-QAM and MIMO (Multiple Input, Multiple Output) antenna helps to provide high throughput. The LDPC (Low-Density Parity-Check) coding mechanism and Midambles are used to establish the reliability in the environment of 500 kmph velocity [14]. In comparison with the "p" variant, which uses BCC, the supported velocity is double. More details there are seen in Table 2. There is also the standard IEEE 802.11bd^{DC}, which uses DCM (Digital Code Modulation) modulation to increase the communication range. It is based on the standard IEEE 802.11ax.

The MAC layer of "bd" variant uses EDCA method for channel access. With the frequency range of 20 MHz and 256-QAM MCS, it is possible to enable the message retransmission by sending each OFDM symbol over two different sub-carriers [33].

Table 2 *Comparison of IEEE 802.11p and IEEE 802.11bd standards [36]*

Feature	802.11p	802.11bd
Radio bands of operation	5.9 GHz	5.9 GHz and 60 GHz
Channel coding	BCC	LDPC
Re-transmission	None	Congestion dependent
Countermeasures against Doppler shift	None	Midambles
Sub-carrier spacing	156.25 kHz	312.5 kHz, 156.25 kHz, 78.125 kHz
Supported relative speeds	252 kmph	500 kmph
Spatial Stream	One	Multiple

3 The V2X technology based on C-V2X

C (Cellular)-V2X technology is good candidate for supporting the vehicular communication due to its coverage, security, mobile services and high network capacity.

LTE-V2X

The LTE (Long Term Evolution)-V2X communication mode is standardized by the 3GPP Organization supporting V2V, V2I, V2P and V2N communication models in the frequency band of 5.9 GHz [33].

Physical Layer

The physical layer of LTE-V2X technology is based on SC-FDMA (Single-Carrier Frequency Division Multiple Access) and supports the channels of 10 or 20 MHz. Each channel is divided into sub-frames, Resource Blocks, of 180 kHz (12 sub-carries each of 15 kHz). In terms of time, the channel is divided into sub-frames of 1 ms. Each sub-frame consists of 14 OFDM symbols with cyclic prefix (9 of them are used for data transfer and the rest of 4 are used for transport of demodulation reference signals, the last symbol is used for switching between the received and transmitted one via the sub-frames) [35].

The resource blocks are formed into sub-channels. Each sub-channel can consist of resource blocks just with the same sub-frame. The number of resource blocks for one sub-frame is variable and configurable. Sub-channels are used for transporting the data and control information. Data are formed into transport blocks and are transported via channel PSSCH (Physical Sidelink Shared Channel). Transport blocks contain the whole data packet and use QPSK, 16-QAM or 64-QAM modulation with turbo coding [21, 24].

Each transport block contains the SCI (Sidelink Control Information) message divided into two resource blocks, which are transported via PSCCH channel. The SCI message contains the critical information about received transport block, which is not able to be decoded. This data should be transmitted in one sub-frame [21, 36].

Transmission modes

By LTE usage, there are two transmission modes:

- LTE-Uu mode: This mode is applicable for short distances. The information is firstly transmitted to the entity eNodeB (also named eNB) via the uplink channel by source node. After that, the information is transmitted via the downlink to destination node [24]. The entity eNodeB is able to transmit the information to other nodes in the network using eMBMS (enhanced Multimedia Broadcast Multicast Service) [36].
- LTE-PC5 mode: This mode supports the direct communication between nodes via the PC5 interface using sidelink channel. The presence of the entity eNodeB is optional [36]. This case can be seen in Figure 6, where the RSU unit represents the eNodeB. The two modes are defined according to this situation. If the entity is present, there is mode 3. If not, there is mode 4 [24, 36-38].

Depending on the mode, which is used for the data transmission, the requirement for the latency is in the range between 20-100 ms [39]. The communication range can reach the value >1200 m [40].

5G NR V2X

5G NR (New Radio) V2X communication mode supports the advanced V2X functionalities and higher level of autonomous driving [37].

