Issue Survey Report

Advanced ITS and Automated Driving
Using Cellular Communications Technologies

January 2021

ITS Info-communications Forum

Cellular System TG

ITS Info-communications
Forum

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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	
2.0	January 12, 2021	Throughout	Information updated and additions investigated	Chapter 1: Glossary and Trends in Standardization updated Chapter 2: Use Cases with Both Short Range Communications and Wide Area Communications added Chapter 3: Compatibility of MEC Installation Sites added Chapter 4: Business Model Diagram added Chapter 5: Text added in conjunction with the above revisions Chapter 6: Text added in conjunction with the above revisions A.3: Content extensively revised A.4: Newly added

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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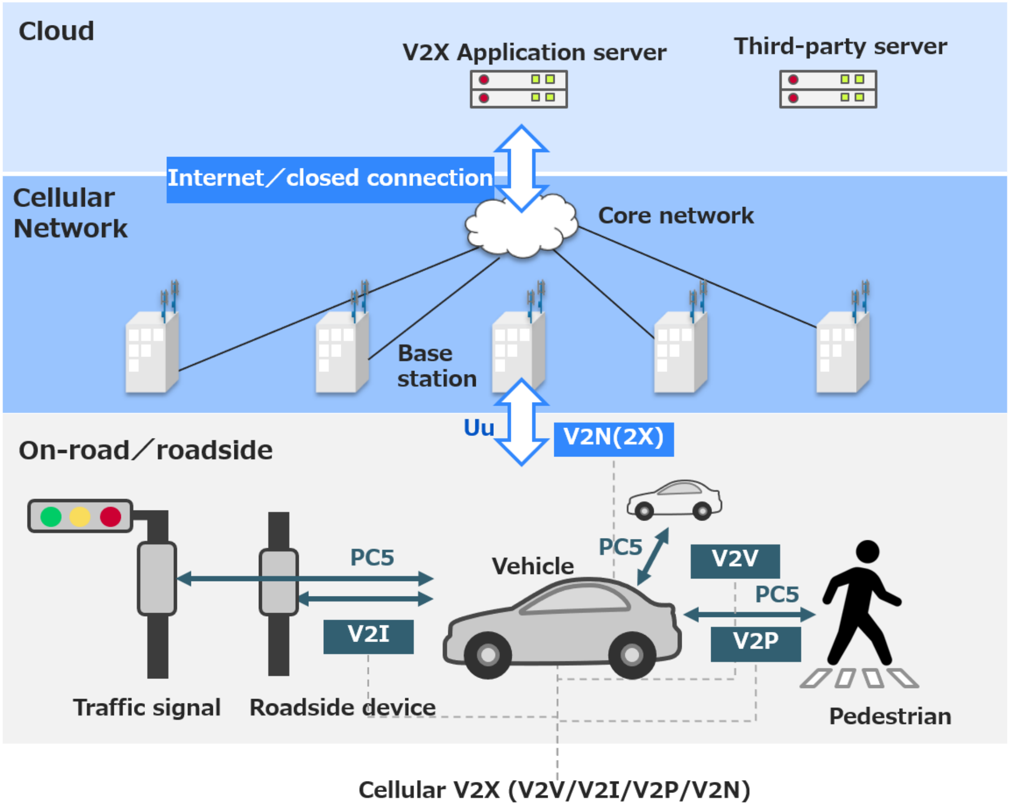
Introduction

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., the Connected Vehicle Pilot Deployment Program [1] is being implemented in the United States, and projects such as C-ROADS [2] and Nordic Way [3] are being carried out in Europe. In China, large-scale trials and commercial deployment are underway in Wuxi and other regions [4], [5]. Amidst this international competition, the Public-Private ITS Initiative/Roadmaps [6] 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, and various demonstration trials and other initiatives are being carried out such as investigations by the Panel on Business Strategies for Automated Driving [7] and the Cabinet Office SIP-adus project [8]. 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, DSRC systems (ETC and ETC 2.0) fee collection and various information services using 5.8 GHz-band-based vehicle to infrastructure communications) and ITS Connect (safe driving and traffic smoothness services using 700 MHz-band-based vehicle to infrastructure and vehicle to vehicle communications) 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 based on cellular communications technologies have been specified 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 and verification and deployment are being conducted based on actual operations, it is necessary to consider business feasibility, operations, and so on in each region [9], [10], [11]. 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.

The first version of this document was issued in June 2019 with the aim of organizing the issues identified for achieving advanced ITS and automated driving using cellular V2X, and also the aim of accelerating future investigation of the effectiveness, identification and resolution of issues of cellular V2X in Japan. This revised version has additional investigations and information on the latest situations around the world. 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.

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Chapter 1 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 [12], [13], [14]. Other detailed terms can be found in the appendix.

Table 1.1 Glossary

Terms	Meaning / Explanation
Cellular V2X, C-V2X	Cellular V2X is a technology that uses cellular communications such as LTE and 5G NR 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 16 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. In general, NR is often recognized as a representative 5G wireless interface.
NR, 5G NR	The new wireless access technology standardized by 3GPP for 5G. Only wide area communications via base stations have been standardized in Release 15, and short range communications is standardized in Release 16.
NR V2X	Wide area and short range communication based on NR in cellular V2X.
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 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.
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.
Multi-access 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.
Communication latency	In communication-related documents published by such as ITU-R and 3GPP, the communication latency often means the shortest latency in one direction under the condition that the communication device is in active state and the light load on the wired and wireless communication links. Further consideration is necessary on the systemic latency on the

	following points 1) data generation frequency and latency in the sensors and communication data generation units, 2) the effects and variation under heavy loads on wired and wireless communication links, 3) the time required for the retransmissions to ensure reliability, and 4) whether the communication units is always active or not.

1.2 LTE

V2X can be broadly divided into (1) V2N (wide area communications) and (2) V2V/V2I/V2P (short range communications). (1) V2N 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) V2V/V2I/V2P refers to direct communications between terminals that do not go through an MNO's base station.

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 route 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 [15], [16], 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.

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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.

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 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.
- In network scheduled operation mode (mode 3), the network centrally controls the allocation of wireless resources. In UE autonomous resources selection mode (mode 4), each terminal autonomously allocated wireless resources.
- Priority control and congestion control are standardized. However, even if priority control applies, it does not guarantee communications performance.
- Regarding priority control, section 4.4.5.1 of TS 23.285 [14] describes conditions applied in both the network scheduled operation mode (mode3) and UE autonomous resources selection mode (mode4). It also described the additional conditions for mode 3, and additional conditions for mode 4 respectively. The PPPP (ProSe Per-Packet Priority) [17] 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 if so-called "mapping" (e.g., linking PPPP priority 1 to LTE QCI (See Section 1.2.1.) 1 or 2) is not standardized, it will be a future operational issue.

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.
- Release 16 Introduction of some control from NR wide area communications to LTE V2X short range communications

1.3 5G and NR

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) [11]. 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. Various subcarrier spacing, low-latency resource allocations, and other standardization of flexible wireless interfaces and wireless performance requirements for high-frequencies are being adopted [18].

Wide area communication (V2N), which the terminal communicates via the mobile operator’s base station, and short range communication (V2V/V2I/V2P), which the terminals communicates directly without going through a mobile operator’s base station, are available in NR similar to LTE. Wide area communications of NR were standardized in Release 15, and short range communications of NR were standardized in Release 16.

