Issue Survey Report

Advanced ITS and Automated Driving
Using Cellular Communications Technologies

June 2019

ITS Info-communications Forum

Cellular System TG

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Revision History

Version No.	Date	Areas of revision	Reasons for revisions	Details of revisions
1.0	June 18, 2019	Established	Newly established	

The ITS Info-communications Forum plans to update the content of this document through further investigation, and if revisions are made, will issue a revised document indicating the version number and the details of the revisions.

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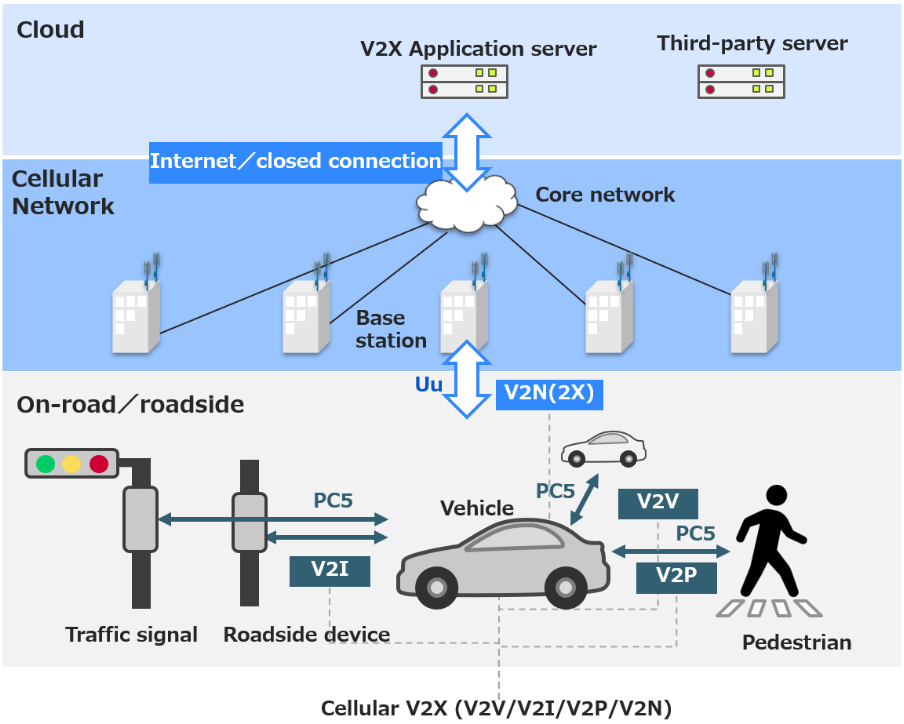
Introduction

The research and development and policy discussion for advanced ITS and the creation of an automated driving society are active on a global scale. Activities toward practical application are being undertaken in various countries e.g., in the United States, the Connected Vehicle Pilot Deployment Program [1] is being implemented, and in Europe, projects such as Corridor [2][2] and Nordic Way [3] are being carried out. In China, a large-scale trial is underway in Wuxi [4]. Amidst this international competition, the Public-Private ITS Initiative/Roadmaps [5] sets forth strategies for Japan to maintain and develop global cutting-edge ITS and allow the public to enjoy the benefits of the world's leading road transport society, [5]and various demonstration trials and other initiatives are being carried out such as investigations by the Panel on Business Strategies for Automated Driving [6]and the Cabinet Office SIP-adus project [7]. The ITS Info-communications Forum is also conducting investigations in the information and communications fields necessary for practical application of ITS, issuing guidelines, proposing standards compatible with the ARIB standards, and taking other measures. In Japan, ETC 2.0 fee collection and various information services using 5.8 GHz-band-based vehicle to infrastructure communictions [n]) and ITS Connect (safe driving and traffic smoothness services using 700 MHz-band-based vehicle to infrastructure and vehicle to vehicle communications [n+1]) have already been put into practical services that use DSRC systems in the ITS frequency bands described in ITU-R M.2121. Moreover, the Advanced Expert Committee, Cellular System TG, of the ITS Info-communications Forum is investigating raising the level of ITS and automated driving by using cellular communications technologies.

As one of methods for inter-vehicle and vehicle to roadside device communications, standard specifications such as cellular V2X and 5G based on cellular communications have been standardized by the 3GPP, and investigation and trials of these technologies are underway regarding the possibility that these communications technologies can contribute to the advancement of ITS and automated driving. Technology that uses cellular communications technologies and makes it possible for vehicles to connect with all other devices is referred to as cellular V2X and includes on-road and roadside short range communications (using a wireless interface referred to as PC5) such as vehicle to vehicle (V2V), vehicle to infrastructure (V2I), and vehicle to pedestrian (V2P) and wide-area communications with vehicles via cellular networks made up of base stations and a core network (vehicle to network (V2N) using a wireless interface referred to as Uu). Possibilities for V2N also include communications by vehicles with pedestrians and roadside devices via cellular networks. This is referred to as a vehicle to network to everything (V2N2X).



Overall Structure of Cellular V2X

In addition to inter-vehicle information sharing, ITS using communications technology makes it possible to deliver to vehicles information on roadside devices or network servers collected by sensors installed in vehicles and on infrastructure, and also possibly adding new value to such information already held on roadside devices or network servers. Compared to data collection and processing by individual vehicles, ITS can (i) use data collected not only from sensors on the subject vehicle but also from other vehicles and infrastructure to expand the possible scope of sensing and (ii) increase processing capacity by processing data not only by the subject vehicle, but also by using the processing capacity of roadside devices and network servers. With regard to automated driving too, autonomous control of individual vehicles has been demonstrated, but it is expected that operational restrictions will be reduced in conjunction with communications and there will be areas where improved functions or performance and added value can be provided. By using already deployed ITS in conjunction with cellular V2X, it will be possible to increase the added value provided to ITS and automated driving, and demonstration of basic performance is currently continuously being verified.

While there are these significant expectations towards cellular V2X, many of the evaluations for practical application discuss only the individual performance of communications (high-data-rate, high-capacity, low latency), and it is difficult to say that they are verifications taking into account practical operation [20], [21], [22]. Specifically, there are many possible investigation items other than communications performance such as frequency allocation, the possibility of coexistence with current systems, the suitability and reliability of communications methods, potential for future expansion, business models that take into consideration ongoing maintenance and management, and legislation. Furthermore, it is possible that in addition to established ITS service providers, entry by new parties and a necessity to develop of new business models will arise, and thus, these measures require adequate prior consideration.

This document was issued with the aim of organizing the issues identified for achieving advanced ITS and automated driving using cellular V2X, and also accelerating future investigation of the effectiveness, identification and resolution of issues of cellular V2X in Japan. Chapter 1 describes basic terminology relating to cellular V2X and provides an overview and the future outlook for the introduction of cellular systems and 5G. Chapter 2 describes use cases incorporating the expectations for communications, and Chapters 3 and 4 describe the respective architectures and business models. Chapter 5 describes distinctive issues of cellular V2X, methods of combining short range communications (V2V/V2I/V2P) with wide-area communications (V2N), methods of developing infrastructure, and issues identified from the perspectives of communications, information, and services. Chapter 6 provides an overall summary.

Contents

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Chapter1 Current Status and Outlook of Cellular Communication Systems

1.1 Glossary

The main terms used in this document are outlined in Table 1.1, with reference made to 3GPP documents [8][9][10] Table 1. Other detailed terms can be found in the appendix.

Table 1.1 Glossary

Terms	Meaning / Explanation
Cellular V2X	Cellular V2X is a technology that uses cellular communications such as LTE and makes it possible for vehicles to connect with all others. It includes short range communications such as vehicle to vehicle, vehicle to infrastructure, and vehicle to a pedestrian on the road and roadside and wide area communications where vehicles use cellular networks consisted of base stations and a core network.
LTE	A 3.9 or 4th generation cellular wireless access technology standardized by 3GPP. Currently, 3GPP Release 8 to Release 15 are specified.
LTE V2X	Cellular V2X using LTE.
5G	The 5th generation cellular wireless access technology standardized by 3GPP. It includes NR and LTE Release 15 and later. It often refers to NR only.
NR	The new wireless access technology standardized by 3GPP for 5G. Currently, only wide area communications via base stations have been standardized in Release 15, and it is expected that short range communications will also be standardized in Release 16.
Wide area communications, Downlink/uplink, Uu, V2N2X	These terms mean wide area communications between mobile devices and base stations. In this document, these terms can also include communications via core networks and application servers; also referred to as V2N2V/V2N2I/V2N2P.
Downlink	Communications from a base station to a mobile device in wide area communications
Uplink	Communications from a mobile device to a base station in wide area communications
Short range communications, sidelink, PC5, V2V/V2I/V2P	These terms mean short range direct communications between mobile devices, i.e., vehicle to vehicle or vehicle to pedestrians. Short range communications based on LTE is standardized in Release 14. Short range communications based on NR is to be standardized in Release 16.
Base station, NB, eNB, gNB	Base station means the equipment that communicates with mobile devices in the cellular network. A base station supports one or multiple cells. NB (node B) is a WCDMA base station. eNB (e node B) is an LTE base station. gNB (g node B) is an NR base station.
Mobile station (MS), user equipment (UE)	Devices that communicate with networks in the cellular network. Strictly speaking, mobile station and UE are different because mobile stations do not include SIM and UE include SIM, but in many cases, they are not distinguished.
Cell	The part of a cellular network that does not rely on wireless access technologies such as WCDMA, LTE, and NR. It includes S-GW and P-GW.
Roadside unit (RSU)	Although there are terminal-type RSU that communicate with mobile devices using short range communications and base station type RSU that communicate with mobile devices using wide area communications, in this document, base station type devices are not referred to as roadside units, and roadside units mean terminal-type devices that communicate with mobile stations using short range communications. RSU can connect to networks using wide area communications.
Mobile Network Operator (MNO)	A telecommunications business operator that provides mobile communications services and develops or operates wireless stations related to those mobile communications services.
Mobile Virtual Network Operator (MVNO)	A telecommunications business operator that provides mobile communications services provided by an MNO or by connecting to an MNO and does not develop or operate wireless stations related to those mobile communications services.
Subscriber Identity Module (SIM)	A module that contains identification of a mobile phone subscriber and subscription and plays a major role in cellular network security in wide area communications.
Mobile Edge Computing (MEC)	Having application layer computing resources close to base stations or core network in the cellular networks instead of having them in the cloud outside of the cellular network to reduce the latency and so on.

1.2 LTE

V2X can be broadly divided into (1) V2N (wide area communications) and (2) V2V/V2I/V2P (short range communications). (1) Refers to communications from a terminal via MNO base station. Used primarily for current commercial services such as smartphone and on-board communications modules. In cases where it is used for vehicle to vehicle communications, it is referred to as V2N2V, V2N2X is also referred to as a form of V2X service using V2N. (2) Refers to direct communications between terminals that do not go through an MNO's base station. Standardization of the initial version has been completed, and it is in the field trial phase.

1.2.1 Wide Area Communications (V2N) Overview

- Communications from a terminal that goes through an MNO's base station. Communications are provided by nation-wide coverage using base stations connected to a core network.
- Normally, a SIM card or eSIM is installed in a terminal. A contract is entered into with an MNO or an MVNO (i.e., subscription)[1]. Generally, each MNO installs its core network and base station facilities (towers, antennas, and BTS (Base Transceiver Stations)).
- As an exception, some of the base station facilities, such as antennas, are shared in underground spaces.
- A base station facility of a particular MNO can be connected only to 1) terminals equipped with a SIM card of that MNO or 2) terminals equipped with a SIM card of an MVNO which have roaming agreements with that MNO.[2]
- In principle, all communication traffic with the terminal flows to the MNO or MVNO core network, and from there it is transferred to a cloud server, a terminal under the same MNO or MVNO, or terminals of other MNO or MVNO.
- As a special case, standardization proposals have been made for a system performs “local-breakout” routing where traffic is not routed to the core network and is currently in the field trial phase. In that system, a kind of MEC identifies a portion of the traffic and route the identified traffic so that they don’t enter into a core network.
- Priority control of traffic has been standardized[3] and implemented. However, even when a priority control is performed, an MNO does not guarantee QoS (e.g., an outgoing call, communication bandwidth, transmission delay, etc.) in terms of neither the communications bandwidth nor the placement of the base stations.
- The extended functions for short range device-to-device direct communications such as defined in 3GPP Release 14 is not mandatory for wide area communications.
- Although LTE is mainly operated by unicast, multicast technologies (e.g., eMBMS, SC-PTM) are also standardized. The eMBMS is in the field trial phase in Japan [11] [12], and there are some countries where it is in practical use.
- LTE is currently a main-stream of commercial cellular services. However, most LTE terminals also support legacy standards such as GSM, WCDMA, and HSDPA/HSUPA. Consequently, LTE terminals support connectivity on networks such that support only legacy standards. As the initial LTE standard supported the coexistence of multiple standards on networks, it is expected that LTE terminals will continue to support the coexistence of the standards. In addition to that, base stations adjust radio parameters according to the capabilities of the terminals. In that way, new standards can be added to the older LTE standards while securing coexistence in the same networks.

