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Cellular V2X Standardization in 4G and 5G

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SUMMARY Recently connected car called Vehicle-to-Everything (V2X) has been attracted for smart automotive mobility. Among V2X technologies, cellular V2X (C-V2X) discussed and specified in 3rd generation partnership project (3GPP) is generally regarded as possibly utilized one. In 3GPP, the fourth generation mobile communication system (4G) and the fifth generation (5G) including new radio (NR) provide C-V2X standards specifications. In this paper, we will introduce C-V2X standards and share our views on future C-V2X.

key words: *C-V2X, 4G, 5G, NR, downlink, uplink, sidelink*

1. Introduction

Automotive industry has grown in unvarying assumptions for a long time. For example, each vehicle is owned by a family, is driven by a human, runs on gasoline, etc. Meanwhile, there are many expectations that the assumptions will be enhanced — in 2016, Daimler propounded 'CASE' that would bring innovation to the automotive industry [1]. CASE is defined as C: Connected, A: Autonomous, S: Shared & Services, E: Electric.

Among the four factors, 'Connected' car called Vehicle-to-Everything (V2X) is the important one to enable smart automotive mobility and to realize the other factors. For example, information that a single vehicle obtains by own sensors is limited due to sensor range or obstacles. More sensor information in other vehicles or road side units (RSUs) is shared via connections with them, and the information is utilized for safe and effective self-driving, i.e. beneficial for 'Autonomous'.

Towards V2X era, many countries/regions/automotive-manufacturers/telecommunications-companies/etc. have been discussing on a lot of aspects including how to do communications. Then the cellular communication system standardized in 3rd generation partnership project (3GPP) has been attracted as one of V2X mechanisms, which is called cellular V2X (C-V2X). The reason to use the cellular communication system is that the system is capable of covering short range to long range, is capable of supporting large capacity, and is available in various fields. Based on such demands, 3GPP has been discussing C-V2X standards since the fourth generation mobile communication system (4G) era. Currently the latest system is the fifth generation (5G), and the discussions have been continued in 5G.

In this paper, we will introduce C-V2X specifications of both long term evolution (LTE) and new radio (NR) from use case perspective and technical perspective. Additionally our views on C-V2X in future release are provided at the later part. Section 2 presents C-V2X overview so far. Use cases assumed in 3GPP are shown in Sect. 3, and technical topics are mentioned in Sect. 4. Section 5 will discuss future C-V2X. Lastly Sect. 6 concludes this paper.

Note: LTE including LTE-advanced and LTE-advanced Pro is the radio interface used in 3.9G/4G/5G. NR is the radio interface introduced for 5G NW.

2. Cellular V2X Overview

V2X communications are generally categorized into the following four types [2] illustrated as Fig. 1:

- Vehicle to vehicle (V2V)
- Vehicle to infrastructure (V2I) — e.g. RSU
- Vehicle to pedestrian (V2P)
- Vehicle to network (V2N)

In V2V/V2I/V2P, the communication purpose is to share information around a vehicle but not detected by the vehicle due to the distances. The communication is performed directly between the two devices. The radio interface is named PC5, and the communication link is called sidelink to align with downlink/uplink. Let this paper use 'sidelink' for the terminology of direct communication.

In V2N, information that is unavailable even in V2V/V2I/V2P is shared from/to conventional cellular networks covering wider area, which can be used by vehicles in the same way as downlink and uplink communications e.g. like normal smartphone. V2N is also available to communicate with other vehicles, RSUs, and pedestrians via network

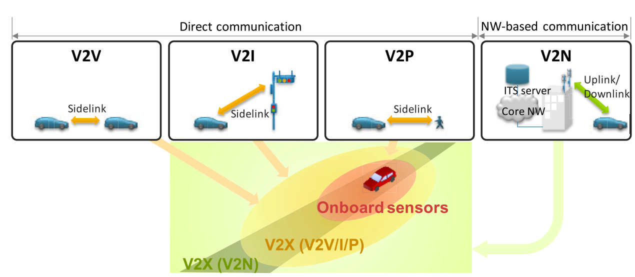

Fig. 1 C-V2X categories.

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base stations (BSs). Note that transmitter/receiver in network side is called BS and transmitter/receiver of each user including smartphone/ vehicle/RSU is referred to as user equipment (UE) in this paper.

From 3GPP perspective, technical standards are discussed and specified separately between downlink/uplink and sidelink since they have many differences as resource management, synchronization, etc. Especially downlink/uplink specifications focus on in-coverage scenario based on assumptions that downlink/uplink coverage is sufficiently provided by network operators, while sidelink specifications consider partial coverage and out-of-coverage scenarios additionally since sidelink communication link is feasible even in these scenarios, i.e. without network control. Here in sidelink 'in-coverage' scenario refers to the case where both UEs are inside the network coverage and can transmit/receive to/from the network. 'partial coverage' does the case where either UE, and 'out-of-coverage' does the case where neither.

As normal procedure in 3GPP, group of service and system aspects (SA) has been discussing and specifying use cases, performance requirements, architectures, and security aspects for C-V2X. Then based on the outcomes, group of radio access network (RAN) has been making radio standard specifications. As mentioned in the last section, there are a lot of studies on V2X communications from organizations. They, e.g. 5G automotive association (5GAA) established with automotive and ICT industries, submit their views to 3GPP sometimes [3]. 3GPP considers the inputs as valuable opinions and takes them into account in the discussions on C-V2X.