Physical layer

By 5G NR V2X, there are two frequency bands defined:

- Frequency band 1 (FR1): from 410 MHz to 7.125 GHz
- Frequency band 2 (FR2): from 24.25 GHz to 52.6 GHz.

In both cases, the sidelink channel is supported. By data transmission, the OFDM method with cyclic prefix

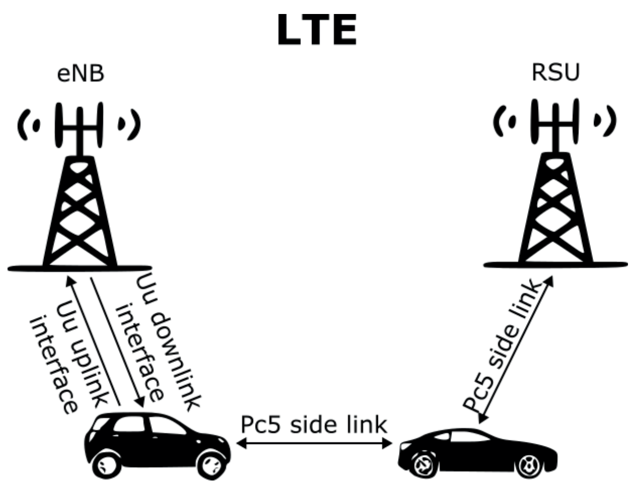

Figure 6 *LTE- communication model [24]*

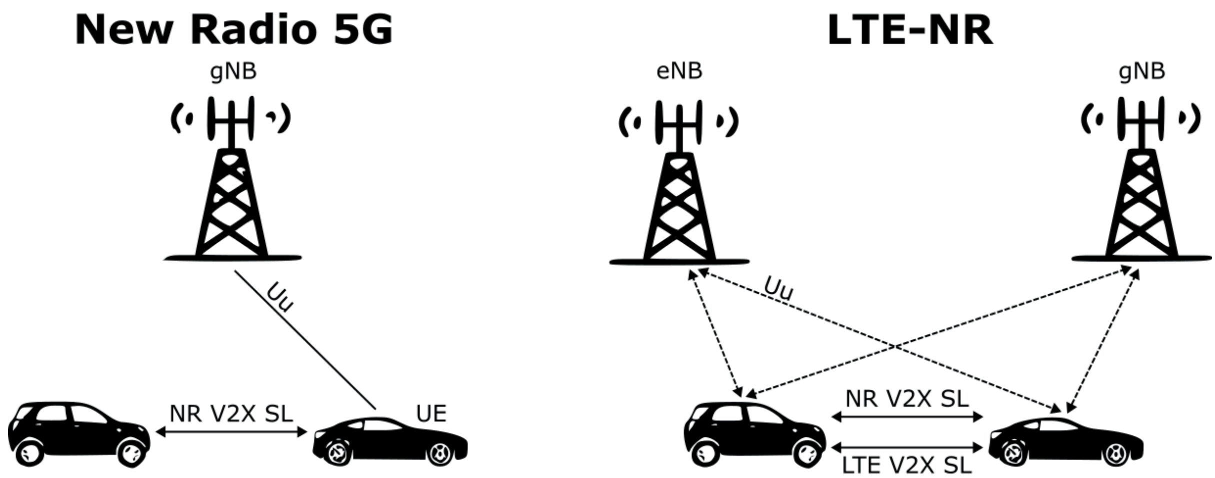

Figure 7 *Standalone (left) and non-standalone (right) 5G communication models [24]*

is used. The frame duration is 10 ms. Each frame is divided into 10 parts with duration of 1 ms. Sub-frames are organized into slots for data transmission. Sub-carrier spacing is defined for both, FR1 and FR2. For FR1, there are values 15 kHz, 30 kHz and 60 kHz. For FR2, there are values of 60 kHz and 120 kHz [21, 41]. In the terms of modulation, 16-QAM and 64-QAM are used [36]. More details, there are in Table 3.