1.2.2 Short Range Communications (V2V/V2I/V2P) Overview

- Refers to communications between terminals that do not go through an MNO's base station. Because of this, compared to wide area communications that go through base stations, the communication range is limited, but communication outside the base station territory is possible and communication with short latency compared to wide area communications is possible. Unlike wide area communications, it is necessary for the terminals to support V2X dedicated functions defined in Release 14.
- The presence of a SIM in terminals is not necessary, and communication without a subscription with

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[1] As an exceptional case, there are privately-operated LTE networks that does not use SIM or eSIM. For example, 1.9 GHz band sXGP (shared eXtended Global Platform), introduction of LTE technology to 900 MHz band private mobile communication systems, and MulteFire using 2.4 GHz band and 5 GHz band.

[2] MNOs enter into agreements with other MNOs or MVNOs to allow shared use of their base station facilities and some core networks to provide connectivity outside service territories such as in other countries.

[3] According to the 3GPP, the priority (QCI; QoS Class Identifier) of the 15 stages (in the case of Release 14) is determined according to the presence or absence of a bandwidth guarantee, latency, priority, packet loss rate, and so on. For example, in cases of problematic services such as cutting out as in VoLTE voice, there is a bandwidth guarantee with priority 2 and high priority equivalent to latency of no more than 100 ms, QCI is 1. On the other hand, in the case of low real-time services such as web browsing and email, a low priority QCI with no bandwidth guarantee is generally set.

an MNO is possible. Because of this, by using common (unlicensed) frequencies, direct communication between terminals is possible even if the MNOs for the wide area communication is different for each terminal.

- The communication protocol and data format are designed for low-latency transmission of the small packets (e.g., several hundred to several thousand bytes). High-data rate communications are not assumed.
- Operation using broadcast is assumed mainly. However unicast is also supported in the standard.
- How the wide-area communication function and the short-range communication function are co-existed within a terminal depends on the implementation of the terminal or chipset. However, the standardized specifications require the independent operation of the wide-area communication function and the short-range communication function, except in the case where the frequencies used for wide-area communication and short-range communication are close to each other. When the independent operation is difficult, it is possible to give priority to the transmission of the short-range communication.
- Release 15 LTE V2X terminals also have Release14 LTE V2X equivalent functions. Therefore, when operating in an environment where Release 14 terminals and Release 15 terminals are intermingled, it is expected that backward compatibility can be supported by transmitting and receiving the basic communication in a conventional communication standard such as Release 14.
- Priority control and congestion control are standardized. However, even if priority control applies, it does not guarantee communications performance.
- Section 4.4.5.1 of TS 23.285 [10] describes conditions applied in both the network scheduled operation mode (mode3) and UE autonomous resources selection mode (mode4), additional conditions for mode 3, and additional conditions for mode 4. The PPPP (ProSe Per-Packet Priority) [11] mechanism described in 5.4.6.1 of TS 23.303 is applied to the communication using the PC5. There are 8 priority classes in PPPP, but so-called "mapping" (e.g., linking PPPP priority 1 to LTE QCI (See Section 1.2.1.) 1 or 2) has not been standardized and is one of the future issues.

1.2.3 Trends in Standardization

- Release 8 Introduction of LTE
- Release 9 Introduction of eMBMS (broadcasting in downlink)
- Release 12 Introduction of D2D (short range communications for public safety)
- Release 13 Introduction of SC-PTM (broadcasting in downlink)
- Release 14 Introduction of D2D specifications for V2V/V2X, SC-PTM for V2X
- Release 15 Throughput enhancement of D2D, introduction of time slot reduction, etc.

1.2.4 Status of Frequencies

(1) Wide Area Communications (V2N)

- Frequencies used in Japan: 700 MHz, 800 MHz, 900 MHz, 1.5 GHz, 1.7 GHz, 2.0 GHz, and 3.4 GHz bands
- Number of terminals in use (number of subscriptions): 131.39 million contracts (as of December 2018)
- Demonstration trials and technical verification are underway in Japan in anticipation of V2N [11] [14] [15].
- Demonstration trials using V2N are also underway overseas [16].

(2) Short range Communications (V2V/V2I/V2P)

- Although mixed operation using the same frequency as existing LTE is partially standardized, dedicated frequency is assumed because of the difficulties of the operation of mixed operation in the same LTE frequency band. 5855 - 5925 MHz is standardized in 3GPP [17] as a dedicated frequency band.
- In Japan, it is in the technical verification phase, including field trials using 5.8 GHz band and experimental radio station licenses [14] [15]. The Ministry of Internal Affairs and Communications (MIC) is conducting research and study on the technical conditions of a new wireless system to complement the already deployed ITS wireless system for realizing a Connected Car society as their technical examination affairs.
- China has allocated 20 MHz of bandwidth in the 5905–5925 MHz range[18] and is conducting large-scale field trials as well as investigation of operation methods[19].
- In Europe and the United States, 5GAA and others are investigating the possibility of applying LTE V2V/V2I/V2P using the 5.9 GHz band ITS frequency [20] [23].

1.3 5G and NR

1.3.1 Trends in Standardization

With regard to fifth-generation mobile phone systems (5G), they are expected to support various use scenarios including further advances in high-data-rate and high-capacity communication (enhanced Mobile Broadband; eMBB), machine type communication that enables multiple simultaneous connections (massive Machine Type Communications; mMTC), and ultra-reliable, ultra-low-latency communications (Ultra-Reliable and Low Latency Communication; URLLC) [22]. With 3GPP, in addition to 5G as an extension of LTE, standardization of NR (New Radio), which is a new radio access technology that can achieve large gains without backward compatibility with LTE and LTE-Advanced, has been carried out. In NR, in consideration of various usage scenarios, in addition to the frequency band used by existing LTE, the usage of the high-frequency band up to about the 100 GHz band is supported. Also, standardization of flexible wireless interfaces and wireless performance requirements for high-frequencies are being adopted [25].

The first version of standardized specifications for NR was formulated in Release 15, which was implemented by June 2018. In Release 15 NR, specifications targeting eMBB and URLLC are established, and in Release 16, scheduled to be issued by March 2020, URLCC reliability improvements including remote drive use cases and various extensions such as specifications for vehicle to vehicle communications based on NR will be specified. For mMTC, NB-IoT and LTE-M extensions based on LTE has been specified. In addition, the Release 15 NR specifications support two types of the operation: an operation that combines NR and LTE to provide a communication area referred to as non-standalone, and an operation that provides a communication area by NR alone, referred to as standalone. With both the non-standalone and standalone operations, connectivity to the network outside NR coverage areas is ensured by connecting to LTE or earlier cellular radio systems, as terminals usually support those legacy standards.

1.3.2 Planned Frequencies and Service Deployment in Japan

In Japan, new 3.6–4.1 GHz, 4.5–4.6 GHz, 27.0–28.2 GHz, and 29.1–29.5 GHz frequencies have been allocated to MNOs for 5G [26]. In addition, 5G frequencies for non-public operation are also being considered. Also, the existing LTE frequency is specified for NR and 700, 800, and 900 MHz and 1.7, 2, and 2.5 GHz bands are specified in the 3GPP specifications [27]. With regard to 5G related service development in Japan, it is difficult to indicate the details of commercial service development at this time because it is assumed that starting times and development methods will differ depending on the service provider, service area, and service content, but service development that integrates Release 15 NR and LTE by utilizing non-standalone operations and service deployment to that utilizes Release 15 LTE specifications are believed to be examples of 5G services. Under guidelines from the Ministry of Internal Affairs and Communications, area development requirement within two years and within five years is specified[28].

Chapter2 Use Case Expected for Communications and Their Roles

2.1 Selection of Use Case Examples

In this chapter, use case examples with potential to use the benefits of cellular V2X are selected. The following matters were taken into consideration when selecting the use cases.

1) The focus is on the update frequency of information handled mainly in communications for automated driving, and the information is organized in comparison with a widely discussed dynamic map. Here, the dynamic map comprises static, high-precision 3-dimensional map information (platform map) and identifiable location information (dynamic information, semi-dynamic information, and semi-static information) that changes over time. It is a concept used in a consistent manner by linking static and dynamic layers. In Japan, consideration of the Cross-ministerial Strategic Innovation Promotion Program (SIP) led by the Cabinet Office is proceeding [29] (Figure 2.1).
   * Times in the figure are general information update frequencies, and permissible latencies for each information may not necessarily match.
2) Based on Figure 2.1, information handled and used levels (primarily reliability) and so on as well as anticipated application examples are given and linked (Table 2.2).
3) In Table 2.2, examples of use cases were selected for each information update frequency (cells in Table 2.2 are colored according to the color scheme in Figure 2.1).

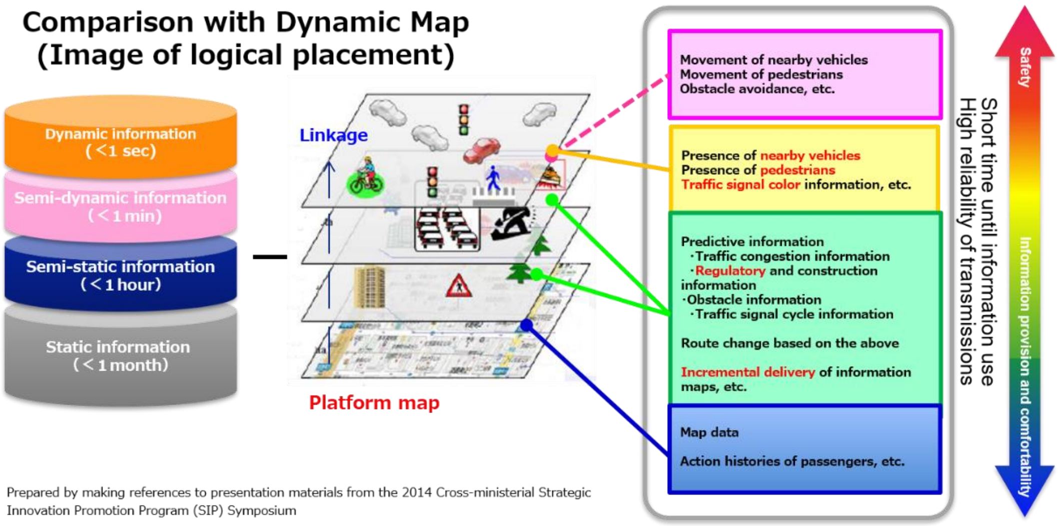


Figure 2.1 Image of Comparison of Handled Data and Dynamic Map.

Table 2.2 Organization of Use Case Examples

Information update frequency		Examples of handled information	Application	Use level (application)	Anticipated applications	Site where information is used	Reference
●Dynamic	Reflected in automated driving as one of multiple sensors (multi-system)	Presence of pedestrians or bicycles	Safety	Control intervention/ warning	Prevention of pedestrian accidents	General road	In this area, there is a possibility that a system can be created by using communication as one of the multi-system sensors in combination with other sensors. Depending on the application, ensuring reliability is the key
		Presence of nearby vehicles (including motorcycles)	Safety	Control intervention/ warning	Prevention of collisions between vehicles crossing paths, lane change support	General road/ exclusive motor-vehicle way	
		Broken-down vehicle or fallen obstacle (immediately ahead)	Safety	Control intervention	Rear-end collision avoidance, emergency braking (1)	General road/exclusive motor-vehicle way	
		Emergency braking by vehicle ahead	Safety	Control intervention		General road/exclusive motor-vehicle way	
		Real time operation information from vehicle driving ahead	Traffic facilitation, comfort	Control intervention	Platooning	Exclusive motor-vehicle way	
		Vehicle information on the main exclusive motor-vehicle way	Traffic facilitation, comfort	Control intervention/ warning/information provision	Merging support	Exclusive motor-vehicle way	
		Signal color (display) information	Safety, comfort	Control intervention/ warning	Intersection passage support (2)-1	General road	
		Presence of oncoming traffic or crossing pedestrians at intersection	Safety	Control intervention/ warning	Prevention of collision with oncoming vehicle when making a right turn, collision with bicycle, etc. when making a left turn, accident involving crossing pedestrians	General road	
		ETC gate opening/closing information	Safety, comfort	Control intervention/ warning/information provision	Prevention of collision during rapid closing, gate selection, lane change	Exclusive motor-vehicle way	
●Semi-dynamic	Predictive information Level for use in safe stopping and lane changing	Signal cycle information	Safety, Comfort	Warning/information provision	Avoidance of dilemma, red traffic light warning (2)-2	General road	Depending on the requirements of the vehicle, there is a possibility that cellular communicat
		Information on presence of obstacle or broken-down vehicle	Safety, traffic facilitation	Information provision	Lane change support, route selection (3)	General road/exclusive motor-vehicle way	

		Nearby emergency vehicle	Safety, traffic facilitation	Information provision	Vehicle avoidance support (4)	General road	ions can be used with other communications or individually.
		Lane-specific traffic congestion information	Safety, traffic facilitation	Information provision	Lane change support, route research	General road	
●Semi-static	Predictive information Level for use in advance route changes, etc.	Updated map information (partial update while traveling)	Traffic facilitation	Information provision		General road	There is a possibility that it can be used with the same performance and mechanisms as conventional cellular communications.
		Regulation information	Traffic facilitation	Information provision	Route research (5)	General road/exclusive motor-vehicle way	
		Construction information	Traffic facilitation	Information provision		General road/exclusive motor-vehicle way	
		Traffic congestion information	Traffic facilitation	Information provision		General road/exclusive motor-vehicle way	
		Traffic congestion end information	Traffic facilitation	Information provision	Turn-off support, automated → manual determination	Exclusive motor-vehicle way	
		Air bag, etc. deployment information		Information provision	HELP	General road/exclusive motor-vehicle way	
●Static	Level for use in route preparation for automated driving	High-precision map			Route search	General road/exclusive motor-vehicle way	This is use of what is referred to telematics and is outside the scope of this investigation.
		Updated map information (acquisition during stoppage)				General road/exclusive motor-vehicle way	

The following five examples were selected as use case examples in this document.