C-V2X discussions have started in 4G. Figure 2 shows C-V2X roadmap. As abovementioned, C-V2X contains downlink/uplink and sidelink. For downlink/uplink, any standard specifications in the 3.9G/4G, and 5G [4]–[6] from Release 8 can be utilized as it is while 3GPP SA has been working on C-V2X since Release 14 [2]. On the other hand, regarding sidelink, making initial dedicated standards completed at Release 14 of 4G [7]. Later releases enhance sidelink standards for advanced use cases and to improve communication performance. As of July 2021 both downlink/uplink and sidelink are discussed in Release 17 for further enhancements, and this direction would be continued in Release 18.

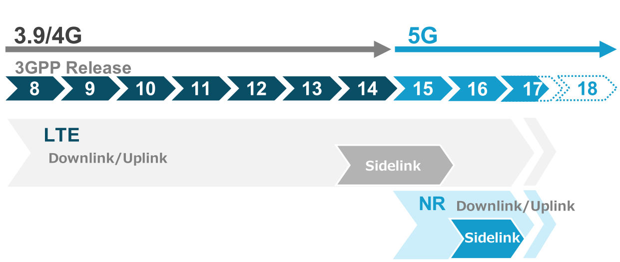


Fig. 2 C-V2X roadmap.

3. Assumed use Cases and Performance Requirements

This section summarizes 3GPP SA works on perspectives of assumed use cases and corresponding performance requirements for C-V2X.

3.1 LTE-V2X

Study/work on C-V2X at LTE, which is called LTE-V2X here, is the initial phase for 3GPP and hence basic road safety is focused on. For example, emergency vehicle/pedestrian warning, road safety service, automated parking system, and so on. In total 27 use cases are listed in [8]. These use cases are summarized into four categories of V2V/V2I/V2P/V2N in [2] and then performance requirements are defined as Fig. 3 and Table 1, where the definition of "reliability" is the maximum tolerable packet loss rate at the application layer. 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. LTE-V2X's target is basic road safety, thus the requirements are not so many and not so severe. It is noted however that there is an exception that for particular usage (pre-crash sensing) only, severer performance requirement is identified and specified.

3.2 NR-V2X

C-V2X in NR, which is called NR-V2X here, is considered on top of LTE-V2X, i.e. NR-V2X supports advanced

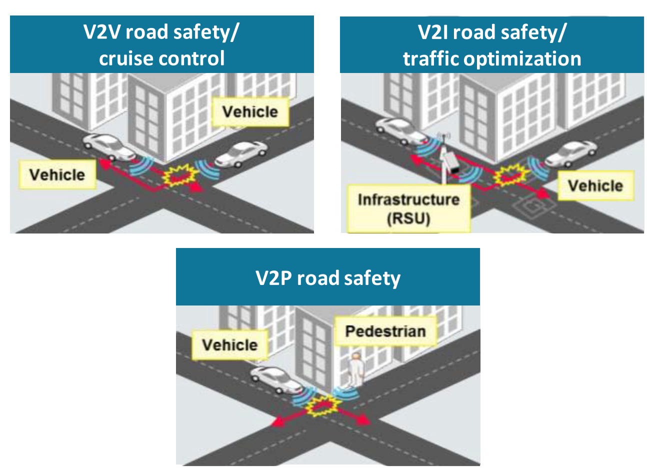


Fig. 3 Use cases in LTE-V2X.

Table 1 Performance requirements in LTE-V2X.

Use cases		E2E latency	Reliability	Message size	Velocity
V2V	Pre-crash sensing	20 ms	High	Periodic TX: 50 - 300 bytes Aperiodic TX: 1200 bytes	Relative velocity: 500 km/h
	Basic	100 ms			
V2I/V2P					Absolute velocity: 250 km/h
V2N		1000 ms			

V2X services beyond the use cases assumed in LTE-V2X. 25 use cases are listed in [9] and they are categorized into four groups [10] as follows:

- Vehicles platooning
- Extended sensors
- Advanced driving
- Remote driving

Vehicles platooning is a use case of dynamic vehicles formation. Vehicles belong to a group to travel together e.g. in line. The distance between the vehicles will be extremely small, that is to say quite severe performance level is required for cooperative driving among the vehicles in the same group. For instance, one requirement is 10 ms latency with 99.99% reliability.

Extended sensors enables to share sensor data including video data among vehicles, RSUs, pedestrians, etc. Each vehicle obtains information on surrounding environment from wider range compared to its own sensors. An example to utilize the information is collective perception of environment. Each vehicle notices the existence of objects in areas not visible to the local sensors, and performs automated forward collision avoidance. Communication performance significantly impacts accuracy of the avoidance mechanism, thereby the requirement is quite severe as 3 ms latency and 99.999% reliability with 50 Mbps for sensor information and 10 ms latency and 99.99% reliability with 700 Mbps for video data.

Advanced driving is use cases of semi/fully-automated driving. Emergency trajectory alignment is one of assumed cases for advanced driving. A vehicle detects necessity to avoid crashing and to share the information to other vehicles. Then they communicate each other to share new possible trajectories or driving intentions so that the vehicles update their trajectories immediately. Similar performance level to Extended sensors is assumed as the requirement.

Remote driving enables someone to drive a vehicle from a safe/secure remote location. The someone can be a human or a V2X application. The remote driver can control a vehicle that is driving along predictable routes such as public bus transport service. To realize this service, the performance requirement is 5 ms latency and 99.999% reliability with 25 Mbps uplink for sensors/video data and 1 Mbps downlink for control messages, which is categorized into ultra-reliability and low latency communications (URLLC) among downlink/uplink communications.