Transmission modes

There are two transmission modes defined:

- Mode 1: This mode uses the interface PC5 supporting sidelink V2X communication for NR.
- Mode 2: This mode uses Uu interface supporting uplink and downlink channel in standalone (SA) and non- standalone (NSA) modes. In the standalone mode, the direct communication between vehicles or towards the entity gNB via sidelink channel is supported. It can be seen in Figure 7, left-hand side. In non-standalone mode, the data are transmitted firstly towards the gNB entity and forwarded to destination node [21, 24]. This can be seen in Figure 7 on the right-hand side. This model includes the possibility of the LTE usage, as well. For sidelink channel usage, there are four sub-modes defined [36]:
- Mode 2 (a): Each node (user) selects its resources autonomously.
- Mode 2 (b): Each node (user) is able to assist to other nodes (users) by resources selection.
- Mode 2 (c): In this sub-mode, the node (user) uses pre-configurable channel sidelink for data transmitting.
- Mode 2 (d): The node (user) selects the resources for another node (user).

Depending on the mode, which is used for the transmission, the requirements for the communication range is between 50-1000 m and 3-500 ms for the latency [39].

4 Conclusion

In this paper is described the V2X communication, which supports the data transmission between subjects in the traffic environment. Regarding to the latency and communication range, it compares C-V2X and DSRC-

***Table 3** Comparison of LTE-V2X and 5G NR V2X [36]*

Feature	LTE-V2X	5G NR V2X
Comm. types	Broadcast	Broadcast, Groupcast, Unicast
MCS	Rel. 14: QPSK, 16-QAM Rel. 15: 64-QAM	QPSK, 16-QAM, 64-QAM
Waveform	SC-FDMA	QFDM
Re-transmission	Blind	HARQ
Feedback channel	Not available	PSFCH
Control and data multiplexing	FDM	TDM
DMRS	Four/sub-frame	Flexible
Sub-carrier spacing	15 kHz	sub-6 GHz: 15, 30, 60 kHz mmWave: 60, 120 kHz
Scheduling interval	one sub-frame	slot, mini-slot or multi-slot
Sidelink modes	Modes 3 and 4	Modes 1 and 2
Sidelink sub-modes	n/a	Modes 2(a), 2(d)

***Table 4** Comparison of DSRC-V2X and C-V2X regarding to V2X use cases [33, 39-40]*

Parameters	IEEE 802.11p	IEE 802.11bd	LTE-V2X	5G NR V2X
Latency [ms]	100	< 100	20 - 100	3 - 50
Communication Range [m]	1000	> 1000	> 1200	50 - 1000
V2N Service Support	No	Yes	Yes	Yes
Supported V2X Use Case	Advanced driving (SAE J3016 level 3)	Advanced driving, Platooning (SAE J3016 level 3)	Advanced driving Platooning	Advanced driving Platooning Collision warning (partially) Remote driving (partially)

V2X communications referring to the V2X use cases in Table 1. In Table 4, are mentioned the V2X use cases in the column of the type, which is able to fulfill the requirements.

Comparing IEEE 802.11p and IEEE 802.11bd, the "p" version is able to fulfill partially the requirements for advanced driving. The problem is the transmission reliability, which is just 78%. For advanced driving of the SAE level 4 or 5 that is not enough. The IEEE 802.11p is just suitable for the cases of the level 3. The version "bd" fulfills the requirements of advanced driving and platooning with the reliability 88%. Thus, that is not enough for the SAE level 4 or 5.

Regarding to C-V2X communication, the LTE-V2X fulfills the specifications for platooning and advanced driving of SAE levels, which are higher than 3. For the use cases like collision warning and remote driving, that is not enough regarded to the latency. In the case of communication range, the LTE is suitable just partially. The 5G NR V2X is able to fulfill the requirements for the use cases of platooning and advanced driving. For the other cases, it fulfills the specifications just partially. By collision warning, the latency is on its lower limit and by remote driving, the communication range is not enough.

To summarize the data, the C-V2X seems to be a good candidate for vehicular communication regarded to extended functionalities. In cooperation with vehicular telematics and with higher functionalities of 5G NR V2X, which are still under research, there is a big potential to reach the higher (4 or 5) SAE level of autonomous driving.

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Conflicts of interest

The author declares that she has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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