- Dynamic data:
  (1) Collision avoidance and emergency braking due to falling object, vehicle involved in accident, etc.
  (2)-1 Intersection passage support using current traffic signal color information

  Reasons for selection:
  This is a typical use case where communication is treated as one vehicle sensor, and in particular, it may

be necessary to consider whether high reliability can be ensured.

- Semi-dynamic data:
  (2)-2 Dilemma zone avoidance/Red traffic signal warning using traffic signal cycle information
  (3) Lane change support/route selection using information on the presence of an obstacle, broken-down vehicle, etc.
  (4) Vehicle avoidance support using information on a nearby emergency vehicle

  Reasons for selection:
  This is an example where compared to already deployed DSRC systems (ETC 2.0, ITS Connect), there is a possibility of using the advantages of a cellular network such as mutual use and wide area communications.

- Semi-static data:
  (5) Route reselection using construction and regulatory information

  Reasons for selection:
  This is an example where it is believed that conventional cellular networks can be used, but integration with existing business models such as the distribution area, responses to abnormalities (such as network problems), and long-term business continuity are necessary.

Possible scenarios and issues relating to these five use cases are set forth below.

2.2 Use case 1: Collision avoidance and emergency braking due to falling object, vehicle involved in accident, etc.

Description
A vehicle that detects a falling object using a vehicle sensor or a vehicle that brakes suddenly transmits that information to the nearby vicinity.

Performance
Normally, when breaking, it is anticipated that the driver's reaction time will be 0.75 seconds, and in this use case, it is necessary that the provision of information occurs at a time sufficiently shorter than this. The stopping distance is 67 m when traveling at 100 km/h, and it is estimated that the necessary range for the provision of information is within several tens to several hundreds of meters. With regard to this type of short range provision of information, V2V has the potential to achieve adequate low latency and reliability (related materials are set forth in Appendix A.3).

Further investigation is needed concerning whether it is possible to achieve adequate performance, taking into consideration shielding, fading, radio interference, and so on. It is necessary to consider not only shadowing, fading, and interference power margin in comparison to minimum reception sensitivity, but also the impact on performance from factors such as multi-access schemes. In addition, extremely high reliability is required, and therefore, use in conjunction with onboard sensors is contemplated, so it will be necessary to investigate the reliability conditions needed for communications and to verify that the reliability is satisfied. Guaranteeing extreme reliability and low latency is desirable, but it is difficult to ensure communications performance in wireless zones, so it is necessary to consider handling and countermeasures in cases where usability condition scanning and performance requirements are not satisfied (such as when there is communications congestion or hardware failure).

Standardization
Provision of this use case will require standardization of the message format, communication protocol, and so on and investigation of testing and certification for ensuring interconnectivity. As of June 2019, there is no frequency that can be used for LTE V2V in Japan, and accordingly, investigation regarding allocation of frequencies will also be necessary. Designs will be needed that take into consideration expansion of and coexistence with already deployed DSRC systems from the perspectives of communication standards and frequencies, flexibility for future expansion, and so on. Also, from the perspective of applications, it is believed to be necessary to establish guidelines on integrating recognition between transmitting and receiving vehicles and making effective use of received information with respect to communication generation conditions and information generated using vehicle control information such as sudden braking.

Handling of Legal Certification
This use case also contemplates reflection in automated driving control, and it will be necessary to clarify the scope to which vehicles and parts will be certified and verified and how they will be certified and verified when necessary.

Security

Ensuring the authenticity of information will be important. Countermeasures against tampering with location information, braking information, and so on and against GPS jamming and so on will be necessary. For example, certification of terminals and applications and electronic signatures in messages are possible. It will also be necessary to obtain consent regarding the use of information from each vehicle owner.

Relationship with already deployed ITS

Communications in this use case are generated from events such as braking by a vehicle ahead, and it is believed that communications frequency will be low. As a result, it will be possible to provide information using already deployed ITS from the perspective of capacity. On the other hand, the required liability is higher than that provided by already deployed ITS, and there is a possibility of interference occurring with already deployed ITS communications and that it will not be possible to ensure high reliability. Because of this, it is believed that there will be advantages to operations not susceptible to effects of interference from other services such as using frequencies (channels) different from already deployed ITS. In Japan, the 5 GHz band is being considered as a new frequency, but the 5 GHz band has high propagation losses compared to the 760 MHz (assigned to ITS Connect (safety/smooth service) using DSRC system in ITS frequency band of ITU-R M.2121) and other bands, and therefore, LTE can make use of its high reception sensitivity compared to other communications (relevant materials are in Appendix A.3).

2.3 Use case 2: Intersection passage support/Dilemma zone avoidance/[3]Red traffic signal warning using traffic signal cycle information

Current Traffic Signals and Traffic Signal Information Distribution Systems

When distributing traffic signal information (the current signal color and cycle information[4]), services that take into consideration the traffic signal structure are necessary. There are two types of traffic signal: (a) signals that are connected to a traffic control center where the traffic control center centrally controls the number of seconds of each color of light, and (b) signals that are not connected to a traffic control center but control light color based on a preset time pattern. Approximately 30% of all traffic signals are connected to a traffic control center. The remainder of traffic signals is unable to receive information on conditions from a traffic control center. In addition, in each of these cases, there are a third type: (c) traffic signals where the color can be controlled based on a sensor or a pushbutton installed near the intersection. In the cases of (a) and (c), traffic cycle information changes frequently.

Currently, traffic signal information distribution services are provided in Japan using optical beacons and 700 MHz band ITS. The systems use communications categorized as V2I and distribution information using dedicated communications devices installed near the traffic signals, and therefore, are compatible with any of the traffic signal structures described above. Traffic signal information distribution is low data rate communications, and it is believed that 700 MHz band ITS, in particular, can adequately provide communications range (the range in which information is provided) necessary for intersection passage support.

Description

Considering the existence of current traffic signal information distribution systems, it is believed that the effects of using cellular V2X in a V2I for this use case would be limited. On the other hand, with the V2I, since infrastructure development is required at each intersection, communications infrastructure development throughout the entire country would be a problem, and the availability of V2N, a type of wide area communication, becomes important. Also, if it were possible to distribute cycle information with distribution of current traffic signal color within traffic signal information, in addition to providing dynamic intersection passage support using current traffic signal color information distribution, it may also be possible to provide integrated dilemma zone avoidance and red traffic signal warnings in an integrated data format. Implementation has been organized below taking into consideration the survey results from the Cross-ministerial Strategic Innovation Promotion Program (SIP) [32].

With traffic signal information distribution using V2N, there are two possible implementations as traffic signal information acquisition and distribution methods using V2X application servers as traffic signal information distribution servers as shown in Figure 2.2.

[3] When a traffic signal changes from green to yellow, there is an area (the dilemma zone) where a vehicle can not pass the stop line or stop without a problem during the time that the signal remains yellow [30].

[4] One round of signal displays is referred to as a cycle [31], and the order of colors within a determined range and the predetermined number of seconds for each color are referred to as cycle information.

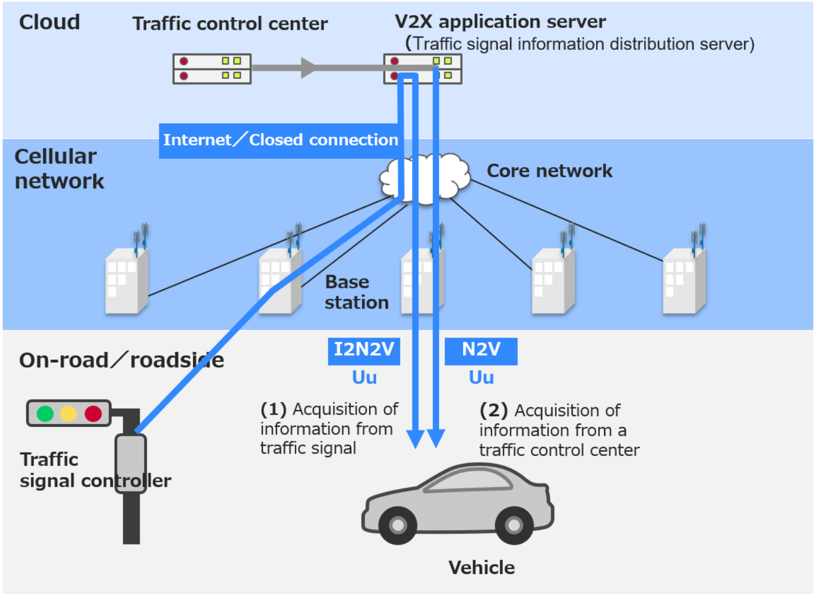


Figure 2.2 Examples of Traffic Signal Information Acquisition and Distribution

(1) Acquisition of information from traffic signal

With this use case, the traffic signal is connected to an LTE/5G communications terminal, which connected to a traffic signal information distribution server (traffic signal information uplink). Similar to V2I, traffic signals would need to be replaced with signals that can acquire signal cycle information, and as a result, effects on the issue of infrastructure investment would be limited. However, as discussed in (b) above, in the case of signals that control the light color based on a preset time pattern, investment costs can be reduced more than V2I by acquiring signal cycle information as semi-dynamic information and generating a time pattern table by other means, making V2N possible.

(2) Acquisition of information from a traffic control center

Under this case, traffic signal information servers and a traffic control center are connected by dedicated lines or VPN, and traffic signal information is acquired from the traffic control center to provide the service. With the current centralized control traffic signal control method, a traffic signal controller that receives traffic signal cycle guidelines from a control center determines the traffic signal cycle taking into consideration the sensing status of sensors. Notice of the results is provided to the traffic control center after execution of the cycle. For this reason, depending on the required information accuracy and other factors, it is necessary to collect traffic signal cycle information determined by the signal controller in the control center before execution of the cycle, and a system for distribution via an information distribution server is necessary, so the effects of introduction may be limited in terms of implementation costs (costs for installation of information distribution servers).

In any case, discussion regarding the service providers and scope of provision (demarcation of responsibility) is also necessary. In cases where private businesses operate traffic signal information distribution servers, disclosure of traffic signal information to the private sector will be needed. In cases where the scope of service provision from traffic signal information distribution servers is limited to distribution of traffic signal information and cellular networks are executed by agreement in the user side, the traffic signal information distribution provider cannot participate in the cellular network communications quality.

Performance

Depending on the performance requirements, it is necessary to investigate the cellular network and improvement of quality, which may necessitate debate in conjunction with consideration of the scope of service provision. For example, [32] shows the results of a survey relating to 100 ms to 300 ms permissible latency. It is necessary to specify the requirements including reliability and availability. It is necessary to create designs taking into consideration transmission routes among cellular networks, traffic control centers, traffic signal information distribution servers with regard to transmission route latency not only in wireless zones, but also in wired zones. In [33], latency times of 137 ms to 350 ms in traffic signal controllers with structures whereby traffic signal information is acquired from a signal controller are reported, and it is necessary to investigate latencies other than transmission depending on the performance requirements. Guaranteeing extremely high reliability performance and low latency communications is desirable, but it is difficult to ensure communications performance in wireless zones, so it is necessary to consider handling and countermeasures in cases where usability condition scanning and performance requirements are not satisfied (such as when there is communications congestion or a hardware or network failure). In cases where existing cellular networks are used, it will be necessary to investigate responses regarding differences in the service areas of each MNO.

Standardization
Provision of this use case will require standardization of the message format, communication protocol, and so on and investigation of testing and certification for ensuring interconnectivity. It will also be necessary to investigate message formats that can recognize traffic signal information accuracy and connection interfaces with traffic signal related devices for acquiring signal information so that vehicles can properly use received signal information. In addition, it will be necessary to investigate guidelines for standardization of information distribution areas within V2N information distribution.

Handling of Legal Certification
This use case also contemplates reflection in automated driving control, and it will be necessary to clarify the scope to which vehicles and parts will be certified and verified and how they will be certified and verified when necessary.

Security and Privacy
Ensuring the authenticity of information and who will bear responsibility for doing so will be important. Possible means of preventing distribution of information from non-certified devices and tampered information include, for example, embedding digital signatures in distributed information and using secure connections among information providers, information distribution servers, and vehicles that receive information. It will also be necessary to investigate privacy issues arising from vehicles tracking for distribution control.

2.4 Use case 3: Lane change support/route selection using information on the presence of an obstacle, broken-down vehicle, etc.

Description
By using the advantages of wide area communication and transmitting information on the circumstances in a range of several hundred meters, which is difficult to detect using vehicles sensors, safe passage (slow travel) and changes to a travel lane with adequate capacity at the site of accidents are encouraged. Although detection of obstacles and broken-down vehicles can be inferred from statistical information such as sudden braking by vehicles, it is necessary to consider how to make detection methods more accurate.