The assumed use cases and the corresponding performance requirements are presented in Fig. 4 and Table 2, respectively, where the definition of "reliability" is the success probability of transmitting X bytes within a certain delay, which is the time it takes to deliver a small packet from the radio protocol layer 2/3 service data unit (SDU) ingress point to the radio protocol layer 2/3 SDU egress point of the radio interface. The 1st/2nd/3rd use cases are involved with V2V/V2I/V2P, i.e. sidelink communication. Meanwhile the 4th one is a typical service based on V2N. It should be noted that it is expected that NR-V2X satisfies these requirements,

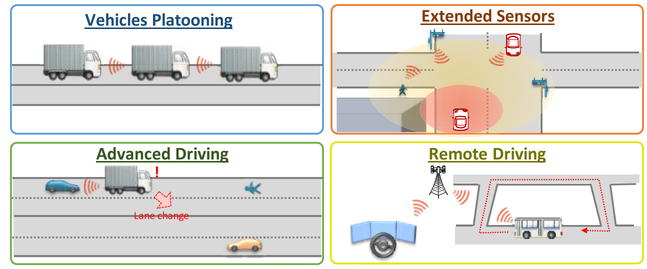


Fig. 4 Use cases in NR-V2X.

Table 2 Performance requirements in NR-V2X (excerpts).

Use case	Scenario	Degree	Payload (Bytes)	E2E Latency (ms)	Reliability (%)	Data rate (Mbps)	Commun. range (m)
Vehicle platooning	Cooperative driving	Lowest	300 - 400	25	90	-	-
		Highest	50 - 1200	10	99.99	-	80
	Info. reporting	-	50 - 1200	500	-	-	-
Extended sensors	Sensor info. sharing	Lower	1600	100	99	-	1000
		Higher	-	3	99.999	50	200
	Video sharing	Lower	-	50	90	10	100
		Higher	-	10	99.99	700	200
Advanced driving	Cooperative collision avoidance	-	2000	10	99.99	10	-
	Emergency trajectory alignment	-	2000	3	99.999	30	500
Remote driving	Info. exchange	-	-	5	99.999	UL: 25 DL: 1	-

but NR-V2X is not intended to replace LTE-V2X but to compliment LTE-V2X. At the same time how to utilize LTE-V2X and NR-V2X is up to regional regulators.

4. Technical Standard Specifications

According to the assumed use cases and the performance requirements identified by 3GPP SA, 3GPP RAN has been working on making technical standard specifications [11]–[22]. Here, mainly lower layer perspectives (PHY/MAC) are introduced as below.

4.1 LTE-V2X

4.1.1 Carrier Frequency

For LTE including LTE-V2X, several hundreds MHz and below/around 2 GHz are typically allocated frequency bands for uplink/downlink communications. Additionally around 3.5 GHz band can be used for them. Basically it is well known that these carrier frequencies are suitable for mobile communications due to the diffractiveness and the pathloss characteristics.

Meanwhile for sidelink, discussions focused on 5.9 GHz band, which is decided and widely assumed as ITS-band at outside of 3GPP. The band is actually allocated for V2X communication at least at US, EU, and China. C-V2X standards will be used as the technique at the frequency band, which has been decided at least at US and China.

4.1.2 Downlink/Uplink

As described above, Release 8 standard is the initial one for downlink/uplink of LTE. Many enhancements were introduced after the initial release to improve achievable data

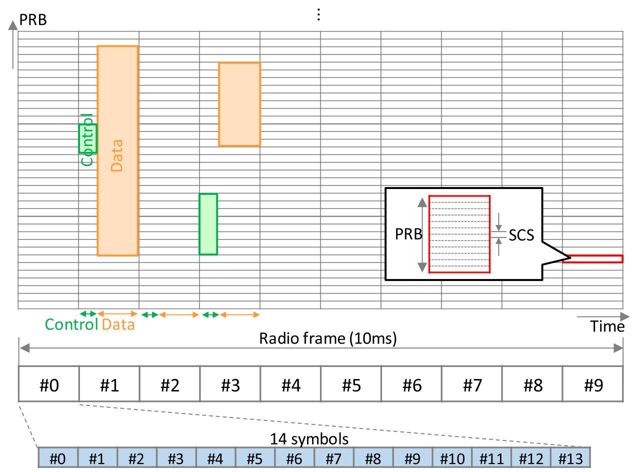
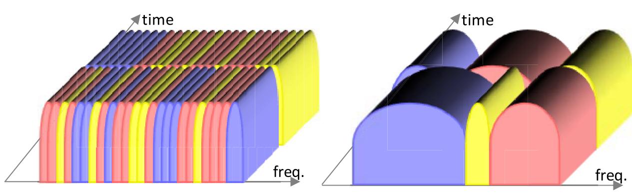


Fig. 5 Overview of 4G LTE downlink/uplink.



OFDM DFT-s-OFDM

Fig. 6 OFDM and DFT-s-OFDM (a color means data to/from a UE).

rate. The following are the notable features for unicast communications. Although almost standards were specified before C-V2X work at 3GPP SA, performance requirement of LTE-V2X presented in Table 1 will be met sufficiently. Fig. 5 shows overview of LTE downlink/uplink.

- Waveform

Orthogonal frequency division multiplexing (OFDM) is used for downlink and discrete Fourier transform-spread OFDM (DFT-s-OFDM) is adopted for uplink. Examples of these waveforms are illustrated in Fig. 6. OFDM is a multicarrier modulation format where information signals are modulated with orthogonal subcarriers and high frequency efficiency is expected. Meanwhile OFDM basically leads to large peak to average power ratio and hence results in either expensive equipment for power amplifier or degraded coverage performance. This is not desirable at UE side, thereby uplink uses DFT-s-OFDM, where DFT is preliminarily applied in OFDM modulation such that peak to average power ratio is not so high.