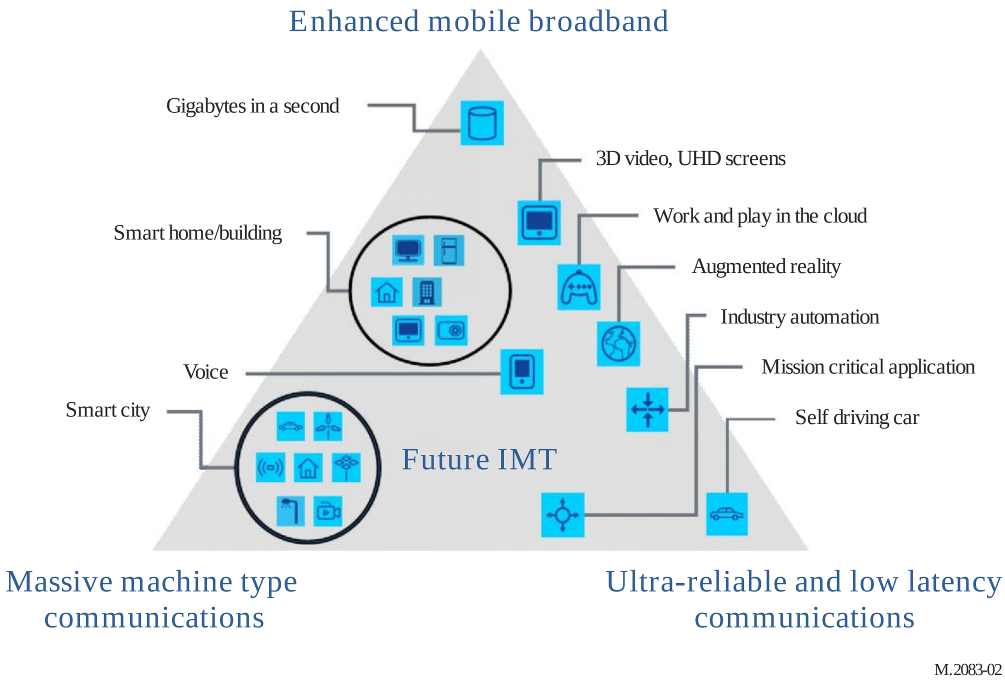

Figure 1.1 IMT for 2020 and beyond Use case (from Recommendation ITU-R M.2083-0)

1.3.1 Wide Area Communications (V2N)

For wide area communication (V2N), which the terminals communicate via the mobile operator's base station, the first specification for NR i.e. Release 15, supports two types of connection: non-standalone and standalone. Non-standalone provides an wireless communication area by combining NR and LTE and connects to a core network referred to as EPC (Enhanced Core Network), while standalone provides an communication area using NR only and connects to the 5G CN (5G Core Network). In outside the NR coverage area regardless of the non-standalone and standalone, the seamless connectivity to the network is provided as the terminals usually support LTE and earlier cellular wireless standards.

LTE uses the subcarrier spacing of 15 kHz and the basic wireless data allocation unit is 1ms. NR uses multiple subcarrier spacings described below and it enables to shorten the latency because basic wireless data allocation unit is shortened.

The basic wireless data allocation unit is 1 ms in subcarrier spacing of 15 kHz
The basic wireless data allocation unit is 0.5 ms in subcarrier spacing of 30 kHz
The basic wireless data allocation unit is 0.25 ms in subcarrier spacing of 60 kHz
The basic wireless data allocation unit is 0.225 ms in subcarrier spacing of 120 kHz

The shorter latency can be also obtained without changing subcarrier spacing by symbol level allocation in addition to the allocation using the basic wireless data allocation unit. The decoding results notification by symbol level indication shorten the delay for the retransmissions. With these latency reduction techniques, basic function of Ultra-Reliable and Low Latency Communications (URLLC) was achieved in Release 15, and the reliability and the latency were further advanced in Release 16.

Release 16 specification can achieve reliability of 99.999% and the communication latency of about 0.5 to 1 ms for the use case such as remote driving, factory automation and AR/VR [19], [20], [21]. In remote driving, 3GPP standardization assumed the requirement of end-to-end latency of 5 ms, reliability of 99.999%, and data speeds of 25 Mbps for uplink and 1 Mbps for downlink [21]. These requirements are achieved by the functions including 1) flexible and frequent downlink and uplink physical layer control signals, 2) flexibility of the repetition of uplink transmissions, 3) prioritization at the physical layer, 4) the transmission cancellation function to protect the other terminal's priority transmission, and 5) extension of the transmission without physical layer control signal. Prioritization at the physical layer means the terminal is informed of two levels notification of the physical layer priority and the terminal cancels the low priority transmission depending on the situations.

Services that can be achieved with LTE Uu are fundamentally all covered in NR, but multicast has not been standardized in Release 15 and Release 16, and plans are to be standardized in Release 17. NR terminals supporting earlier standards including LTE and the connectivity to networks in areas that do not support NR is possible by these earlier standards including LTE. The control by the base stations according to terminal capacity enables to add new functions such as those in Release 16 while ensuring coexistence in networks. For the NR subcarrier spacing of 15 kHz, dynamic spectrum sharing (DSS), which can dynamically share wireless resources with LTE according to the traffic volume, is specified.

General rule is the NR terminal has four receiver antennas, but onboard terminals embedded in vehicles that are permanently connected to an external antenna is allowed to have only two receiver antennas.

1.3.2 Short Range Communications (V2V/V2I/V2P)

Short range communications based on NR whereby terminals communicate directly with each other without going through a base station of the mobile operator were standardized in Release 16 [22], [23], [24], [25].

- Compared to wide area communications through a base station, the communication range is limited, but communication is possible even outside the base station area. Compared to wide area communication using URLLC, the minimum latency in the wireless segment is relatively long, but compared to short range communication using LTE, the minimum latency in the wireless segment is shorter thanks to the use of high subcarrier spacing such as 30 kHz and reliable thanks to the feedback to the sender of the decoding result. The terminals are required to equip the specific short range V2X function compared with the terminal support only wide area communications.
- It is not a replacement for LTE V2X, but it is standardized as a complement to LTE V2X for more advanced use cases. However, this does not mean that basic use cases cannot be supported. Which technologies are to be used for which use cases is a decision of the regional standards bodies and the ecosystem of automobile industry of each country.
- Similar to LTE based short range communications, the existence of SIM is not essential, and communication is possible without a contract with a mobile operator. This means that terminals with the different contracts of wide area communications mobile operators can communicate directly by using shared frequencies.
- The system design is optimized for low-latency of packet size from several hundred to 10K bytes.
- The system design is more optimized for aperiodic transmission compared with LTE-V2X.
- The same wireless resources can be shared among broadcast, groupcast, and unicast (one-to-one communications). Notification of decoding results in the physical layer (HARQ feedback) is supported for groupcast and unicast. In addition, two layer MIMO operation and the reporting of the wireless channel status to the sender known as CQI/RI are supported for unicast.
- For groupcast, two types of group formation method are supported: one is to form groups by approaching to a certain distance and its use case is primarily sensor sharing. The other is to form groups in the application layer and its use case is primarily platooning.
- Similar to NR wide area communications, subcarrier spacing of 15 kHz, 30 kHz, 60 kHz, and 120 kHz are supported, and the specifications also cover millimeter wave communications, but there is no optimization specific to millimeter wave. Also, the performance has not been specified with millimeter wave operation.
- Although how to both wide area communication functions and short range communication functions are realized in the terminal depends on the terminal or the chipset, the specifications require that the wide area communication functions and short range communication functions operate independently except in cases where the frequencies used for wide area communications and short range communications are close to each other. In cases where independent operation would be difficult, prioritization may be applied to wide area communication functions or short range communication functions.
- In network scheduled operation mode (mode 1), the network centrally controls the allocation of wireless resources. In autonomous resources selection mode (mode 2), each terminal independently allocates wireless resources.
- Priority control and congestion control are standardized. However, even if priority control applies, it does not guarantee communications performance.