Performance
It is possible that latencies on the order of several seconds to several tens of seconds can be permitted, and it is believed that use of existing cellular networks that can convey information over wide areas will be possible. It is necessary to consider handling and countermeasures in cases where usability condition scanning and performance requirements are not satisfied (such as when there is communications congestion or a hardware or network failure). The sizes of permissible on-road coverage holes will be determined according to the latency conditions, and therefore, communications coverage may become an issue in this use case as well, depending on the conditions. In cases where existing cellular networks are used, it will be necessary to investigate responses regarding differences in the service areas of each MNO.

Standardization
Provision of this use case will require standardization of the message format, communication protocol, and so on and investigation of testing and certification for ensuring interconnectivity. In cases where already deployed ITS acquires information on obstacles, broken-down vehicles, and so on, it will be necessary to consider connection interfaces with already deployed ITS infrastructure. In addition, it will be necessary to investigate guidelines for standardization of information distribution areas within V2N information distribution.

Security and Privacy
Ensuring the authenticity of information and who will bear responsibility for doing so will be important. With this use case, it is necessary to perform authentication from the perspectives of both information provider vehicles and roadside sensors as well as devices that make determinations regarding obstacles and broken-down vehicles. Possible means of preventing distribution of information from non-certified devices and tampered information include, for example, embedding digital signatures in distributed information and using secure connections among information providers, information distribution servers, and vehicles that receive information. It will also be necessary to investigate privacy issues arising from vehicles tracking for distribution control.

2.5 Use case 4: Vehicle avoidance support using information on a nearby emergency vehicle

Description
Notice of emergency vehicles in the vicinity is provided so that emergency vehicles engaged in emergency travel can be detected and vehicles can stop so that emergency vehicles can pass through intersections with traffic signals (green lights). It is anticipated that information will be provided by emergency vehicles and their control centers. In the future, it will be possible to simultaneously provide information on the planned routes of emergency vehicles and to provide notice of the presence of other vehicles on the road by making use of wide area communications.

Performance
It is possible that latencies on the order of several hundred ms can be permitted, and it is expected that existing cellular networks can be used when route plans and the like are used at the same time. Simultaneous V2V use may also be possible depending on the communications range requirements. It is necessary to consider handling and countermeasures in cases where usability condition scanning and performance requirements are not satisfied (such as when there is communications congestion or a hardware or network failure). Communications power coverage may also be an issue depending on the performance requirements. In cases where existing cellular networks are used, it will be necessary to investigate responses regarding differences in the service areas of each MNO.

Standardization
Provision of this use case will require standardization of the message format, communication protocol, and so on and investigation of testing and certification for ensuring interconnectivity. In cases where already deployed ITS and emergency systems acquire information on emergency vehicles, it will be necessary to consider connection interfaces with those systems. In addition, it will be necessary to investigate guidelines for standardization of information distribution areas within V2N information distribution. In the case where V2V and V2N are used simultaneously, it will be necessary to investigate measures for integrating the information provided by both and guidelines relating to information handling by the receiving vehicle in cases where inconsistencies arise.

Security and Privacy
Ensuring the authenticity of information and who will bear responsibility for doing so will be important. Possible means of preventing distribution of information from non-certified devices and tampered information include, for example, embedding digital signatures in distributed information and using secure connections among information providers, information distribution servers, and vehicles that receive information. It will also be necessary to investigate privacy issues arising from vehicles tracking for distribution control.

2.6 Use case 5: Route reselection using construction and regulatory information

Description
This use case is used as information for making detours on ordinary roads, make decisions whether to use or not use exclusive motor-vehicle roads, and change lanes with sufficient time in advance. Information updates on the order of several seconds or more and the ability to distribute information over wide areas without selecting the location of the information provider are required, and is expected that cellular systems can be used.

Performance
It is possible that latencies on the order of several seconds or more can be permitted, and it is believed that use of existing cellular networks that can convey information over wide areas will be possible. It is necessary to consider handling and countermeasures in cases where usability condition scanning and performance requirements are not satisfied (such as when there is communications congestion or a hardware or network failure). The sizes of permissible on-road coverage holes will be determined according to the latency conditions, and therefore, communications coverage may become an issue in this use case as well, depending on the conditions. In cases where existing cellular networks are used, it will be necessary to investigate responses regarding differences in the service areas of each MNO.

Standardization
Provision of this use case will require standardization of the message format, communication protocol, and so on and investigation of testing and certification for ensuring interconnectivity. In cases where already deployed ITS or roadside managers acquire information on obstacles, broken-down vehicles, and so on, it will be necessary to consider connection interfaces with those systems. In addition, it will be necessary to investigate guidelines for standardization of information distribution areas within V2N information distribution.

Security and Privacy
Ensuring the authenticity of information and who will bear responsibility for doing so will be important. With

this use case, it is necessary to perform authentication from the perspective of information provider organizations. Possible means of preventing distribution of information from non-certified devices and tampered information include, for example, embedding digital signatures in distributed information and using secure connections among information providers, information distribution servers, and vehicles that receive information. It will also be necessary to investigate privacy issues arising from vehicles tracking for distribution control.

Chapter3 Communications Architecture

3.1 System Structure

This chapter outlines each element of the overall structure of cellular V2X discussed in the introduction and further explains the architecture of short range (V2V/V2I/V2P) and wide area communications (V2N) using LTE as an example.

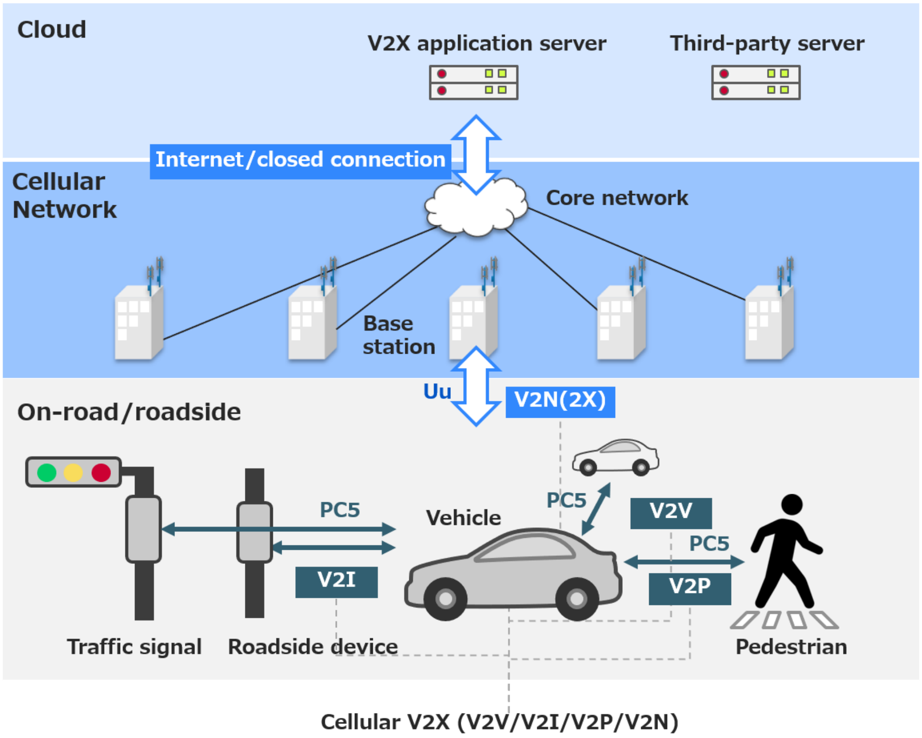


Figure 3.1 Overall Structure of Cellular V2X (re-posted)

Vehicles
Vehicles transmit information acquired from GPS, CAN, and onboard sensors to other vehicles and V2X application servers on networks. The onboard application controls transmission and reception of V2X messages by one or both of two types of communication interface for short range (PC5) and wide area communication (Uu). The received information is provided to the driver or the automated driving AI via the onboard application. Vehicles with both short range and wide area communications functions are assumed as the initial step, although there is a need to consider vehicles supporting either short range or wide area communications functions from the cost reduction perspective, and there is also a need to consider vehicles equipped with DSRC such as ITS Connect.

Roadside Units
Roadside units can connect with roadside sensors and nearby traffic signals. In this document, roadside units mean terminal-type devices that have short range and wide area communications functions, not devices with base station functions. For example, a roadside unit can use short range communications as the means of communication with vehicles and use a dedicated line or wide area communications for connecting with a backbone communications network and the backbone server. Such roadside unit can distribute information about traffic signals and roadside sensors from base stations as I2N2V. Due to infrastructure costs, roadside unit is assumed to be used for spot-point services at key traffic points instead of large area service.

Pedestrians
Terminals such as smart phones carried by pedestrians can connect with nearby vehicles using short range and wide area communications. The main purpose is to provide the presence of pedestrians to vehicles. For the reason of battery consumption, terminal costs, and so on, terminals may support only either short range or wide area communications, but it is assumed here that terminals support both short range and wide area communications.

V2X Application Servers
V2X application servers have the function to collect, provide, relay, and store information among terminals (roadside

units, vehicles, and pedestrians) for the use cases discussed in Chapter 2. These servers may be realized by multiple servers from the reasons for implementation, load distribution, and role separation. These application servers may perform distribution of information received from third-party servers (discussed below). V2X application servers and terminals are connected using cellular networks comprising base stations and core networks. Using inter-vehicle communications via a base station (V2N2V) as an example, communications are divided into two segments—from a vehicle to the V2X application server and from the V2X application server to a vehicle—and from the perspective of terminals, they communicate with the V2X application server in both segments. V2X application servers and third-party servers will be connected by the Internet or dedicated lines according to the requirements such as security and communications performance.

Third-Party Servers
Third-party servers are servers that provide information such as traffic signal information, construction information, regulatory information, and dynamic maps to V2X application servers and connect to V2X application servers via the Internet or dedicated line.

3.2 Short Range Communications (V2V/V2I/V2P) Architecture

Short range communications use dedicated frequency to avoid interference with wide area communications. It is assumed that V2V, V2I, and V2P communications will use shared or dedicated sub-channels.

3.2.1 Protocol Stack

V2V, V2I, and V2P using LTE short range communications will be achieved with common communications specifications, and V2V, V2I, and V2P services will be achieved on the corresponding upper application layer. The protocol stack is indicated in Figure 3.2. The protocol stack includes the C-plane protocol stack that exchanges information with the control system and the U-plane protocol stack that exchanges information with users. Here, discussion focuses on the U-plane protocol stack. From the physical layer to the PDCP layer [5] is standardized under 3GPP, and the other upper layers use the ITS standards of other standardization organizations. In cases where use cases that are not standardized in Japan, it is necessary to prepare new upper layer specifications. Wide area communications using V2N is IP-based communications while short range communications are used mainly for broadcast communications to nearby devices, and therefore, basically, non-IP is used.

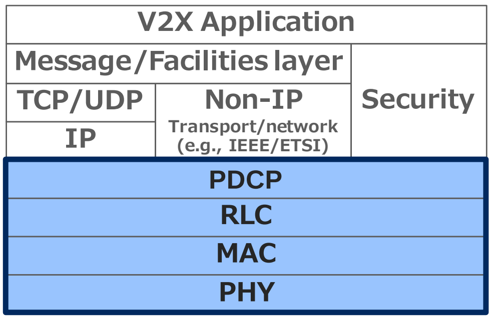


Figure 3.2 Short Range Communication Protocol Stack

3.2.2 Communications Architecture

Using LTE V2X short range communications, various types of the operations are possible according to the amount of use of cellular infrastructure. Examples of operation types are shown in Figure 3.3. Two main functions of the use of cellular infrastructure are parameter management and selection of transmission wireless resource.

[5] One of the sub layers in layer 2 inthe LTE wireless interface; the protocols perform ciphering, integrity protection, header compression, and other functions.

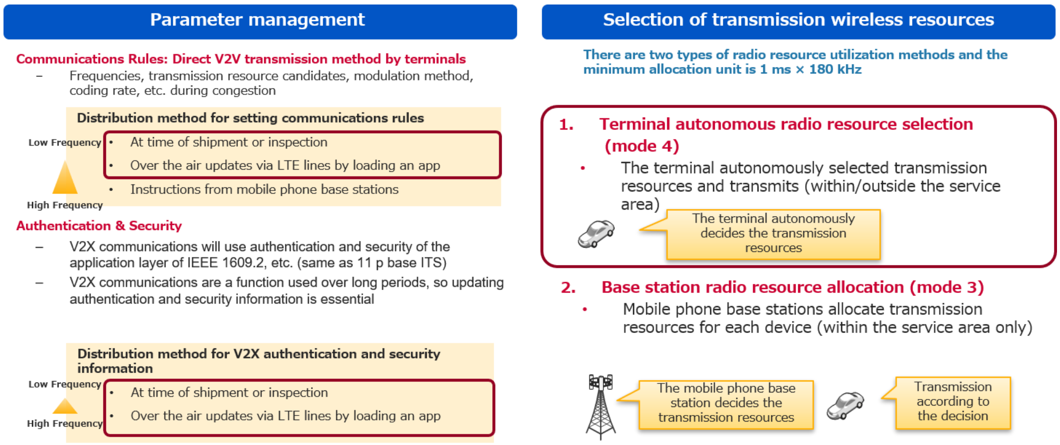


Figure 3.3 Types of Short Range Communication Operations

This document describes operational modes not using cellular network (indicated by the red frame in the figure) so that short range communications can be used outside the wide area communications areas. With this operation mode, the short range communications parameters are pre-configured [34], and short range communications are performed based on the parameters for the terminal's current location according to the parameters for each region stored in the terminal. The pre-configuration parameters can be set for each longitude and latitude polygon. Therefore, different parameters can be applied for each country or making it possible to optimize parameter settings according to area conditions such as urban and suburban areas. Setting and managing parameters for different use case can also be achieved using this parameter setting function. Selection of transmission wireless resources is based on autonomous mode (Mode 4) based on the sensing.