- Frame structure

Figure 5 explains the frame structure. For time-domain resource, one radio frame of 10 ms contains 10 time units where each time unit is composed of 14 OFDM symbols. For frequency-domain resource, the minimum element is a sub-carrier with 15 kHz sub-carrier spacing (SCS) and 12 sub-carriers compose a single frequency unit named physical resource block (PRB). A set of 14 symbols and 12 subcarriers is the smallest resource unit of network scheduling.

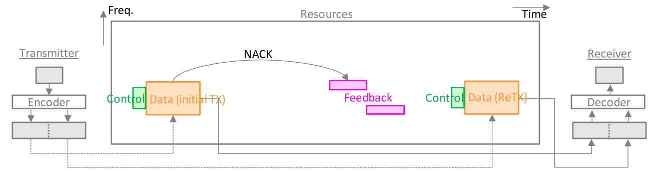
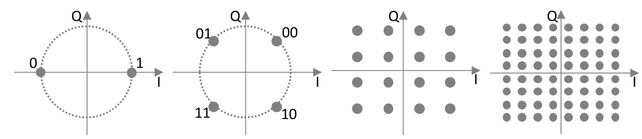


Fig. 7 HARQ operation.



BPSK QPSK 16QAM 64QAM

Fig. 8 Modulation constellation.

- Scheduling/HARQ operation

Control information including information for data transmission/reception is transmitted to each UE at a couple of the initial symbols included in each time unit, which is described in Fig. 5. Based on the control information, data is transmitted to/from each UE at the remaining symbols according to indications conveyed in the control information. (In this paper, control/data in other illustrations are used in the same/similar way.) Success/failure of the data reception is reported via feedback channel and corresponding retransmissions are scheduled if failed. Data receiver maintains the old and failed data as soft-bits (i.e. numerical values with decimal point) and combines them with the newly retransmitted data to improve performance. A series of these procedures are named hybrid automatic repeat request (HARQ) illustrated as Fig. 7. In HARQ operation, for downlink any resources can be used for retransmissions flexibly. Meanwhile, retransmission resource for uplink is fixed corresponding to the original transmission resource.

- Modulation order

On each subcarrier, more than one bit can be multiplexed and conveyed according to phase shift keying (PSK) or quadrature amplitude modulation. Available methods are shown in Fig. 8, i.e. Binary PSK (BPSK), Quadrature PSK (QPSK), 16 quadrature amplitude modulation (16QAM), and 64QAM, where 1/2/4/6 bits are multiplexed respectively. Additionally 256 QAM, which multiplexes 8 bits on each subcarrier, is available for downlink from Release 12. More bits multiplexing can achieve higher bit rate while more sufficient reception power will be necessary.

- MIMO

Multiple-input multiple-output (MIMO) mechanism, i.e. communications with multiple antennas is another promising mechanism to improve bit rate, where multiple bits are conveyed on the same subcarrier by using multiple antennas. Multiple antennas with signal processing do space division and different data can be transmitted via each space. Release

8 supports downlink MIMO, and Release 10 enables uplink MIMO as well as enhancement on downlink MIMO.

- Carrier aggregation

Carrier aggregation introduced in Release 10 also enhances data rate performance. Multiple frequency resources/bands supported for LTE are aggregated and assigned to each UE simultaneously.

Then multicast mechanism specified in Release 9 and Release 13 is also available for V2X applications, where the same data of e.g. emergency message is transmitted to all vehicles in a specific area. More efficient communication becomes possible for such a same data transmission to multiple or massive vehicles.

- MBSFN

Multimedia broadcast multicast service single frequency network (MBSFN) is a transmission mode where multiple cells are tightly synchronized/coordinated and send same multicast data to UEs within the cells.

- SC-PTM

Single cell point to multipoint (SC-PTM) is another transmission mode where multicast data is transmitted per cell without special synchronization/coordination among cells such as MBSFN. It seems that SC-PTM provides easier operatability and better frequency efficiency.

4.1.3 Sidelink

Release 14 and 15 discussed and specified sidelink standards for LTE-V2X. Actually these sidelink standards are based on the sidelink standards for non-V2X services specified in Release 12 and 13. The following notable features make it possible to support high velocity, high reliability, and good frequency efficiency to accommodate UEs of V2V/V2I/V2P sufficiently.

- Communication type

LTE sidelink is optimized for periodic transmissions of broadcast packets with several hundreds bytes. Having said that, aperiodic transmissions or unicast/groupcast packets transmissions are also possible on the standards. When unicast/groupcast packets are transmitted, the destination is included as higher layer information. All receivers need to encourage decoding the packet at lower layer and some of the receivers drop the packet after recognizing at higher layer that the packet is not addressed to itself.

- Waveform

DFT-s-OFDM is adopted as uplink transmissions since sidelink transmitter is a UE where the equipment issue will be the same.

- Frame structure

Basically same as downlink/uplink, but multiple PRBs are treated as a sub-channel as in Fig. 9 and resource allocation explained below is performed in increments of a sub-channel.