1.3.3 Trends in Standardization

The first version of of NR were specified in Release 15 in June 2018. In Release 15, eMBB and URLLC were specified. In Release 16, which was completed in June 2020, various enhancements were made such as improving the reliability of URLLC including use cases for remote driving and specifications for inter-vehicle communications based on NR. Release 17 standardization began in May 2020. Under Release 17, NR short-range communications will include low power consumption to support VRUs (vulnerable road users) such as pedestrians.

1.3.4 Current Status of Frequencies

1.3.4.1 Exclusive Frequencies for ITS

1.3.4.1.1 United States

In the United States, the ITS band, 5850 MHz – 5925 MHz, using DSRC technology was allocated in 1999, and in December 2019, the FCC made a proposal to change the ITS band by reducing it to 30 MHz (20 MHz for LTE-V2X and the remaining 10 MHz for LTE-V2X or DSRC. On November 20, 2020, the 1st R&O (Report and Order [26] was issued to make 5895 MHz – 5925 MHz the ITS band using C-V2X (LTE-V2X/NR-V2X) and allocate the 5850 MHz – 5895 MHz band as an unlicensed band. It is required that the DSRC that has been used until now be shifted to C-V2X after a certain period. The transition period and method will be subject to further investigation in the future.

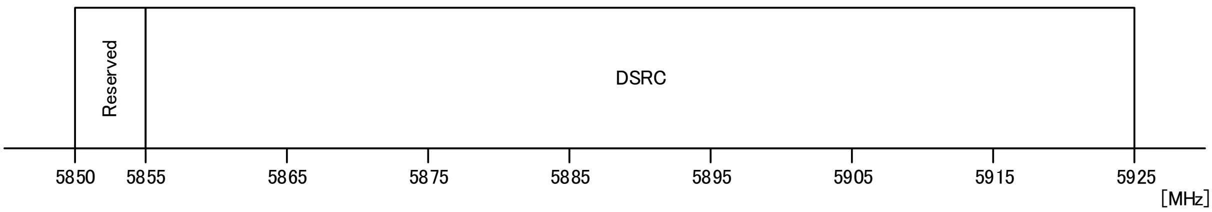

Figure 1.2 Original Allocation of DSRC Frequencies in the United States

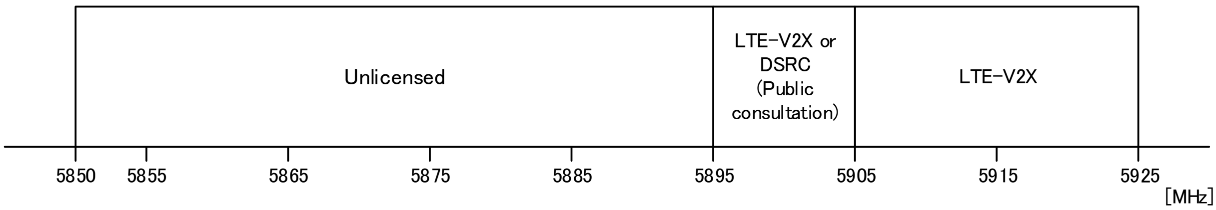

Figure 1.3 Proposal for Change Made by the FCC in December 2019

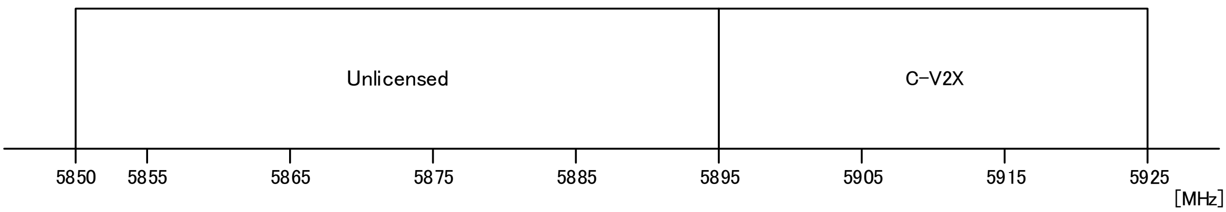

Figure 1.4 November 2020 FCC R&O

1.3.4.1.2 Europe

In Europe, the system relating to frequencies for ITS was revised in 2020, including the addition of frequencies for Urban Rail. The technologies used are not specified by the regulation (technology neutral), but the purposes of use are specified for each band.

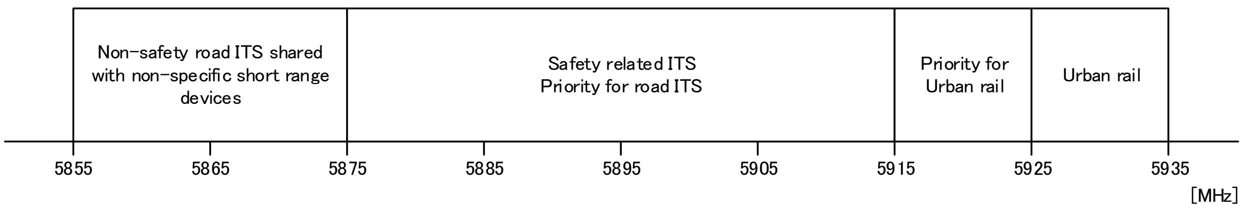

Figure 1.5 Allocation of ITS Frequencies in Europe

The 5855 MHz – 5875 MHz band was allocated to non-safety ITS, the 5875 MHz – 5815 MHz band was allocated to ITS for safety, and the 5815 MHz – 5835 MHz band was allocated to ITS for Urban Rail.

1.3.4.1.3 China

In China, the 5905 MHz – 5925 MHz band was allocated to LTE-V2X in 2018, and as of December 2020, multiple automakers are selling vehicles equipped with LTE-V2X [27], [28]. Development of ITS services for safe driving support is steadily progressing.