Although the distribution of parameters may be limited only at the time of terminal shipment, there are cases parameters are required to be changed during long-term use. For this reason, it is desirable to enable parameter updates. Depending on how often parameter updates are required for short range communications, it is necessary to determine how to realize the distribution of the parameters such as distributions from a parameter management server via a cellular network, a distribution based on the car maintenance through operational management organization or the fixed parameters in the specification. As indicated in Figure 3.4. parameter distribution via cellular network is possible using the application layer. Therefore, no special cellular network functions are required.

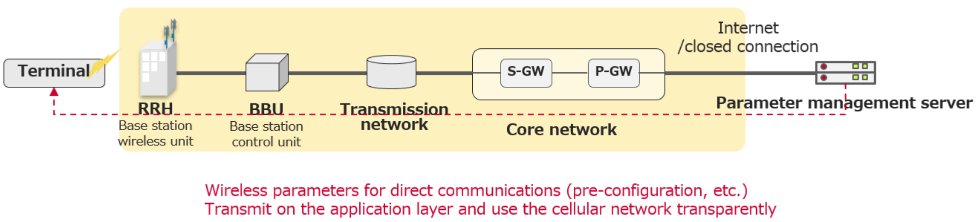


Figure 3.4 Distribution of Short Range Communication Parameters via Cellular Network

LTE V2X short range communications is a synchronized system. Inter-terminal synchronization is achieved via a combination of GPS (or other GNSS), base station synchronization signals, and inter-terminal synchronization signals. As the vehicles obtain the positionining information from GPS, it is expected that GPS would be the main synchronization source. Two-thirds of Japan's territory is mountainous and there are a lot of tunnels, with the total length of tunnels reaching 4,620 km [35]. As GPS signals cannot be used in tunnels, it is necessary to discuss the need for synchronization methods other than GPS for inside tunnels.

3.2.3 Security

As discussed above, short range communications (V2V/V2I/V2P) assume the application layer security specified by other standardization organizations. In many ITS standards, security and privacy in application layers are ensured using an electronic certificate method, which is an authentication foundation that uses public key infrastructure (PKI). The electronic certificates used with PKI are distributed by a certification authority (CA). One possible means of preventing the compromise of signals is to enable over the air (OTA) updates of electronic certificates. Areas of concern regarding PKI include CA operational costs, costs to distribute renewed certificates and lists of lost certificates, and increases in processing costs for signature certificates on onboard units, and consequently, one of the possibilities is to use a common key prior sharing method such as used in the ITS connect (in fact, ITS connect also uses PKI in combination).

3.2.4 Support of Multiple MNO

As indicated in Figures 3.3 and 3.4, for V2V, V2I, and V2P using short range communications without using a cellular network, an operation that does not use special functions is possible. Although it may be possible to use the cellular network to connect with parameter management server for parameter updates and so on, the use of MNO specific functions is not required. Because of this, terminals with different MNO subscriptions can be operated well using V2V, V2I, and V2P.

3.3 Wide Area Communications (V2N) Architecture

With regard to wide area communications using V2N, although there are scenarios using V2X dedicated infrastructure, the use of existing MNO infrastructure will be investigated because of the feasibility of infrastructure investment and operational costs. In this case, an additional allocation of frequencies will not be necessary. In addition, although there is an operational mode where the frequency allocation between the dedicated frequency and the common frequencies such as in the case of local 5G is under investigation by the Ministry of Internal Affairs and Communications [36] and public safety LTE in the United States, initially, the investigations will be conducted with the assumption that existing MNO infrastructure is used. Overviews of the V2N communications architecture, protocol stack, and geo-messaging necessary for information distribution are explained below. Similar investigations can be found in [37] and [38].

3.3.1 Communications Architecture

The architecture of a cellular network for implementing V2N is explained in Figure 3.5 using the LTE network as an example. Examples of similar architectures are summarized in Figure 4.2.1.1-1 of 3GPP TS23.285 [10]. Although there are differences in the detailed architecture, a similar structure can be achieved with 5G as well. As indicated in Chapter 1, current cellular systems are fundamentally operated using unicast, and below, a unicast architecture that is believed to be realized within a short period is explained.

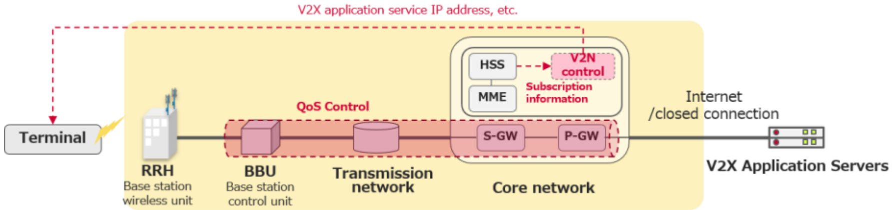


Figure 3.5 Example of a Cellular V2X System Architecture

Similar to general cellular communication, V2N application packets connect terminals and V2X application servers via base stations, transmission networks (the communications network portion unique to the wireless systems), and core network (the communications network portion not exclusive to the wireless systems). In addition, with this architecture, it is also possible to additionally use V2X control functions in the core network as unique V2X functions. These functions are logical functions that perform all of the V2X functions unique to the MNO. It is assumed that operational parameters unique to MNOs and IP addresses of V2X application servers will be distributed. QoS class identifiers (QCI) that assume cases, where QoS control is applied to V2N communications, are also specified. As discussed in Chapter 1, however, QoS control cannot provide QoS-guaranteed communication. It is also necessary to discuss whether to use cellular infrastructure to control V2V, V2I, and V2P using short range communications or whether to switch the availability and content of V2N service according to the contract type. In these cases, it is also necessary to discuss whether to store the contract information relating to HSS (home subscriber server).

3.3.2 Protocol Stack

Next, an overview of the V2N protocol stack is presented using the example in Figure 3.6. In that figure, S-GW is omitted for simplicity. The protocol stack includes the C-plane protocol stack that exchanges information with the control system and the U-plane protocol stack that exchanges information with users. Here, discussion focuses on the U-plane protocol stack.

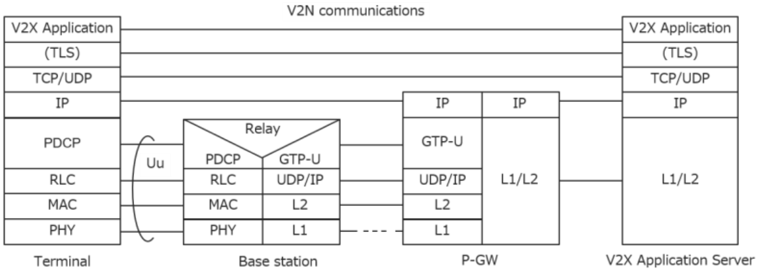


Figure 3.6 Example of the V2N Protocol Stack

With the exception of short range communications, LTE networks are all-IP systems, and IP packets are sent between terminals and V2X application servers via P-GW. Therefore, base stations and S-GW are transparent. The protocol above IP is not specified in 3GPP, and it is necessary to use Internet standard specified by the Internet Engineering Task Force (IETF) or other regional ITS specifications depending on the required conditions. It is necessary to determine the scope to be defined as the upper layer specifications and the scope to be defined as the guidelines, and so on.

In cases where terminals performed communications via a network such as in V2N2V, at a minimum, the terminal communicates with the V2X application server on the IP layer. An example of the V2N2V protocol stack is shown in Figure 3.7. Base stations to S/P-GW and the layers below IP are omitted for simplicity.

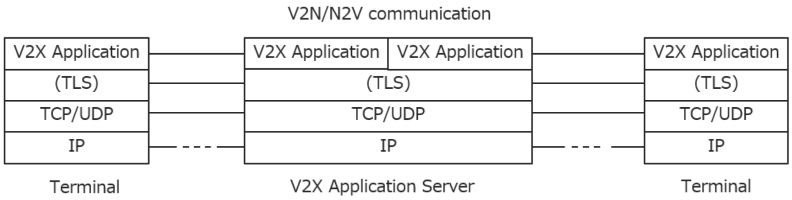


Figure 3.7 Example of the V2N2V Protocol Stack (Layers below IP Omitted)

In this example, communications with the terminal are terminated at the V2X application server, and packet generation and distribution are performed based on the traffic situation determined by the V2X application server. Although latency increases because of packet termination and generation on the network side compared with MEC, communications can be achieved with the same protocol stack as in the case of V2N and N2V. Depending on MEC realization, the application server with multiple network interfaces is also possible. It is also possible to add an intermediate layer to perform geo-messaging and to perform packet reproduction and distribution based on information appended to the packet header on the network side.

3.3.3 Geo-messaging

When information is distributed to terminals by downlink, processing to determine the distribution targets based on terminal position and other information at the V2X application server side are necessary. This is referred to as geo-messaging. An overview is provided below. With geo-messaging, as shown in Figure 3.8, unicast requires distribution based on vehicle position while multicast requires distribution determinations based on base station coverage. It is necessary to create guidelines for distribution of information to assumed vehicles and to define the detailed implementation method as indicated below.

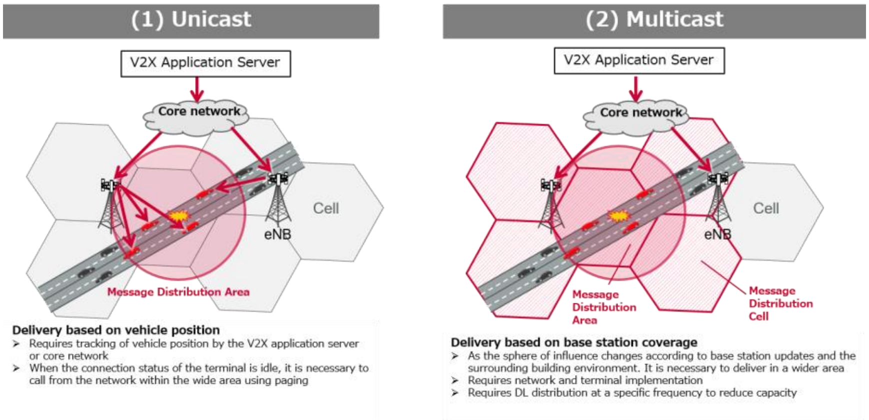


Figure 3.8 Geo-messaging in V2N DL Distribution

For unicast information distribution, it is necessary to perform mapping between the distribution area and the terminal IP address or vehicle ID (DL destination management). For multicast information distribution, it is necessary to map the base station to the distribution area. A pattern diagram is indicated in Figure3.9. With unicast, a structure that implements this with the V2X application server and a structure that implements this on the core network are both possible. It may also be possible to reduce unnecessary notifications in consideration of the vehicle terminal position as well as the moving status and other factors. With multicast, distribution processing must be performed on the core network, and therefore, destination management on the core network is necessary.

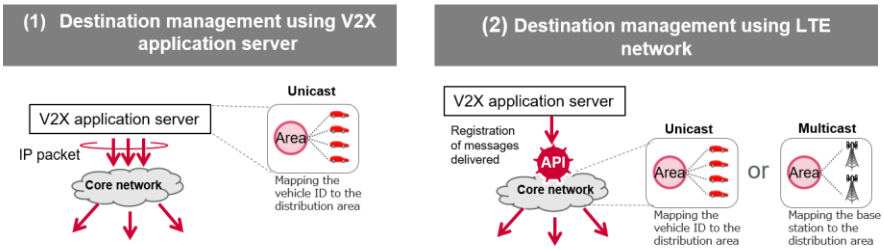


Figure 3.9 Example of Destination Management Function Allocation

3.3.4 Security

The 3GPP specifications support encryption on the PDCP layer for cellular communication part as security [39]. It is also possible to use security measures that employ web services such as Transport Layer Security (TLS). It is possible to use application layer security equivalent to short range communications, but it is necessary to define required security after determining the requirements for security and privacy protection in V2N communications. In cases where closed connection types are adopted in particular, it is difficult to falsify or intercept information in the communications path, and it is necessary to discuss security and privacy requirements.

3.3.5 Support for MEC and Multiple MNO

In general, communications via cellular network are implemented between Internet cloud servers, but it may also be possible to use Mobile Edge Computing (MEC) to reduce communications latency and increase reliability. Various forms of communication can be considered from P-GW that does not go through the Internet to direct connection to base stations [40]. Figure 3.10 shows an example of a physical connection to a MEC server. The closer the MEC servers are installed to the base stations, the shorter the transmission latency and load reduction effects on the core network can be expected, but a large number of servers are required, and the cost for infrastructure investment and maintenance increase. Also, latency and overhead increase in conjunction with switching between MECs as terminals move and with coordination among MECs. In cases where MEC servers are installed on multiple MNO lines, it is necessary to investigate the connection interfaces between the MEC servers on each MNO and other MNO networks. For example, since MEC servers are configured to have IP addresses at the connection points for each MNO network, provision by the cellular network of the API related to the MEC servers such as providing a name resolution function to the MEC server using DNS for each MNO network is under consideration [41]. Considering the above, premised on low-latency communications being covered by short range communications, it is desirable to consider V2N in the form of a cloud server as a common interface between MNOs or by installing MEC servers outside existing P-GW. Using MEC for the purpose of close connections with external systems that do not allow Internet connections may also be possible.