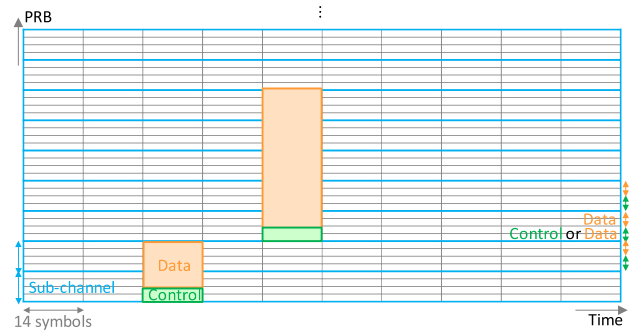


Fig. 9 Overview of LTE sidelink.

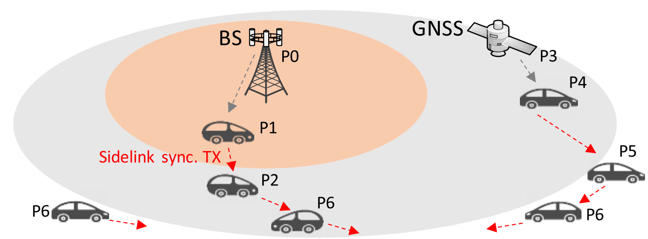


Fig. 10 Sidelink synchronization (network-based).

- Synchronization

For communications among UEs, timing/frequency synchronization among UEs is an essential feature. As abovementioned, C-V2X sidelink standards consider partial coverage and out-of-coverage; thereby two synchronization mechanisms are available — network-based and global navigation satellite system (GNSS)-based.

In network-based, BS signal is set as the highest synchronization priority and UEs that can receive it are aligned according to the signal. The UEs transmit sidelink synchronization signal based on the alignment, and UEs that cannot receive the BS signal are aligned with the sidelink synchronization signal if received. If there is no synchronization signal from BS or UEs synchronized to BS directly or indirectly within a single hop, GNSS signal or UE signal aligned with GNSS is used as synchronization source. This is illustrated as Fig. 10, where P0/P1/... mean priorities defined in ascending order.

Meanwhile in GNSS-based, the highest priority is set to GNSS signal and UEs that can receive it are aligned according to the signal. Sidelink synchronization signal based on the alignment that is transmitted from the UEs can be used for synchronization as the next priority in the same manner.

- Resource allocation

For sidelink communications, there are two kinds of resource allocation mechanisms — network-based and UE-autonomous. Let us define the former mechanism as M1 and the latter as M2 here. Which M1 or M2 is used is determined based on configuration.

In M1, it is assumed that sidelink resources are totally controlled by BSs. That is, control information is transmitted via downlink to each UE in similar manner to downlink/uplink data transmissions. Then a set of sidelink data + control information to receive the data is transmitted from each UE to other UEs according to indication conveyed in the control information via downlink. The transmitter UE shall be an in-coverage UE while UE out of coverage can be one of the receivers.

In M2, each UE selects its transmission resources autonomously, and accordingly collision avoidance method is essential. UE transmits data with reservation information of periodic resources, i.e. a single periodicity. Other UEs detect the reservation information and select their transmission resources based on the reservation information with packets priorities and receptions power such that collisions do not occur. This mechanism can be used by any UE including in-coverage UE.

Sidelink control information including reservation information is attached at adjacent frequency resources of the corresponding data in frequency division multiplexing manner, which is illustrated in Fig. 9. Each data is multiplexed with more reference signals for channel estimation than downlink/uplink such that higher relative velocity is covered sufficiently. In M2, the resource reservation mechanism is beneficial to avoid packet collisions, but is not perfect one e.g. when traffic load is high. An further enhancement mechanism called congestion control is additionally available in Release 15, where each UE measures traffic conditions and its transmission occasions are restricted based on both the conditions and its previous transmissions.

- Soft combining

HARQ operation including feedback is not supported for simpler system, unlike downlink/uplink of LTE. Alternatively a single packet can be transmitted repeatedly regardless of receivers' conditions and the receivers can combine them to achieve better reliability, which is given in Fig. 11.

- Modulation order

BSPK/QPSK/16QAM are supported from the initial standard, i.e. Release 14, while 64QAM is additionally available in Release 15 to enhance peak data rate.

- Carrier aggregation

Carrier aggregation feature can be enabled only in Release 15 similarly to 64QAM. This feature is beneficial for better peak data rate and traffic offloading.

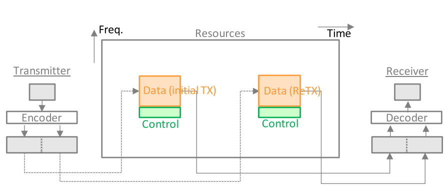


Fig. 11 Soft combining.

4.2 NR-V2X

4.2.1 Carrier Frequency

In NR including NR-V2X, more bands are considered for uplink/downlink — frequency range 1 of below 6 GHz including bands in LTE and frequency range 2 of 24.25 GHz to 52.6 GHz. Wider bandwidth becomes available, thereby higher data rate is expectable. On the other hand, the straightness and the large pathloss are significant issues on the higher frequencies for mobile communications. Corresponding technical enhancements have been discussed and introduced.

This direction is followed by sidelink. Sidelink standards at NR is expected to cover any frequency of both frequency range 1 and range 2. Having said that, main target is still 5.9 GHz as LTE-V2X due to regulations or allocations in each region/country. Few technical enhancements to support frequency range 2 are introduced so far.

4.2.2 Downlink/Uplink

One of the key words in NR specification is flexibility. NR supports quite wide frequency bands and many kinds of requirements such as enhanced mobile broadband (eMBB), URLLC, and massive machine type communications (mMTC). Flexibility is significantly important to adjust network deployments for each frequency/requirement. Here it is noted that multicast (and broadcast) is not supported in NR downlink while multicast at service level is possible by multiple unicast transmissions.