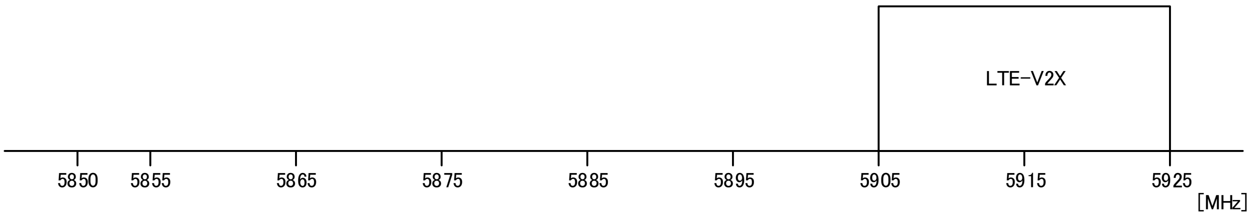

Figure 1.6 Frequencies for V2X in China

1.3.4.1.4 South Korea, Singapore, Australia, Canada, and Brazil

The 5855 MHz - 5925 MHz band is allocated to ITS.

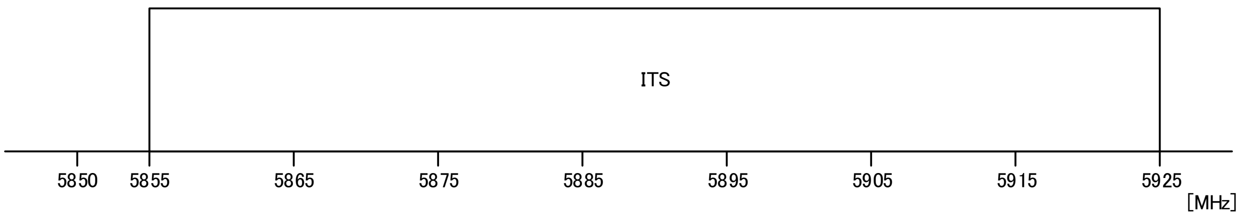

Figure 1.7 ITS Frequencies for V2X in South Korea, Singapore, Australia, Canada, and Brazil

In South Korea, allocation was implemented in 2016, and discussions concerning technologies that use that band are currently ongoing.

1.3.4.1.5 Japan

In Japan, the 755.5 MHz – 765.5 MHz band has been allocated exclusively to ITS, and ITS Connect driving support systems using road-to-vehicle and inter-vehicle communications have been in operation since 2015. In addition, the 5.8 GHz band (5770 MHz – 5850 MHz) is used for ETC for collecting tolls on toll roads and so on and the provision of traffic congestion information, safe driving support, guidance during emergencies, and other information services using ITS spots based on ETC 2.0 [29].

The Frequency Reorganization Action Plan of the Ministry of Internal Affairs and Communications announced in May 2020 (FY 2020 revised version) and the FY 2020 second revised version announced in November state that investigations into allocation of the 5.9 GHz bans will be conducted. Below is an excerpt of the relevant section.

Based on the progress and importance of automatic driving systems (including safe driving support), a study is being carried out, which will finish by the end of FY 2021, into the technical conditions for frequency sharing with needed existing wireless systems, for example when introducing V2X[3] communications, and with consideration for existing wireless systems on frequency bands being studied internationally (5.9 GHz band), in addition to the existing ITS frequency bands (760 MHz band, etc.,). In addition, based on the results of these studies, in cases where V2X communications are to be introduced on the same frequency band, there is a goal to allocate frequencies to V2X in FY 2023 after the necessary frequency bandwidth has been secured by migrating existing wireless systems, etc. [30].

[3] This V2X is a general terminology. Particular technology for V2X is not identified.

1.3.4.2 Frequencies for Wide Area Communications

1.3.4.2.1 5G Frequencies Around the World

With respect to the frequencies (licensed spectrum) newly assigned to carriers for 5G, both the frequency band below 6 GHz and the millimeter wave bands are assigned in different countries and regions, as shown in Table 1.2.

Table 1.2 5G Frequencies Around the World (including planned allocations)

Country/Region	Frequency Band
United States	600 MHz (FDD) 2.5 GHz, 3.9 GHz (TDD) 25 GHz, 28 GHz, 39 GHz (TDD)
Canada	600 MHz (FDD) 3.6 GHz (TDD) 27 GHz, 39 GHz (TDD)
Europe	700 MHz (FDD) 3.6 GHz (TDD) 26 GHz (TDD)
United Kingdom	700 MHz (FDD) 3.6 GHz (TDD) 26 GHz (TDD)
Germany	700 MHz (FDD) 3.6 GHz (TDD) 26 GHz (TDD)
France	700 MHz (FDD) 3.6 GHz (TDD) 26 GHz (TDD)
Italy	700 MHz (FDD) 3.7 GHz (TDD) 27 GHz (TDD)
China	700 MHz (FDD) 2.5 GHz, 3.4 GHz, 4.9 GHz (TDD)
South Korea	700 MHz, 800 MHz (FDD) 2.3 GHz (TDD), 3.5 GHz, 3.8 GHz (TDD) 28 GHz (TDD)
India	700 MHz (FDD) 3.5 GHz (TDD)
Australia	3.5 GHz (TDD) 26 GHz, 39 GHz (TDD)

1.3.4.2.2 Frequencies Allocated to 5G in Japan

In Japan, 5G frequencies have been allocated to four mobile network operators, and development of systems for allowing 5G operation in existing 4G frequencies has been completed. Table 1.3 shows the new allocation of frequency bands to each mobile phone carrier for 5G.

Table 1.3 5G Frequencies Newly Allocated in Japan

Mobile Phone Carrier	Allocated Frequencies
NTT Docomo	3.6 – 3.7 GHz, 4.5 – 4.6 GHz (TDD) 27.4 – 27.8 GHz (TDD)
KDDI	3.7 – 3.8 GHz, 4.0 – 4.1 GHz (TDD) 27.8 – 28.2 GHz (TDD)
SoftBank	3.9 – 4.0 GHz (TDD) 29.1 – 29.5 GHz (TDD)
Rakuten	3.8 – 3.9 GHz (TDD) 27.0 – 27.4 GHz (TDD)

In Japan, other frequencies have been allocated for local 5G use, but wide area use is not possible, so they are omitted here.

1.3.4.2.3 Frequency Bands for 4G

Communications carriers have been allocated the frequency band at 6 GHz and below for some time in various countries and regions, as shown in Table 1.4.

Table 1.4 4G Frequency Bands Around the World

Country/Region	Frequency Band
United States, Canada	600/700/850 MHz(FDD) 1700/1900 MHz (FDD) 2300 MHz, 2600 MHz (FDD/TDD) 2500 MHz (TDD)
Europe	450/800/900 MHz (FDD) 1800/2100 (FDD) 2600 MHz (TDD)
China	800/1800/2100 MHz (FDD) 1900/2300/2500/2600 MHz (TDD)
South Korea	850/900 MHz (FDD) 1800/2100/2600 MHz (FDD)
Southeast Asia	700/850/900 MHz (FDD) 1800/2100/2600 (FDD) 2300 MHz (TDD)
Australia	700/850/900 MHz (FDD) 1800/2100/2600 MHz (FDD) 2300 MHz (TDD)
India	850/1800 MHz (FDD) 2300 MHz (TDD)
Middle East, Africa	800/1800 MHz (FDD) 2300 MHz (TDD) 2600 MHz (FDD/TDD)
Japan	700/850/900 MHz (FDD) 1500/1800/2100 MHz (FDD) 2500/3500 MHz (TDD)

Chapter 2 Use Case Expected for Communications and Their Roles

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.

2.1 Selection of Use Case Examples Focusing on Information update interval

1) The focus is on the update interval 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 [31] (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 interval (cells in Table 2.2 are colored according to the color scheme in Figure 2.1).