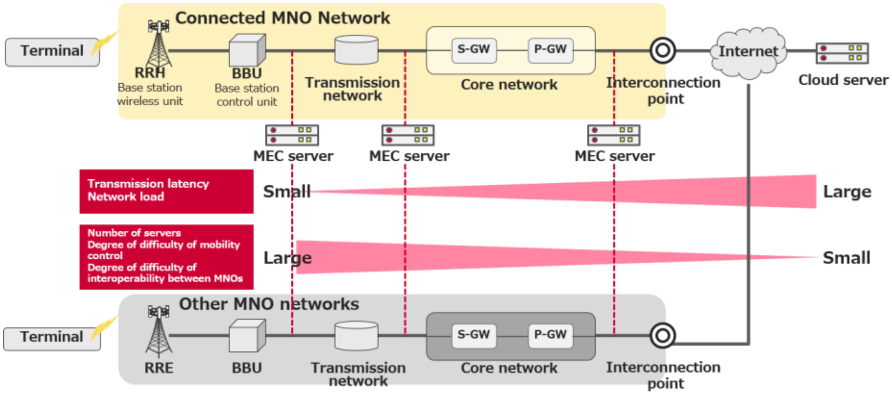


Figure 3.10 Example of MEC Server Physical Connection

Chapter4 Business Models

In implementing each use case, it is desirable to have a model in which beneficiaries who enjoy the value of V2X technologies (e.g., reducing accidents and expanding the range of operation design for self-driving vehicles) can bear the cost, based on the principle of beneficiary burden. The following is a summary of our approach to stakeholders, cost factors, and V2V/V2I/V2N.

4.1 Stakeholders under Each Use Case

For each use case described in Section 2, the informants, system providers, and direct and indirect beneficiaries are listed in Table 4.1. In all use cases, the direct beneficiary is the driver who receives the information, but in use cases involving safety, the car owner (can be different from driver); in use cases involving driving facilitation, the road administrator; and in use cases involving the smooth implementation of public interest activities such as emergency vehicle operations and construction work, the corresponding operator is also considered to be the beneficiary.

In order to realize each use case, in addition to providing the system directly related to the communication of the cellular V2X, it is necessary to construct the ecosystem including the linkage with the existing system which was not related to the cellular V2X.

Table 4.1 Stakeholders of Each Use Case

Use Case		Information Provider	System Provider	Beneficiary	Value
1	Collision avoidance and emergency braking due to falling objects, vehicles involved in accidents, etc.	Drivers, car owners, etc.	Car OEMs, system operation managers, etc.	Drivers, car owners, etc.	Safety
2	Intersection passage support/dilemma zone avoidance/red traffic signal warning using traffic signal cycle information	Traffic signal managers, etc.	Traffic signal managers, MNOs, system operation managers, etc.	Drivers, car owners, road administrators, etc.	Safety Traffic facilitation
3	Lane change support/route selection using information on the presence of an obstacle, broken-down vehicle, etc.	Drivers, car owners, road managers, etc.	Road administrators, MNOs, system operation managers, etc.	Drivers, car owners, etc.	Safety
4	Vehicle avoidance support using information on nearby emergency vehicles	Emergency vehicle operators, etc.	Hospitals, MNOs, system operation managers, etc.	Drivers, emergency vehicle operators, and users, etc.	Safety
5	Route reselection using construction and regulatory information	Road administrators, constructors, etc.	Road administrators, MNOs, system operation managers, etc.	Drivers, road administrators, constructors, etc.	Traffic facilitation

4.2 Cost Factors in Cellular V2X Business

Figure 4.1 shows six general cost factors in cellular V2X (V2V and V2I/N) business.

i. Information acquisition costs (scope: V2N, V2I)
This is an information provision fee, such as the degree of traffic congestion and road regulations, paid to the rights holder of the third party server such as a road administrator for use in the V2X application server. Contracts are made by region, period, etc..

ii.CAPEX for V2X dedicated application systems (scope: V2N, V2I, V2V)
These include development costs for a V2X application server, a monitoring server for the V2X system itself, an electronic certificate management server for security and privacy management, and software licensing costs. In some cases, there is only a lump sum payment, and in other cases, there is an annual maintenance fee.

iii.OPEX for V2X dedicated application system (scope: V2N, V2I, V2V)
These are the operation and management costs of the above-mentioned server facilities, V2I/N infrastructure, and authentication systems including those for V2V terminals. Initial provisioning work such as issuance and installation of electronic certificates, general server monitoring work, remote monitoring of facilities and fault isolation work, etc. conducted by operation management bodies. This is a cost that continues to occur regularly over the operation period. When an electronic certificate is issued from an external public key authentication infrastructure business operator, a license fee is incurred for each issuance.

iv.CAPEX and OPEX for communications infrastructure (scope: V2N, V2I, V2V)
The initial and running costs of the communications infrastructure portion. Initial costs include the development of RSUs, cellular base stations, and a certification system for V2V/V2I/V2N connectivity, and the installation of backhaul lines. The running costs include licensing fees for RSUs and cellular base stations, backhaul line usage fees, development costs in the event of system updates to RSUs and cellular base stations, and the distribution and application costs of updates.

v.Communications fee (scope: V2N, V2I, V2V)
These are V2N packet communications charges paid to mobile operators and radio spectrum user fees paid to the government. In the V2N form, the user pays in the form of communication packet cost including (4) and a part of (3). In general, they are paid on a monthly or yearly basis as regular contracts.

Note: In the case of V2V/V2I, there is a possibility that it will be exempted from the application of the collection of the radio spectrum user fee, but from the standpoint of this document, it is interpreted that the burden is uniformly required.

vi.Onboard equipment costs (scope: V2N, V2I, V2V)
It is the cost of a device such as an on-board terminal, antennas, and an application installed on the terminal. Initial costs include development costs. Running costs may include material component costs, manufacturing, storage, distribution, and maintenance services, as well as licensing costs for installed applications and libraries. In some cases, (5) is sold as a bundle with the cost of the terminal equipment.

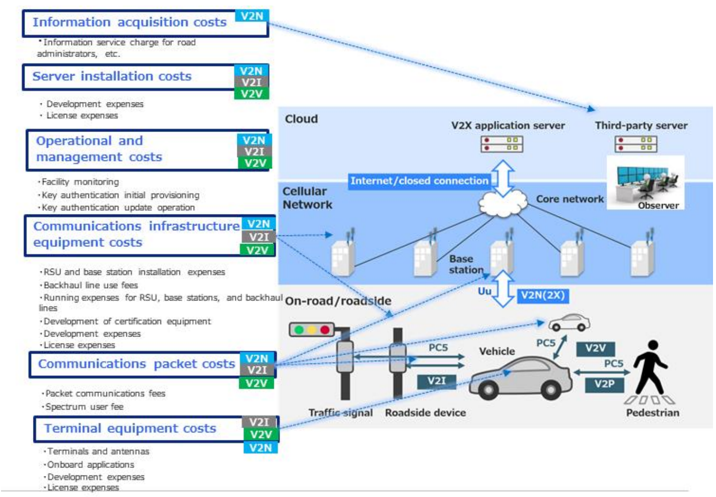


Figure 4.1 Cost Factors in Cellular V2X Business

4.3 Approach to V2V

In V2V, as in the case of existing ITS, it is assumed that vehicle owners purchase V2V-capable terminals. Although there are exceptions such as electronic certificate management for security and privacy protection, the necessary infrastructure costs are small, so it is assumed that there is a possibility that the business will become a terminal purchase business. It is possible to reduce the cost of in-vehicle terminals by sharing communication components with other services, but careful and specific consideration of sharing is necessary. There is a possibility that a smartphone can be used as a V2V communication device for a vehicle, but there are many uncertainties such as the support of V2V communication function and GPS accuracy. Therefore, when smartphones cannot be used as terminals for vehicles, the factors that promote the spread of V2V-capable in-vehicle terminals are considered to be the cost reduction of in-vehicle terminals and the provision of incentives for the introduction.

4.4 Approach to V2I/N

Both V2I/V2N require costs of infrastructure investment and maintenance in addition to the introduction of V2I/V2N-capable terminals. In order to recoup initial investment costs, it is desirable to ensure business continuity for a certain period of time. In existing ITS in Japan, infrastructure improvement is carried out as a public investment. When V2I and V2N provide common services, they are used in a complementary manner, and increasing the places where services are available in V2I or V2N is effective in increasing the value enjoyed by the beneficiaries. At this time, the provision of V2N services using existing cellular networks is a factor to promote the penetration of infrastructure. The service may be started in the form of V2N using the existing network, and dedicated infrastructure or evolution of the existing infrastructure may be introduced in order to respond to the strongly requested use cases.

In particular, V2I/V2N may be able to improve profitability by providing the collected information to a third party service or receiving information from a third party service. As an example of receiving information from a third-party service in Japan, it is conceivable to utilize probe data in existing ITS such as VICS (Vehicle Information and Communication System Center) and ETC 2.0 [42]. For example, VICS provides information such as road transit times and traffic volume to outside operators based on information from sensors installed on roads.

Chapter5 Organization of Issues

The main issues identified in prior chapters are organized in Table 5.1. Examples of use cases to which each issue applies are indicated by checkmarks (✓) in the table. The issues of the use cases using V2V communications (use cases 1 and 4) and of the use cases using V2N or V2I communications (use cases 2,3,4, and 5) differ not only in perspective of communications but also perspective of services (ex. the structure of cost burden). It is also necessary to organize issues for each information source in cases where information is provided via base stations or roadside infrastructure. In use case 4, where information may be obtained from vehicles, clarifying the division of roles between V2V and V2N is an issue, and in use cases 2, 3, 4, and 5, where information may be obtained from associations and organizations, it will be necessary to work on the issues in coordination with those associations and organizations corresponding to the information sources. Clarification of the business model is also one of the issues, as there are many stakeholders in the process of the vehicle receiving the information.

Table 5.1 Organization of Issues for Achieving Each Use Case Using Cellular V2X

Perspective		**Issue**	**Corresponding Use Case**				
			#1	**#2**	**#3**	**#4**	**#5**
Communications	**Short Range Communications (V2V/V2I; PC5)**	Acquisition of frequency allocation, standardization of communication methods	✓			✓	
		Establishment of communications parameters and operational methods	✓			✓	
		Creation and maintenance of interconnectivity and security operational management systems	✓			✓	
		Verification of feasibility (latency and reliability) and availability	✓			✓	
		Responses in cases where performance requirements are not met and countermeasure costs	✓			✓	
	Wide Area Communications (V2N; Uu)	Verification of feasibility (latency and reliability) and availability		✓	✓	✓	✓
		Investigation of communications quality improvement methods (if necessary)		✓	✓	✓	✓
		Responses in cases where performance requirements are not met and countermeasure costs		✓	✓	✓	✓
		Responses to differences in the service areas of each MNO		✓	✓	✓	✓
Information	**Acquisition from associations and organizations**	Obtaining approval to acquire source information from associations and organizations		✓	✓	✓	✓
		Creation of systems for acquiring information from information sources (precision, security, etc.)		✓	✓	✓	✓
		Standardization of equipment specification, formats, etc. for acquiring information from information sources		✓	✓	✓	✓
	Acquisition from vehicles	Adoption of message format and protocol specifications	✓		✓	✓	
		Adoption of guidelines for controlling variations among vehicles generating information	✓		✓	✓	
		Security and privacy countermeasures	✓		✓		
		Obtaining consent regarding the use of information from each vehicle owner	✓		✓		
	Use by transmission-receiving vehicles	Adoption of message format and protocol specifications	✓	✓	✓	✓	✓
		Ensuring the reliability of received information (communications route security)	✓	✓	✓	✓	✓
		Formulation of guidelines on the use of received information (including consideration of latency)	✓	✓	✓	✓	✓
Services	**Services**	Formulation of service definitions and guidelines	✓	✓	✓	✓	✓
		Development of systems from acquisition of source information to provision to vehicles		✓	✓	✓	✓
		Securing service opportunities (promoting widespread adoption of terminals, developing infrastructure, etc.)	✓	✓	✓	✓	✓
	Business	Reducing the cost of PC5 onboard devices (to promote widespread adoption)	✓			✓	
		Burden of Uu communications costs		✓	✓	✓	✓

		Investment relating to improvement of communications quality (if necessary)	✓	✓	✓	✓	✓
		Development of servers for information acquisition, collection, and distribution and establishment of business taking into consideration costs for maintenance of distribution servers and other equipment (including acquisition of public funding and cooperation and collaboration with associations and organizations)		✓	✓	✓	✓
	Responsibility	Clarification of the allocation of responsibility from acquisition of source information to provision to vehicles	✓	✓	✓	✓	✓
		Formulation of response policies when services are suspended due to hardware failures, network problems, etc.	✓	✓	✓	✓	✓
		Clarification of the scope of certification and inspection (pre-shipment inspection, vehicle inspections, etc.)	✓	✓			

Chapter6 Summary

In this document, with regard to issues concerning the advancement of ITS and autonomous driving using cellular communications technologies (cellular V2X), (1) collision avoidance and emergency braking due to falling object, vehicle involved in accident, etc., (2)-1 intersection passage support, (2)-2 dilemma zone avoidance/red traffic signal warning using traffic signal cycle information, (3) lane change support/route selection using information on the presence of an obstacle, broken-down vehicle, etc., (4) vehicle avoidance support using information on a nearby emergency vehicle, and (5) route reselection using construction and regulatory information were investigated from the perspectives of communications architecture and business models. The issues identified as a result of this examination were arranged according to the use cases from the perspectives of communications, information, and services.