- Waveform

For downlink, OFDM is used as LTE. On the other hand uplink can use either OFDM and DFT-s-OFDM, which is determined by network side. For example, OFDM is configured to a UE nearby a BS to maximize frequency efficiency, and DFT-s-OFDM is indicated to a UE around cell edge such that sufficient coverage is provided.

- Frame structure

Figure 12 shows the frame structure. Flexible frame structure is introduced while baseline is LTE's structure, that is, one radio frame of 10 ms can contain 10 to 80 time units corresponding to configured SCS. As SCS, 15/30/60/120 kHz are available so that an appropriate SCS is selected for each of more frequency bands. The minimum scheduling time unit is reduced from a set of 14 OFDM symbols to one symbol, which can bring better scheduling flexibility and lower latency performance.

- Scheduling/HARQ operation

Control information can be transmitted to each UE at any symbols of a set of 14 symbols, and also data can be transmitted to/from each UE at any symbols. For example, it is possible to map in a same symbol control and data from a BS

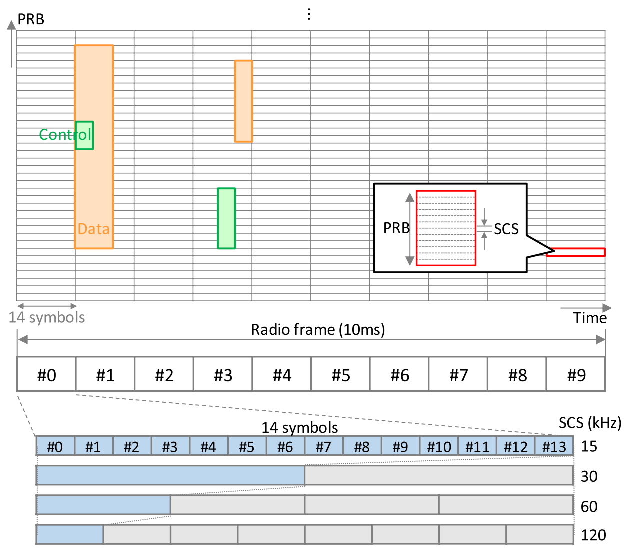


Fig. 12 Overview of NR downlink/uplink.

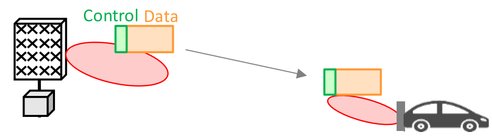


Fig. 13 MIMO beamforming.

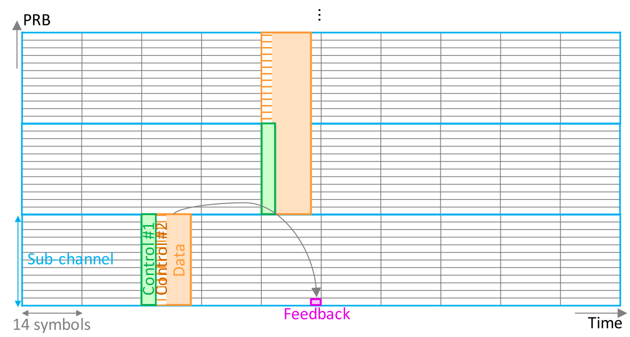


Fig. 14 Overview of NR sidelink.

to a UE as illustrated in Fig. 12. Naturally HARQ operation including feedback is supported and thus data receiver will combine initial reception and the subsequent receptions of a packet. The key difference between LTE and NR on HARQ is flexible HARQ operation for uplink. Any resources can be scheduled for uplink retransmissions. This flexibility leads to lower latency since quicker feedback and retransmission become possible.

- Modulation order

Up to 256QAM is available for both downlink and uplink, and additionally Release 17 probably supports 1024QAM for downlink. Meanwhile low modulation order with much lower coding rate can be configured and indicated for URLLC transmissions.

- MIMO beamforming

As abovementioned, higher frequencies such as frequency range 2 are one of main aspects and beamforming generated by MIMO with many antenna elements e.g. called Massive MIMO is an important technique to utilize the frequencies effectively. MIMO beamforming transmits the same signal from massive elements with different phase shifters. Appropriate phase shifts generate one or more beams as described in Fig. 13. The large pathloss is compensated by MIMO beamforming at BS and/or UE. Beamforming management and beamforming failure recovery are implemented in BS and UE. The straightness of radio wave, which is another issue in higher frequency bands can be solved by multiple transmission/reception points (TRPs) introduced in Release 16 and probably enhanced in Release 17. Multiple TRPs are deployed at different locations and thus root diversity is obtained. If the same data is transmitted, better reliability performance is expected; otherwise it results in higher data rate.

- Carrier aggregation/Dual connectivity

NR assumes flexible carrier aggregation such that many combinations of frequency bands considered in NR are available sufficiently, e.g. intra-band/inter-band/inter-frequency range. Another mechanism to use many frequency bands is dual connectivity, where a UE has connections to two BSs that coordinate less than carrier aggregation. For instance this feature can be used to connect a BS via frequency range 1 and another BS via frequency range 2 on the same network operator. Which technique is used is dependent on each network deployments. It should be noted that there is a scenario of dual connectivity between LTE and NR, which is required for network migration.

4.2.3 Sidelink

Baseline of Release 16 sidelink is that in LTE Release 14 and 15, while new techniques are available to cover the advanced V2X use cases. Therefore flexibility is naturally aimed in the discussions similarly to downlink/uplink. Here it is noted that carrier aggregation is not supported in NR sidelink so far. Figure 14 shows overview of NR sidelink.