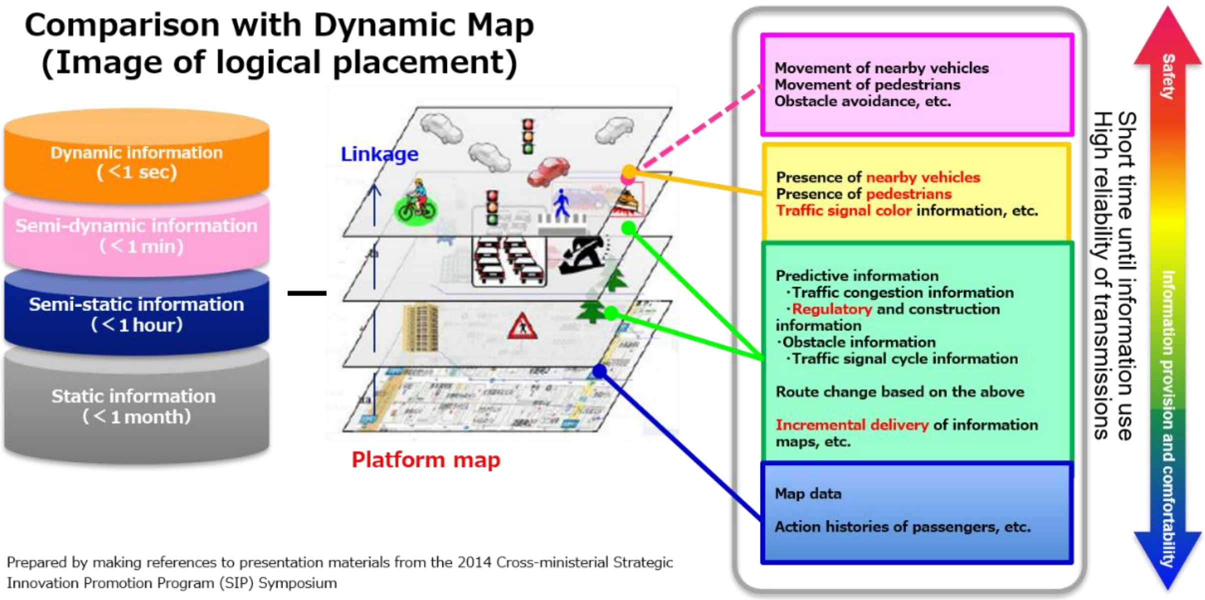

Figure 2.1 Image of Comparison of Handled Data and Dynamic Map.

Table 2.2 Organization of Use Case Examples

Information update interval		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 communications can be used with
		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	Safety, traffic	Information provision	Vehicle avoidance support (4)	General road	

		vehicle	facilitation				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, 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.

2.1.1 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. In cases where there are existing systems, it will be necessary to discuss use taking into consideration compatibility with the new system, costs, vehicle and infrastructure life cycles, ensuring that there are no new effects (from the perspectives of services, interference, etc.), and so on.

On the other hand, if the required reliability is higher than that provided by already deployed ITS, there is a possibility that achieving the feature of LTE of high receiver sensitivity compared to other communications protocols will be effective. In addition, LTE has a high degree of freedom in setting parameters, so it is necessary to make appropriate settings; related materials are described in A.3. In Japan, the 5.9 GHz band is being considered as a new frequency using multiple communication methods such as cellular V2X and so on, but the 5.9 GHz band has higher propagation loss than the 760 MHz band, and it is necessary to consider the conditions of coexistence with adjacent systems.

2.1.2 Use case 2: Intersection passage support/Dilemma zone avoidance/[4]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[5]), 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) [34].

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.

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[4] When a traffic signal changes from green to yellow, there is an area (the dilemma zone) where a vehicle cannot pass the stop line or stop without a problem during the time that the signal remains yellow [32].

[5] One round of signal displays is referred to as a cycle [33], and the order of colors within a determined range and the predetermined number of seconds for each color are referred to as cycle information.

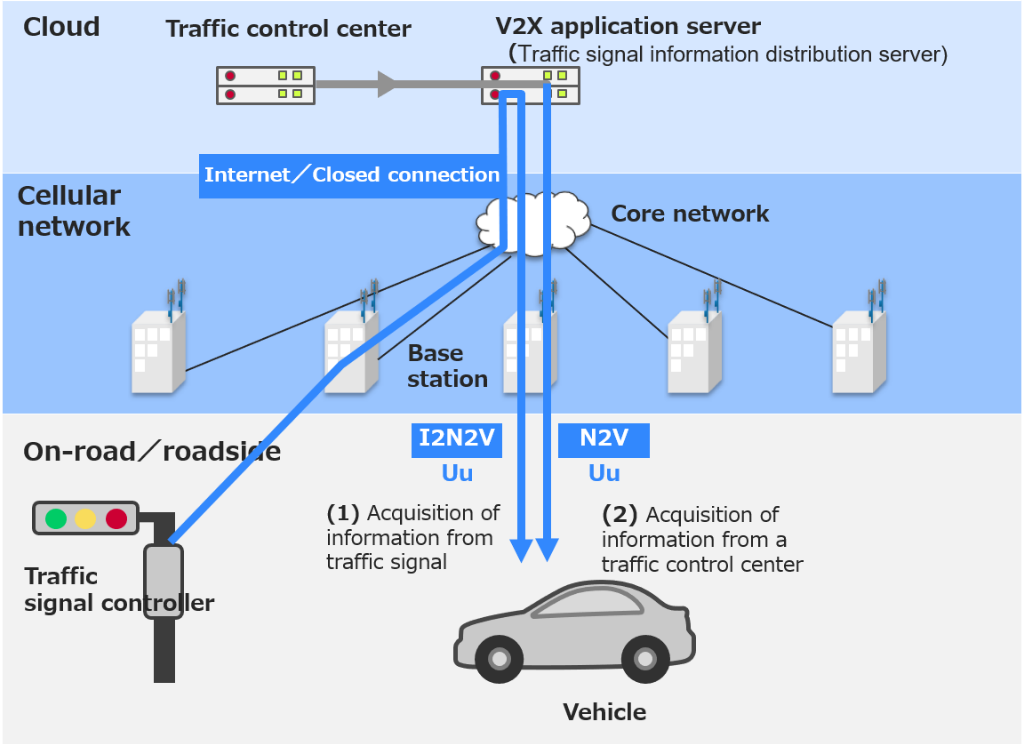


Figure 2.2 Examples of Traffic Signal Information Acquisition and Distribution

(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, [34] 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 [35], 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.

2.1.3 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.

2.1.4 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.

2.1.5 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.

2.2 Selection of Use Case Examples Also Using Combined Wide Area Communications

In this section, additional use case examples were selected and new items that will be necessary when using cellular V2X technology were arranged and considered based on the progress of research and development as well as policy discussions for the advancement of ITS and the creation of an automated driving society since version 1.0.

1) Scope of additional use cases

Investigation of SIP-adus, 3GPP, and 5GAA was taken into consideration as progress in research and development and policy discussions for the advancement of ITS and the creation of an automated driving society.