As various services are being investigated for the advancement of ITS and autonomous driving, the necessary communications performance and regulatory systems, as well as the impact on business, are being discussed. There are significant appeals to using both the wide area communications (V2N) and short range communications (V2V, V2I, and V2P) and creating flexible designs compatible with various services, but there are many issues that would need to be investigated to achieve this. Going forward, the automotive and telecommunications industries will need to work closely together from a variety of perspectives, including use cases, performance requirements, implementation patterns, and business models, to make systems a reality. In addition, close collaboration between the public and private sectors will be necessary from the perspectives of frequencies, formulation of communication specifications, design of systems, and infrastructure development.

The comparison of communication performance alone is not enough to complete the discussion. It is expected that discussions will be held on the true merits and value creation of using cellular V2X and its impact on the legal system and business and that discussions will move forward in the direction of providing better ITS services.

This document will be updated in the future to incorporate those discussions. It is hoped that this document will be widely used as an aid for investigating ITS and autonomous driving in Japan.

Appendices

A.1 Detailed Glossary

A detailed version of the glossary found in Chapter 1.1 is described below.

Table A.1 Glossary (Detailed Version)

Term	Meaning / explanation
Cellular V2X	Cellular V2X is technology that uses cellular communications such as LTE and makes it possible for vehicles to connect with all others. It includes short range communications such as vehicle to vehicle, vehicle to infrastructure, and vehicle to pedestrian on road and roadside and wide area communications where vehicles use cellular networks consisted of base stations and a core network.
LTE	A 3.9 or 4th generation cellular wireless access technology standardized by 3GPP. Currently, 3GPP Release 8 to Release 15 are specified.
LTE V2X	Cellular V2X using LTE.
5G	The 5th generation cellular wireless access technology standardized by 3GPP. It includes NR and LTE Release 15 and later. It often refers to NR only.
NR	The new wireless access technology standardized by 3GPP for 5G. Currently, only wide area communications via base stations have been standardized in Release 15, and it is expected that short range communications will also be standardized in Release 16.
Wide area communications, Downlink/uplink, Uu, wide area communications, V2N2X	These terms mean wide area communications between mobile devices and base stations. In this document, these terms can also include communications via core networks and application servers; also referred to as V2N2V/V2N2I/V2N2P.
Downlink	Communications from a base station to a mobile device in wide area communications.
Uplink	Communications from a mobile device to a base station in wide area communications.
Short range communications, sidelink, PC5, V2V/V2I/V2P	These terms mean short range direct communications between mobile devices, i.e. vehicle to vehicle or vehicle to pedestrians. Short range communications based on LTE is standardized in Release 14. Short range communications based on NR is to be standardized in Release 16.
Base station, NB, eNB, gNB	Base station means the equipment that communicates with mobile devices in the cellular network. A base station supports one or multiple cells. NB (node B) is a WCDMA base station. eNB (e node B) is an LTE base station. gNB (g node B) is an NR base station.
Mobile station (MS), user equipment (UE)	Devices that communicate with networks in the cellular network. Strictly speaking, mobile station and UE are different because mobile stations do not include SIM and UE include SIM, but in many cases, they are not distinguished.
Cell	A certain geographic area to which a base station transmits radio waves on a single frequency and is uniquely recognized by mobile devices.
Core network (CN)	The part of a cellular network that does not rely on wireless access technologies such as WCDMA, LTE, and NR. It includes S-GW and P-GW.
Radio access network (RAN)	The portion of a cellular network including base stations that unique to wireless access technologies such as WCDMA, LTE, and NR. The portion unique to LTE is referred to as E-UTRAN, and the portion unique to NR is referred to as NG-RAN.
Unicast	One-to-one communications link between base stations and single mobile devices.
Broadcast	In wide area communications, uni-directional, one-to-many transmission from a base station to all mobile devices in the corresponding area. In short range communications, transmission from a mobile device to all mobile devices in the neighboring area.
Multicast	In wide area communications, uni-directional, one-to-many transmission from a base station to a specific mobile device group identified by a group identifier in the corresponding area. It includes eMBMS, which broadcasts the same information simultaneously from multiple cells, and SC-PTM, which broadcasts different information from each cell. In short range communications, transmission from a mobile device to specified multiple mobile devices in the neighboring area.
Handover	In wide area communications, in the broad sense, the mobility between cells, regardless of in connected mode or idle mode. Strictly speaking, the mobility between cells according to network instructions in connected mode and not including the mobility between cells in idle mode.
Connected mode	In wide area communications, the mobile device existence in a cell is recognized by the network and the mobile devices are ready to transmit and receive the radio waves. It is also referred to as connected.

Idle mode	In wide area communications, the mobile device existence in a cell is not recognized by the network, and mobile devices are in standby mode. It is also referred to as idle.
Subframe	The basic wireless time resource allocation unit in LTE and NR, i.e., 1 msec. In NR, although the subframe is 1 msec, the time allocation of less than 1 msec is also supported.
Roadside unit (RSU)	Although there are terminal-type RSU that communicate with mobile devices using short range communications and base station type RSU that communicate with mobile devices using wide area communications, in this document, base station type devices are not referred to as roadside units and roadside units mean terminal-type devices that communicate with mobile stations using short range communications. RSU can connect to networks using wide area communications.
Discontinuous reception (DRX)	Intermittent reception. In wide area communications, mobile devices are turned on at regular intervals in order to check if there are any transmissions from the network. DRX is specified in both connected mode and idle mode. In connected mode, DRX can be turned off.
Scheduling request (SR)	In wide area communications, it means the communication to notify the network initially when there is an uplink communication from a mobile device. There is a method where the wireless resource for such communication is specifically allocated to a mobile device and a method where the wireless resource for such communication is shared among mobile device.
Semi-Persistent Scheduling (SPS)	In short range communication and wide area communication, it means the transmission and reception are performed at predetermined regular intervals. In wide area communications, it especially refers to transmission and reception at regular intervals without using a control signal for the resource allocation.
Mobile Network Operator (MNO)	A telecommunications business operator that provides mobile communications services and develops or operates wireless stations related to those mobile communications services.
Mobile Virtual Network Operator (MVNO)	A telecommunications business operator that provides mobile communications services provided by an MNO or by connecting to an MNO and does not develop or operate wireless stations related to those mobile communications services.
Subscriber Identity Module (SIM)	Module that contains identification of a mobile phone subscriber and subscription and plays a major role in cellular network security in wide area communications.
Mobile Edge Computing (MEC)	Having application layer computing resources close to base stations or core network in the cellular networks instead of having them in the cloud outside of the cellular network in order to reduce the latency and so on.

Information update frequency		Examples of handled information	Application	Use level (application)	Anticipated applications	Site where information is used	Reference
●Dynamic	Reflected in automated driving as one of multiple sensors (multi-system)	Presence of pedestrians or bicycles	Safety	Control intervention/warning	Prevention of pedestrian accidents	General road	In this area, there is a possibility that a system can be created by using communication as one of the multi-system sensors in combination with other sensors. Depending on the application, ensuring reliability is the key
		Presence of nearby vehicles (including motorcycles)	Safety	Control intervention/warning	Prevention of collisions between vehicles crossing paths, lane change support	General road/exclusive motor-vehicle way	
		Broken-down vehicle or fallen obstacle (immediately ahead)	Safety	Control intervention	Rear-end collision avoidance, emergency braking (1)	General road/exclusive motor-vehicle way	
		Emergency braking by vehicle ahead	Safety	Control intervention		General road/exclusive motor-vehicle way	
		Real time operation information from vehicle driving ahead	Traffic facilitation, comfort	Control intervention	Platooning	Exclusive motor-vehicle way	
		Vehicle information on the main exclusive motor-vehicle	Traffic facilitation, comfort	Control intervention/ warning/information provision	Merging support	Exclusive motor-vehicle way	

		way					
		Signal color (display) information	Safety, comfort	Control intervention/warning	Intersection passage support (2)-1	General road	
		Presence of oncoming traffic or crossing pedestrians at intersection	Safety	Control intervention/warning	Prevention of collision with oncoming vehicle when making a right turn, collision with bicycle, etc. when making a left turn, accident involving crossing pedestrians	General road	
		ETC gate opening/closing information	Safety, comfort	Control intervention/ warning/information provision	Prevention of collision during rapid closing, gate selection, lane change	Exclusive motor-vehicle way	
●Semi-dynamic	Predictive information Level for use in safe stopping and lane changing	Signal cycle information	Safety, Comfort	Warning/information provision	Avoidance of dilemma, red traffic light warning (2)-2	General road	Depending on the requirements of the vehicle, there is a possibility that cellular communications can be used with other communications or individually.
		Information on presence of obstacle or broken-down vehicle	Safety, traffic facilitation	Information provision	Lane change support, route selection (3)	General road/exclusive motor-vehicle way	
		Nearby emergency vehicle	Safety, traffic facilitation	Information provision	Vehicle avoidance support (4)	General road	
		Lane-specific traffic congestion information	Safety, traffic facilitation	Information provision	Lane change support, route research	General road	
●Semi-static	Predictive information Level for use in advance route changes, etc.	Updated map information (partial update while traveling)	Traffic facilitation	Information provision		General road	There is a possibility that it can be used with the same performance and mechanisms as conventional cellular communications.
		Regulation information	Traffic facilitation	Information provision	Route research (5)	General road/exclusive motor-vehicle way	
		Construction information	Traffic facilitation	Information provision		General road/exclusive motor-vehicle way	
		Traffic congestion information	Traffic facilitation	Information provision		General road/exclusive motor-vehicle way	
		Traffic congestion end information	Traffic facilitation	Information provision	Turn-off support, automated → manual determination	Exclusive motor-vehicle way	
		Air bag, etc. deployment information		Information provision	HELP	General road/exclusive motor-vehicle way	
●Static	Level for use in route preparatio	High-precision map			Route search	General road/exclusive motor-vehicle way	This is use of what is referred to telematics

	n for automated driving	Updated map information (acquisition during stoppage)				General road/exclusive motor-vehicle way	and is outside the scope of this investigation.

Figure A.1 Organization of Use Cases (Expanded)

A.2 Features of LTE V2X (PC5; V2V/V2I/V2P) Communications Performance

Supplemental information on the communications performance characteristics of LTE V2X (PC5: V2V/V2I/V2P), regarding which it is stated in section 2 of Chapter 2, "V2V has the potential to achieve adequate low latency and reliability" and "LTE can make use of its high reception sensitivity compared to other communications systems." In addition, the results of verification trials conducted in various countries have also been publicly released [15] [23].

Link Design (1 of 2)

Challenges

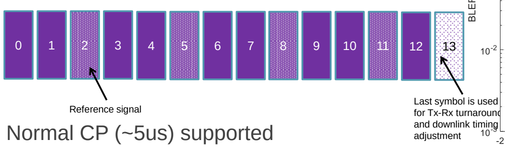
- ITS spectrum @ 6 GHz
- High speed
  - Max vehicle speed of 250 kph ⇔ max relative speed is 500 kph
  - At 6 GHz, 2700Hz Doppler shift ⇔ channel variation within a subframe
- High frequency offset
  - Up to 0.3ppm frequency offset
  - At carrier frequency of 6GHz ⇔ 1800Hz
- Focused on enhancing sidelink (V2V) channels
  - PSCCH : Assignment Channel for sidelink
  - PSSCH : Data Channel for sidelink

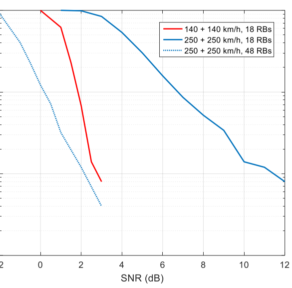
2

Link Design (2 of 2)

Solutions

- High reference signal density with regular spacing
  - Symbol location: #2, #5, #8, #11





300 bytes, QPSK, two Tx, random frequency error

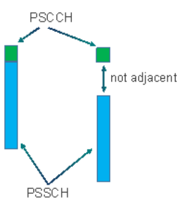
- Normal CP (~5us) supported
- Intra-symbol estimation of frequency offset
- Pre-specified limits on MCS, #RBs, #Tx
  - Possibly based on speed and synchronization source

3

PSSCH and PSCCH (1 of 2)

Intra subframe PSSCH and PSCCH transmission

- PSSCH and PSCCH transmitted on the same subframe
  - Separate DFT and reference signals (two cluster SC-FDM)
  - Same subframe transmissions reduces the impact of in-band emissions
  - Reduces issues related to half duplex operation
- PSSCH and PSCCH may or may not be adjacent in frequency
  - Depends on the resource pool (pre)configuration
  - We simulate adjacent case => lower MPR



- Same open loop power control parameters are used for both channels
  - 3 dB PSD boosting for PSCCH => try to make sure that control does not become the bottleneck