- Communication type

According to 3GPP SA specification, NR focuses on aperiodic transmissions and unicast/groupcast packets as well as periodic and broadcast as in Fig. 15. Control information transmitted in physical layer includes a destination ID of the corresponding data. Each UE needs to detect the data only when the ID indicates the UE itself; otherwise the UE can skip the data decoding. In sidelink unicast, higher layer connection is established like typical downlink/uplink while sidelink groupcast/broadcast of LTE and NR is connectionless communication. Connection-oriented one is motivated by better QoS management, e.g. optimal communication parameters can be shared between the two devices.

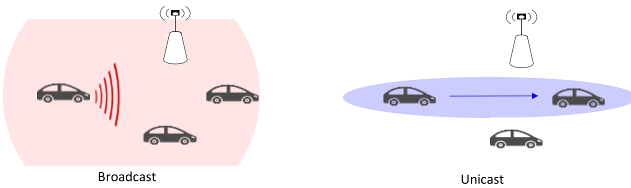


Fig. 15 Sidelink unicast communication.

- Waveform

Only OFDM can be used for sidelink communications. The reason is that each UE would be equipped with OFDM modulator for uplink and the required coverage is not so severe.

- Frame structure

Sidelink supports 15/30/60/120 kHz of SCSs as downlink/uplink. Meanwhile resource allocation unit is same as LTE sidelink, i.e. in increments of a sub-channel per a time unit of 14 OFDM symbols. Sidelink communications need to support autonomous resource allocation by each UE, so more flexibility leads to more overheads to have alignment and common understanding among UEs. It was concluded that symbol-level resource allocation is not efficient from this perspective.

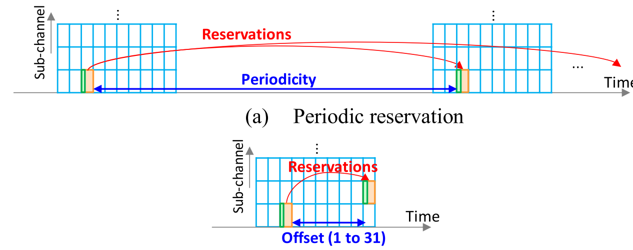
- Synchronization

Regarding synchronization mechanism, basic procedure is almost same as that in LTE sidelink though there are appropriate enhancements to work in NR-V2X system.

- Resource allocation

NR-V2X also supports both network-based and UE-autonomous mechanisms of resource allocation, i.e. M1 and M2. For M2, on top of LTE sidelink as baseline, UE can do aperiodic reservation as well as periodic reservation. The examples are given in Fig. 16. One or two resources within the next 1st to 31st time units are indicated in control information separately from a periodicity for periodic reservation. This reservation indication will be used for aperiodic transmissions. Then even if the reservation is used, an initial transmission of aperiodic traffic might occur at UEs, which means that still many resource collisions are assumed. The solution to the issue is re-evaluation and pre-emption check, where UE checks just before its transmission whether or not the selected but non-reserved resource and the already reserved resource respectively is actually available.

A set of sidelink control information that is transmitted with data is divided into two subsets as illustrated in Fig. 14. Receivers firstly decode the 1st subset and then the 2nd subset based on the 1st subset. After that, the corresponding data is decoded by using the control information. The 1st subset includes reservation information while a destination ID is included in the 2nd subset. That means all UEs shall detect both subsets. This two-step approach is beneficial for better reservation detection and for better forward compatibility due to easiness to enhance 2nd subset. The 1st subset is mapped at earlier symbols of a single sub-channel and followed by the 2nd subset in a frequency-first manner. Then the remaining part is used for data mapping. This mapping manner brings lower latency than LTE sidelink since for data detection, there is no/less need to wait completion of control information detection.



(a) Periodic reservation

(b) Aperiodic reservation

Fig. 16 Sidelink reservation mechanism.

- HARQ operation

HARQ feedback, which is necessary for better QoS management/reliability/spectral efficiency, becomes available in NR sidelink. As downlink/uplink, feedback information is reported to the data transmitter as shown in Fig. 14. If NACK is reported on sidelink, the transmitter can retransmit the data and the reception combines them. It should be noted that HARQ operation on sidelink is supported only for unicast/groupcast. In case of M1 resource allocation, UE can report corresponding feedback information to BS so that further resources are requested if needed.

- Modulation order

Sidelink also supports both up to 256QAM for higher data rate and low modulation order with low coding rate to support URLLC-type traffic.

5. Towards 5G-Advanced/6G

Currently 3GPP Release 17 is discussing further enhancements on NR downlink/uplink and sidelink. For the former, multicast mechanism will be introduced similarly to LTE but with some enhancements such as HARQ feedback feature for better performance of reliability and resource efficiency [23]. Throughput, reliability/latency, power consumption, etc. of unicast will also be improved in this release. For the latter, i.e. sidelink, two aspects are identified as the objectives — the 1st one is power saving mainly for pedestrian UEs and the 2nd one is reliability/latency enhancement so that the identified use cases with significant severe requirements are enabled for NR-V2X sufficiently and effectively [24]. Having said that, in our view, current NR sidelink is not enough from reliability and latency perspectives to cover significantly severe requirements identified in 3GPP SA, e.g. 99.99% reliability has not been evaluated enough. It seems that in future release firstly evaluation metrics should be updated based on 3GPP SA specifications and then further enhancements should be discussed.