SIP-adus (The Cross-Ministerial Strategic Innovation Promotion Program-Innovation of Automated Driving for Universal Services)
Task Force on V2X Communication for Cooperative Driving Automation was launched. The TF has stated that “The TF aims to “envision the ideal situation of cooperative driving automation, create a road map toward achievement, and establish the policy on optimal communication protocols at the national level while taking into account the international standard” the goal of activity is to propose optimal communication protocols for cooperative driving automation and create a road map for communication protocols” [36]. In its FY 2019 activity report, the TF announced SIP Use Cases for Cooperative Driving Automation for investigating communications formats. These use cases are highly-feasible with a high degree of likelihood of practical implementation.

3GPP
In addition to the use cases anticipated in Releases 14 and 15, the use cases anticipated in Release 16 are organized as TR [37].

5GAA
A white paper describing use cases relating to cellular V2X, methodologies, and service level requirements was released [38], [39].

When confirming the use cases given in these investigations, it was determined that many of them overlap with the use cases that focus on the frequency of information updating in Chapter 2.1 (Figure 2.2). However, the communications means anticipated in these use cases is V2V, V2I, or V2N in many instances. In this TG, the focus is on combining short range communications and wide area communications (combined wide area communication) and use cases that exhibit high added value are investigated.

2) Benefits of combined wide area communication

The following benefits are expected from use of combined wide area communication.

(1) Creation of seamless services
When short range communications and wide area communications complement one another’s respective strengths and weaknesses, optimal information can continuously be provided according to the distance and time. For example, information provided by multiple vehicles using wide area communications and other information (sensors, maps, weather, etc.) can be analyzed on a server, and a wide scope or more detailed information can be provided, although not in real time, and by using short range communications, urgent and real time information can be provided over a range of several hundred meters.

(2) Improvement of service feasibility
Service feasibility could be improved by sharing exchange of vehicle information, data, and so on, vehicle dentification and authentication, and security and other functions between short range communications and wide area communications.

When implementing actual services, communications will be added based on autonomous on-board sensors. This is because it is necessary to consider not just the relationship between short range communications and wide area communications, but also how to complement autonomous sensors.

3) Selection of combined wide area communications use cases

Use cases were investigated by making reference to investigation of SIP and so on and in light of the benefits of combined wide area communications. A portion of the use cases are indicated in Figure 2.4.

When selecting the use cases discussed in this chapter, the conditions were that using communications offered benefits over using means other than communications and combined wide area communications can be expected in order to solve problems at the target scenes. In contrast, if the problem in a target scene is suitable for addressing by means other than communications or by existing services or if the problems other than communications are significant and the penetration rate of the required connected cars is high, then the use case was not selected. Use cases that were not selected are shown in attachment A.4.

The following five use cases were selected.

(1) Vehicle group presence information near a highway exit
(2) Information concerning road conditions requiring attention
(3) Fast Emergency Vehicle Preemption Taking into Consideration Emergency Vehicle Routes
(4) Recording and notification service of accident site conditions
(5) Platooning security, certification, and billing

The use formats and issues considered for these five use cases are as follows.

No	Anticipated Use Case	Location	Examples of Handled information	Main Information Users, Use Level	Beneficiaries	Benefits
1	Support for exiting a highway using information on platoons near highway exits	Highways	Wide area: Approximate information on the presence of platoons (presence of platoons to consider near an exit) Short range: Real-time information on platoons (position, speed, platoon vehicle identification, etc.)	Provision of information to general vehicles (non-platooned)/Warnings	General vehicles Platoons	Seamless service provision
2	Provision of information on road hazards	General roads/ Highways	Wide area: Specific road status using big data Short range: Real-time information on road abnormalities detected by vehicles	Provision of information to general vehicles	All vehicles (including vehicles that provided information)	Seamless service provision
3	Merging support using mapping and coordination control of merging vehicles and vehicles traveling in the main lane	General roads/ Highways	Wide area: Presence information (position, speed) of merging/main lane vehicles, control instructions to vehicles in the main lane (distant) Short range: Control instructions for merging vehicles and vehicles in the main lane (near the site of the merge)	Control of general vehicles	All vehicles	Seamless service provision
4	Notification of the presence of pedestrians who may suddenly enter the road	General roads	Wide area: Approximate information on the presence of pedestrians Short range: Real-time information on pedestrians (position, images)	Provision of information to general vehicles	All vehicles	Seamless service provision
5	Determination of the presence of stopped vehicles to prevent sudden braking	General roads	Wide area: Information on nearby vehicles (position, speed, route), signal control information, traffic congestion/convoy prediction information Short range: Real-time information on vehicles that braked suddenly	Provision of information to general vehicles	All vehicles	Seamless service provision
6	Fast Emergency Vehicle Preemption Taking into Consideration Emergency Vehicle Routes	General roads	Wide area: Emergency vehicle route information Short range: Emergency vehicle information (position, authentication IT, directional signals, etc.)	Prefectural police traffic control	Emergency vehicles General vehicles	Enhancement of service feasibility Seamless service provision
7	Accident site situation recording and reporting service	General roads/ Highways	Wide area: Images and videos of accident site Short range: Information on vehicles involved in an accident	Notification to and recording by vehicles in the vicinity of an accident	Vehicles involved in an accident Police and fire Insurers, etc.	Enhancement of service feasibility Seamless service provision
8	Re-formation when a platoon is divided	Highways	Wide area: Information on each divided platoon (position, speed), planned site for re-formation Short range: Information necessary for platoon re-formation (identification of other members, authentication, position, acceleration, order, etc.)	Provision of information to vehicles participating in a platoon	Platoons	Enhancement of service feasibility
9	Platooning security, authentication, billing	Highways	Wide area: Vehicle inspection status inquiry and verification, billing information Short range: Information necessary for forming a platoon (identification of other members, position, acceleration, order, etc.), verification of validity of billing information	Authentication of vehicles participating in a platoon, billing	Platoons	Enhancement of service feasibility

Figure 2.4 Examples of Combined Wide Area Communications Use Cases

2.2.1 Use case 1: Vehicle Group Presence Information near a Highway Exit

Description

Platooning on highways, which can be expected to reduce the burdens on truck drivers and improve fuel efficiency, is being investigated. During platooning, large vehicles are linked over relatively short distances using onboard autonomous sensors, short range communications, and so on, and when a platooning vehicle group travels near the exit of a highway, it is possible that it would be difficult for nearby vehicles traveling in the area to exit (Figure 2.5) or that nearby vehicles will change lanes to between the platooning vehicles, dividing the platoon (Figure 2.6). This could occur when nearby vehicles try to drive parallel to or pass a platoon without being aware of its presence. If a platoon is broken up, it may be difficult to restore depending on the traffic conditions. It is also possible that accidents could occur if other vehicles force their way into a platoon. Therefore, by notifying nearby vehicles about the presence of platooning vehicles near an exit, a mechanism to encourage nearby vehicles to change lanes in advance and not to pass the platooning vehicles may be possible (Figure 2.7).