4

PSSCH and PSCCH (2 of 2)

Details

- PSCCH
  - One PSCCH transmitted for each PSSCH on the same subframe
  - No combining of PSCCH retransmission
  - Number of RBs = 2
  - Blind detection of cyclic shift to improve PSCCH to PSCCH interference
  - Group id *(u)* fixed to 8 ⇔ better performance for high frequency offset
- PSSCH
  - Max number of transmissions = 2
  - RV ID sequence for HARQ transmissions are given by 0, 2
  - Maximum distance between initial transmission and HARQ retransmission is 15
  - Various phy parameters are a function of PSCCH CRC

5

C-V2X range benefits from multiple reasons

- Longer transmission time: allows for higher energy per information bit
  - Enabled by synchronization which allows frequency multiplexing
- HARQ : Enables higher energy per information and more time/frequency diversity
- Channel estimation: More density in frequency makes less susceptible to multi-path
- Coding: Turbo coding typically provides for more coding gain compared to convolution coding
- Waveform: SC-FDM allows for higher Tx power due to lower PAPR

6

C-V2V - PC5 Transmission Modes

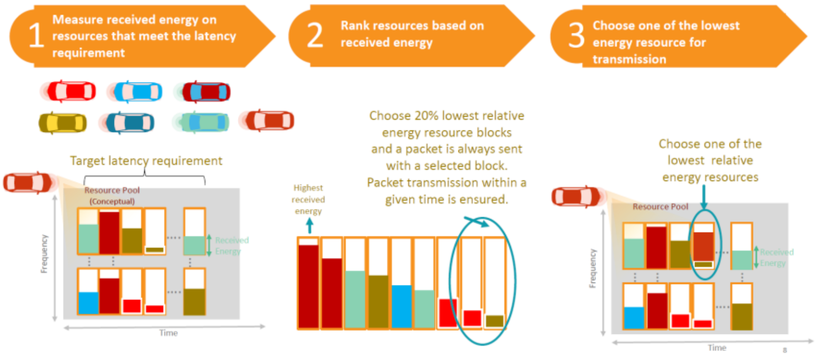
Modes 3 and 4 - Default is Mode 4

- Mode 3
  - eNB scheduled resource selection
- Mode 4
  - Autonomous resource selection without eNB scheduling
  - Uses sensing with semi-persistent transmission ⇔ frequency domain LBT
    - Semi-persistent transmission allows one to take advantage of semi-periodic traffic arrival
    - Uses past interference patterns to predict the future
  - Random selection/energy based selection allowed for one shot transmissions
  - Sensing ⇔ combination of priority information, energy sensing, PSCCH decoding
  - Energy sensing ⇔ Rank resources according to energy received and pick low energy resource
  - PSCCH decoding ⇔ Avoid resources for whom control is decoded and received energy is above a threshold
  - Priority ⇔ Avoid resources that are being used for higher priority packet transmission

7

Mode 4 Resource Selection Concept

Choose resources with close to lowest relative energy level

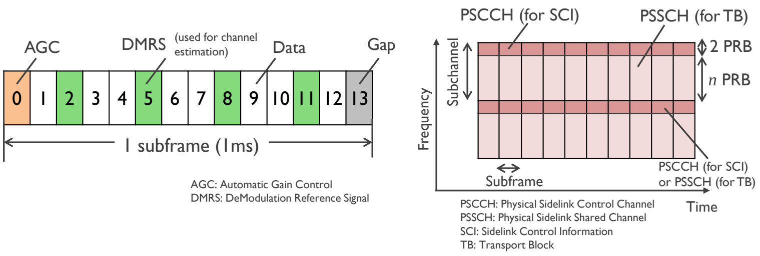


A.3 Impact on Performance from Factors such as LTE V2X (PC5: V2V/V2I/V2P) Multi-access Schemes

Supplemental information on "the impact on performance from factors such as multi-access schemes" described in Section 2 of Chapter 2 as "an item requiring investigation."

Note: Any multi-access schemes have potential packet collision or performance degradation. However, LTE-V2X PC5 mode 4 has additional aspects that do not exist in other multi-access schemes. This Appendix describes those aspects unique to LTE-V2X PC5 mode 4 that requires further study.

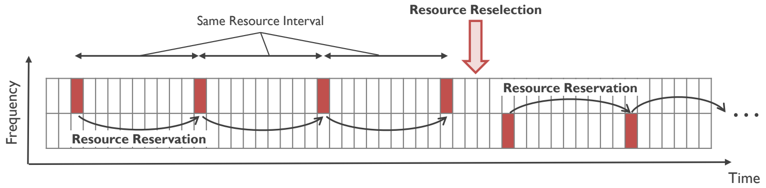
Rel-14 LTE-V2X PC5: PHY Aspects



Access Scheme	SC-FDMA
Modulation	QPSK, 16QAM
Channel Coding	Turbo Coding (for data), Tail Biting Convolutional code (for control)
System Bandwidth	10, 20 MHz
Sub-Carrier Spacing	15 kHz
Cyclic Prefix Length	Normal: 4.7 μs
# of MIMO streams	1

p. 1

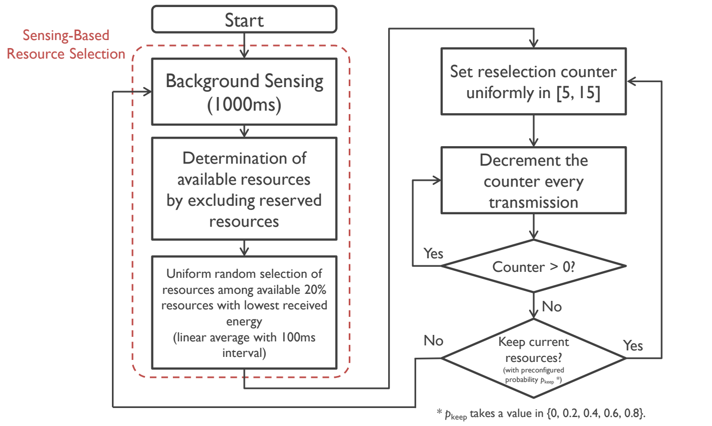
Rel-14 LTE-V2X PC5 Mode 4: Semi-Persistent Scheduling (SPS)



- SPS is used for LTE-V2X PC5 to efficiently support periodic message traffics.
  - Keep using the same resource with a fixed time interval
  - Explicitly indicate the use of the next resource for the next transmission (i.e., resource reservation)
  - Reselect the resource after several transmissions with a certain probability

p. 2

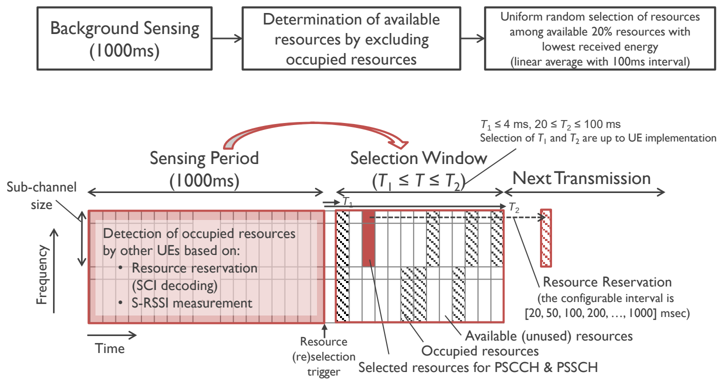
Rel-14 LTE-V2X PC5 Mode 4: Channel Access Procedure of SPS



* p_{keep} takes a value in {0, 0.2, 0.4, 0.6, 0.8}.

p. 3

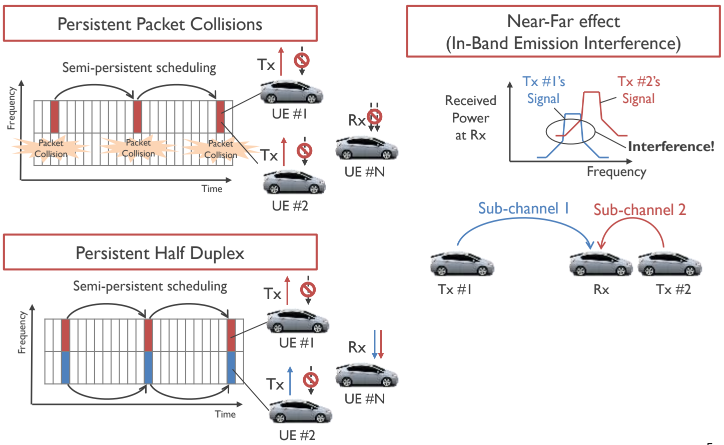
Rel-14 LTE-V2X PC5 Mode 4: Sensing-Based Resource Selection



In case that the retransmission feature is enabled, if some resources (same frequency resources) are available within 15ms from the initial transmission, resources for retransmission are randomly selected among available resources.

p. 4

Factors Affecting LTE-V2X PC5 Mode 4 Performance (1/2)



p. 5

Factors Affecting LTE-V2X PC5 Mode 4 Performance (1/2)

Note:

- Persistent packet collisions, persistent half duplex and near-far effect can be mitigated by blind retransmission (HARQ) and geo-zoning resource selection.
  - It is not sure whether repetition is disabled on congestion. Congestion control can be performed by adjusting MCS, i.e., using higher order modulation or coding rate. However, using a higher MCS has some factors affecting to communication range. One is required higher CN values, it reduce communication range. Another is increase power spectrum density, it improve communication range. Since there are factors that work both positive and negative in communication range, more quantitative analysis is needed to assess the impact of congestion control for V2X services.
  - Geo zoning may not provide meaningful improvement. Instead, geo zoning will introduce inefficient spectrum utilization by reducing resource candidate from UE perspective.

- Persistent half duplex and near-far effect due to in-band emission can be avoided by disabling FDMA. However, there are pros and cons when FDMA is disabled. One of the cons is the reduced power spectrum density, and thus the reduced communication range. Another cons is that the number of vehicles that can be accommodated in the same area would be reduced due to reduced number of resource candidates in the frequency domain in each subframe. One of the pros is the improved spatial spectrum reuse by virtue of the reduced communication range. Another pros is the improved communication range by using a lower MCS as more number of resource blocks in the frequency domain can be allocated to each vehicle. Since there are pros and cons when FDMA is disabled to mitigate persistent half duplex and near-far effect, more quantitative analysis is needed to assess the impact of these effects for safety services.

p. 6

Factors Affecting LTE-V2X PC5 Mode 4 Performance (1/2)

Note:

- Half-duplex issue is a common problem for any wireless communication systems when a vehicle uses the same channel for transmission and reception. However, the sub-channelization and SPS of LTE-V2X PC5 mode 4 cause persistent half-duplex (i.e., two vehicles using different subchannels in the same subframe for transmission cannot receive the other's packets consecutively).

- Cross-channel interference is another common problem for any wireless communication systems when multiple adjacent channels are used by each vehicle for transmission and reception. However, in addition to cross-channel interference, the sub-channelization of LTE-V2X PC5 mode 4 in a channel causes in-band emission interference (i.e., interference among different subchannels in the channel).

- Assuming IBE, Tx UEs which are in the vicinity each other may avoid selecting FDMed resource at least if FDMed resource has strong reception power where RSSI of adjacent resource has some RSSI level due to IBE. However, depending on the positions of Tx UEs, hidden terminal UEs may not be able to avoid selecting the FDMed resources with IBE. In addition, avoiding FDMed resources due to IBE may result in a limited number of similar candidate resources in resource selection and affect the occurrence probability of Persistent Packet Collisions. So, it is necessary to quantitatively evaluate its impact.

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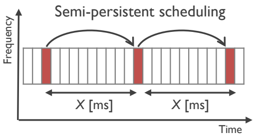
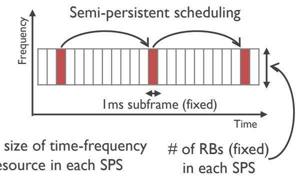
Factors Affecting LTE-V2X PC5 Mode 4 Performance (2/2)

Support of variable message Interval	Support of variable message sizes



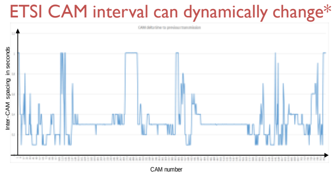
The allowed resource interval X [ms] is limited to: {20, 50, 100, 200, 300, …, 1000} [ms]



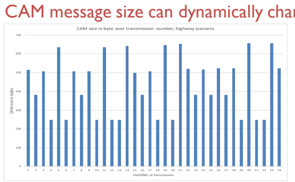
Fixed size of time-frequency resource in each SPS

# of RBs (fixed) in each SPS

ETSI CAM interval can dynamically change*



ETSI CAM message size can dynamically change*



* https://mentor.ieee.org/802.11/dcn/11-18-1731

CAM: Cooperative Awareness Message

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Factors Affecting LTE-V2X PC5 Mode 4 Performance (2/2)

Note:

- Potential impact of variable message interval and message size
  - ➢ Variable message interval --> unused reserved resources and frequent resource reselection, i.e., 1) UE reserves certain resources, but those resources may not be used for transmission due to resource reselection, and 2) frequent resource reselection caused by message interval change potentially increase packet collision.
  - ➢ Variable message size --> variable MCS causes a reduced communication range for bigger messages (e.g., shorter communication range for messages with full security certificate than messages with certificate digest)

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