3GPP Release 18 study/work will begin at early of

2022. For C-V2X, there are several proposals from companies/organizations, e.g. positioning support for UE at in-coverage/partial coverage/out-of-coverage, or co-channel coexistence between LTE sidelink and NR sidelink [25]. Note that Release 18 topics have not decided yet as of August 2021. In near feature, many demonstration experiments or commercial services of C-V2X can be seen around the world and they could reveal that there are issues to support further advanced V2X services in NR-V2X. If any, Release 18 or 5G-advanced can focus on introducing mechanisms to solve the issues.

Towards 6G network, which would be implemented around the 2030s, the definition of vehicle might be different from the conventional one. For example, combined/separated vehicles might be possible. Each car is quite small and the riding capacity is only one person. Meanwhile the car can be combined with other cars by using wireless communications, and the combined one drives as a single car. As another example, fully automated driving under control from network side can be raised. Each vehicle is equipped only with components to report sensors information to network and to control its driving according to network indication. Detailed calculation is performed in network side to enable total optimization. Furthermore, flying vehicles are possibly realistic in the 2030s. If such futuristic ideas are realizable, much more high performance level will be required for 6G technologies. Actually there are activities/experiments of this direction [26]. We will have been working to make 6G network realizing such innovations.

6. Conclusion

In this paper, current cellular V2X standards, which has been specified in 3GPP, were introduced briefly. Firstly overview, secondly work at group of service and system aspects, and then work at group of radio access network. Additionally this paper shared our views on future cellular V2X.

References

[1] Daimler, "CASE — Intuitive mobility," https://www.daimler.com/innovation/case-2.html, accessed Aug. 2nd, 2021.
[2] 3GPP TSG-SA, "3GPP TS 22.185 v14.4.0, Service requirements for V2X services; Stage 1 (Release 14)," June 2018.
[3] 3GPP RP-181530, "LS on prioritized use cases and requirements for consideration in Rel-16 NR-V2X," Sept. 2018.
[4] 3GPP, "LTE," https://www.3gpp.org/technologies/keywords-acronyms/98-lte, accessed Aug. 2nd, 2021.
[5] 3GPP "LTE-advanced," https://www.3gpp.org/technologies/keywords-acronyms/97-lte-advanced, accessed Aug. 2nd, 2021.
[6] K. Takeda, et al., "Status of investigations on physical-layer elemental technologies and high-frequency-band utilization," NTT DOCOMO Technical Journal, vol.19, no.3, Jan. 2018.
[7] 3GPP, "C-V2X," https://www.3gpp.org/v2x, accessed Aug. 2021.
[8] 3GPP TSG-SA, "3GPP TR 22.885 v14.0.0, study on LTE support for vehicle to everything (V2X) services (Release 14)," Dec. 2015.
[9] 3GPP TSG-SA, "3GPP TR 22.886 v15.3.0, study on enhancement of 3GPP support for 5G V2X services (Release 15)," Sept. 2018.
[10] 3GPP TSG-SA, "3GPP TS 22.186 v15.4.0, enhancement of 3GPP support for V2X scenarios; Stage 1 (Release 15)," Sept. 2018.
[11] 3GPP TSG-RAN, "3GPP TS 36.211 v15.13.0, evolved universal terrestrial radio access (E-UTRA); Physical channels and modulation (Release 15)," March 2021.
[12] 3GPP TSG-RAN, "3GPP TS 36.212 v15.14.0, evolved universal terrestrial radio access (E-UTRA); Multiplexing and channel coding (Release 15)," June 2021.
[13] 3GPP TSG-RAN, "3GPP TS 36.213 v15.14.0, evolved universal terrestrial radio access (E-UTRA); Physical layer procedures (Release 15)," June 2021.
[14] 3GPP TSG-RAN, "3GPP TS 36.321 v15.11.0, evolved universal terrestrial radio access (E-UTRA); Medium access control (MAC) protocol specification (Release 15)," Dec. 2020.
[15] 3GPP TSG-RAN, "3GPP TS 36.331 v15.14.0, evolved universal terrestrial radio access (E-UTRA); Radio resource control (RRC); Protocol specification (Release 15)," June 2021.
[16] 3GPP TSG-RAN, "3GPP TS 38.211 v16.5.0, NR; Physical channels and modulation (Release 16)," March 2021.
[17] 3GPP TSG-RAN, "3GPP TS 38.212 v16.6.0, NR; Multiplexing and channel coding (Release 16)," June 2021.
[18] 3GPP TSG-RAN, "3GPP TS 38.213 v16.6.0, NR; Physical layer procedures for control (Release 16)," June 2021.
[19] 3GPP TSG-RAN, "3GPP TS 38.214 v16.6.0, NR; Physical layer procedures for data (Release 16)," June 2021.
[20] 3GPP TSG-RAN, "3GPP TS 38.215 v16.4.0, NR; Physical layer measurements (Release 16)," Dec. 2020.
[21] 3GPP TSG-RAN, "3GPP TS 38.321 v16.5.0, NR; Medium access control (MAC) protocol specification (Release 16)," June 2021.
[22] 3GPP TSG-RAN, "3GPP TS 38.331 v16.5.0, NR; Radio resource control (RRC) protocol specification (Release 16)," June 2021.
[23] 3GPP RP-201038, "WID revision: NR multicast and broadcast services," July 2020.
[24] 3GPP RP-202846, "WID revision: NR sidelink enhancement," Dec. 2020.
[25] 3GPP RWS-210659, "Summary of RAN Rel-18 Workshop," July 2021.
[26] Klein-vision, https://www.klein-vision.com/concept-2, accessed Sept. 2021.

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