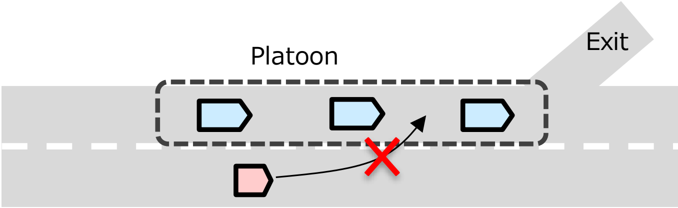


Figure 2.5 Situation When Nearby Vehicles Have Difficulty Changing Lanes When a Platoon Is Near an Exit

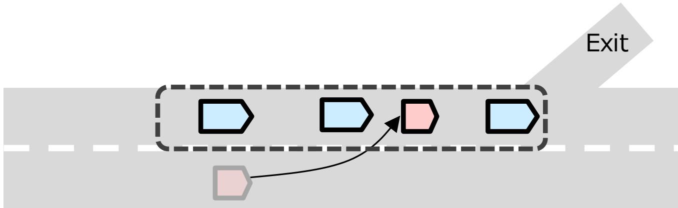


Figure 2.6 Breaking into a Platoon When a Platoon Is Near an Exit

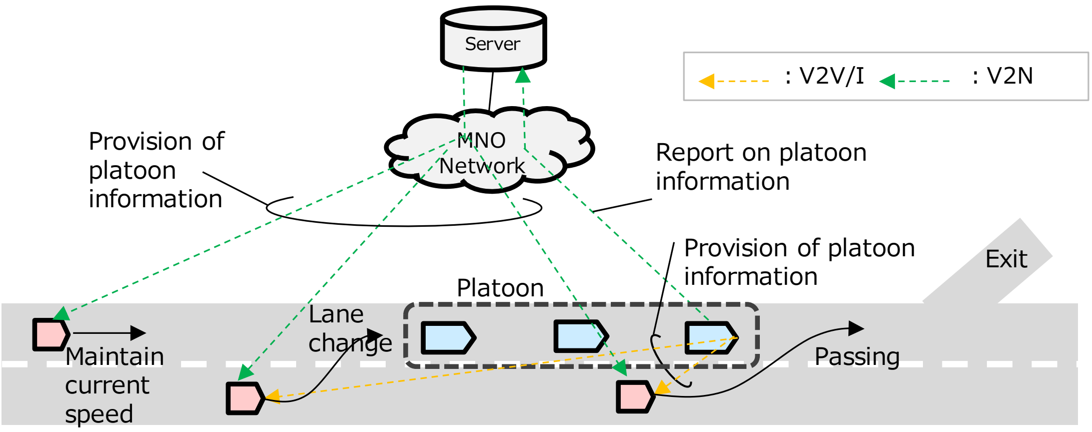


Figure 2.7 Notification of Platooning Vehicles Using V2V and V2N

If communication is not used, one possible method of notification of the presence of platooning vehicles would be electric signboard, but the amount of information that can be displayed is limited, and installation sites are limited, so it would be difficult to obtain accurate information about the size and location of groups of platooning vehicles in real time. If communication is used, periodically distributing information about platoons to nearby vehicles would enable nearby vehicles to learn of the size and location of groups of platooning vehicles. This information could be used to adjust the timing of passing a platoon and changing lanes as well as vehicle speed, and this can be expected to contribute to driving in accordance with driving plans to facilitate overall traffic flows.

It is expected that both short range communications (V2V) and wide area communications (V2N) would be used. With V2V, it is possible to notify vehicles within a distance of several hundred meters from the platooning vehicle group with real time vehicle group information, to identify the last vehicle in the group, and to provide notice that the platoon should not be passed. In addition, if V2N is also used, by determining on a server the position of platooning, notice of the presence of the platoon can be provided to nearby vehicles within several hundred meters to several kilometers of the platoon, as indicated in Figure 2.7. As a result, it can be expected to be effective even in situations where it is difficult to recognize the platooning vehicles because other vehicles are lined up behind the platoon as the volume of traffic increases, as shown in Figure 2.8.

Performance
Since these are not urgent notices, it is expected that the latency performance of short range communications will be adequate within the range of several hundred meters from platooning vehicles. With regard to wide area communications, since notice will be provided to vehicles within a range of several hundred meters to several kilometers of the platooning vehicles, latency on the order of several seconds or even more can be permitted. It is necessary to consider handling and countermeasures in cases where performance requirements are not satisfied

(such as when there is communications congestion or a hardware or network failure). In the case of wide area communications, it is necessary to also consider responses relating to differences in the service areas of each mobile operator.

Standardization
It is necessary to investigate standardization of message formats, communications protocols, and so on for provision of this use case as well as testing and verification to ensure compatibility. With regard to the distribution of information using V2N, it is necessary to investigate methods of collecting, managing and distributing information on servers concerning the presence of platooning vehicles and guidelines on standardization of information distribution area categories. With regard to V2V, in the case where communication is carried out by PC5 rather than existing systems, as of January 2021, there are no frequency bands that can be used in Japan, and therefore, it will also be necessary to investigate frequency allocation. It will be necessary to create designs that take into consideration expansion of and coexistence with existing systems, flexibility for future expansion, and so on from the perspectives of both communication specifications and frequency bands. In addition, in the case where the combination of both V2V and V2N are used, it will be necessary to investigate countermeasures to coordinate the information distributed by each, handling by receiving vehicles in cases where inconsistencies occurred, and guidelines concerning vehicle operations such as coordination of vehicle speeds in cases where notice regarding the presence of groups of platooning vehicles is provided.

Handling of Legal Certification
It is expected that this use case will be reflected in automated driving control, and it is necessary to clarify to what extent vehicles and parts will be subject to certification and inspection, and if required, how to perform certification and inspection.

Security and Privacy
Guaranteeing the authenticity of information and responsibility for such guarantees will be important. In this use case, certification of vehicles that are the sources of provided information will be necessary. To prevent the distribution of information from unauthenticated organizations or falsified information, for example, it may be possible to embed an electronic signature in the distributed information and use secure connections between information providers, information distribution servers, and information receiving vehicles. It is also necessary to investigate issues of privacy arising from vehicle tracking for distribution control.

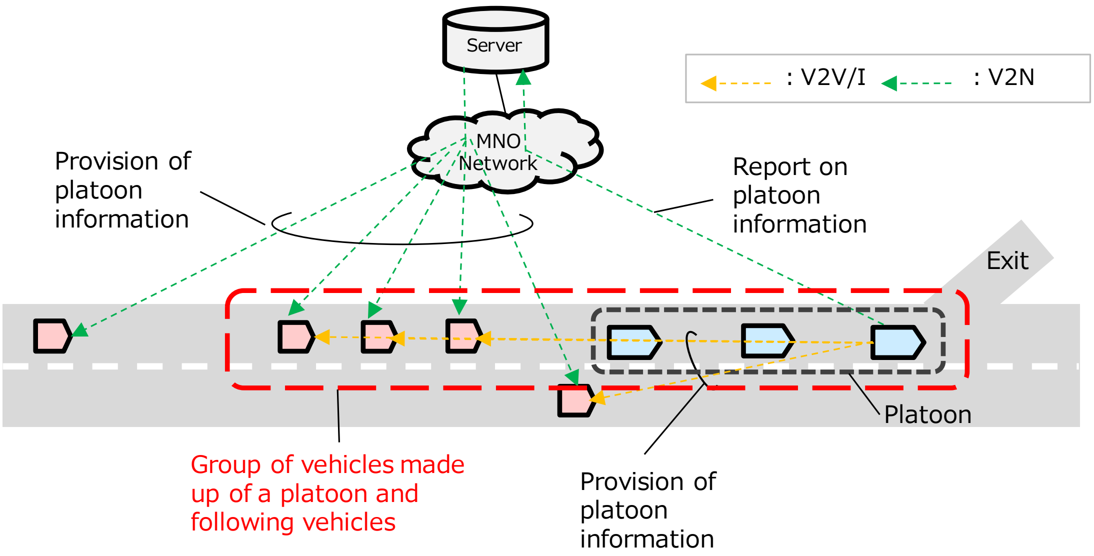


Figure 2.8 Lining Up of Nearby Vehicles Behind a Platoon

2.2.2 Use case 2: Information on Road Hazards

Description
In cases where there are dangerous conditions such as ice or falling objects on the road, if a driver or vehicle does not notice, the vehicle may skid or collide or operations such as sudden stopping or sudden steering may be necessary immediately before encountering such conditions, and there is a risk of collision with following or nearby vehicles.

If communication is not used, electric signboards and so on could be used to provide notice to vehicles in advance, but there are issues including difficulty detecting changes in conditions over the course of time and limited installation locations. Accordingly, dangerous road conditions can be detected by infrastructure sensors as well as cameras, sensors, and the operating status of stability control systems on vehicles driving in the dangerous area. By transmitting that information to other vehicles approaching the location in question using communication, a system that encourages drivers to pay attention, adjust speed in advance, and change routes would be possible.

It is expected that both short range communications (V2V/V2I) and wide area communications (V2N) would be used. It is anticipated that information will be provided to nearby vehicles through direct communication, information will be aggregated on a server for provision to more distant vehicles, and notice will be provided using wide range communications. With V2V/V2I, information can be provided in real time to vehicles within several hundred meters of the relevant location so that they can avoid the danger that they are approaching. On the other hand, V2N can be used for communications at distances of several hundred meters to several kilometers, and by also utilizing data other than that from vehicles such as temperature change forecasts, it will be possible to provide information over a wider range, providing sufficient margin for vehicles to select routes and adjust speed.

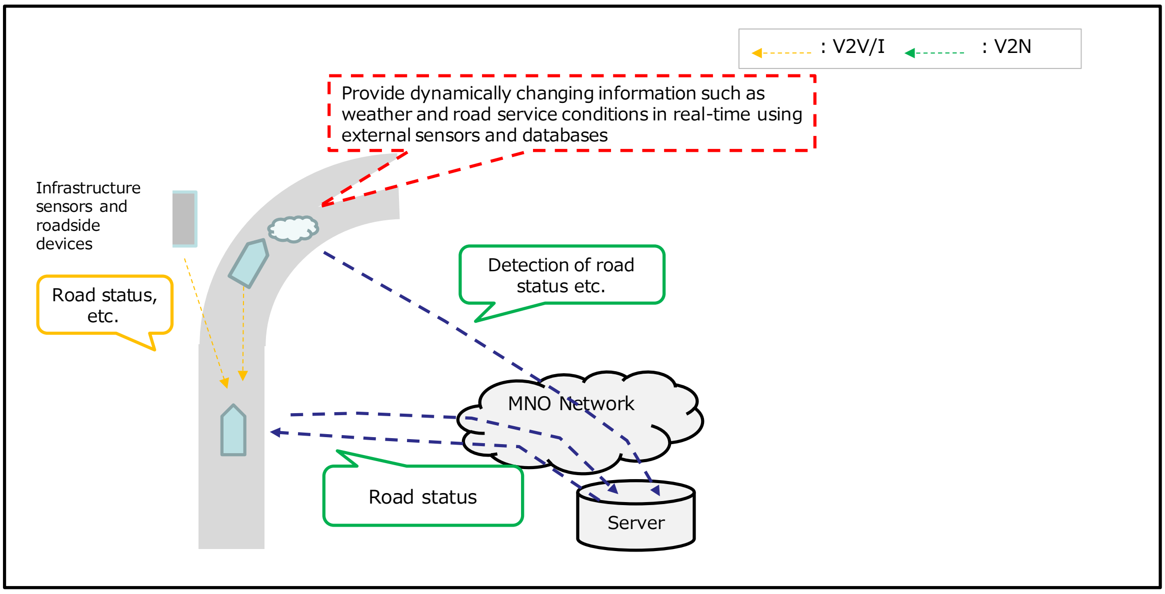


Figure 2.9 Overview of Information on Road Hazards

Performance
Information on ice, falling objects, and so on that is handled under this use case is not expected to change on the order of several seconds. In addition, since information distributed to the vicinity of the relevant location is covered by short range communications, it is assumed that vehicle route information will be delivered to vehicles sufficiently behind the subject location using wide area communications, so system latency of several seconds or more is acceptable. Therefore, based on the latency requirements and wide area requirements, it is expected that existing cellular services can be used for this use case.

Standardization
To provide this use case, standardization of message formats, communications protocols, and so on is necessary as well as investigation of tests and certification to ensure interconnectivity including sensors and vehicles. Also, it is necessary to develop guidelines on how to notify drivers concerning the provided information. Possible methods of detecting ice and falling objects include infrastructure cameras and temperature and freezing sensors and onboard cameras or operation of a stability control system to prevent skidding. In the case of wide area communications, it is anticipated that these types of infrastructure and vehicle information will be used with weather and road information acquired by servers to generate notification information to be provided to remote vehicles, but it is necessary to investigate how to assess events based on the information from each sensor and to take into consideration that there will be variations among manufacturers.

Security and Privacy
Guaranteeing the authenticity information and who has responsibility for doing so will be important. In this use case, authentication from the perspective of the agencies providing information and vehicles will be necessary. To prevent the distribution of information from unauthenticated organizations or falsified information, for example, it may be possible to embed an electronic signature in the distributed information and use secure connections between information providers, information distribution servers, and information receiving vehicles. It is also necessary to investigate issues of privacy arising from vehicle tracking for distribution control.

2.2.3 Use case 3: Fast Emergency Vehicle Preemption Taking into Consideration Emergency Vehicle Routes

Description
When an emergency vehicle travels to its destination, if there is traffic congestion as it approaches an intersection, there may not be sufficient space for general vehicles to give way even if they are aware of the presence of the emergency vehicle and there are instances when oncoming vehicles and vehicles in lanes at a right angle may have difficulty detecting the emergency vehicle, preventing the emergency vehicle from proceeding with priority through the intersection or its vicinity. Fast Emergency Vehicle Preemption Systems (FAST) and Public Transportation Priority Systems (PTPS), which have already been put into practical use, communicate with emergency vehicles and route buses using optical beacons to preferentially control the corresponding traffic signals at a point or in a line. By using V2N, a mechanism that periodically informs a traffic control center of the planned travel route of the emergency vehicle and the approximate current location, speed, and so on and more appropriately controls the traffic signals on that route would be possible (e.g., priority control including at intersections where turns will be made). Expanding the scope of priority control may result in significant impacts on general traffic flows, and therefore, considering the implementation of secure priority control measures to reduce the impact on traffic flows by allowing emergency vehicles to pass through intersections and their surrounding areas in a shorter time, V2I would confirm the presence of emergency vehicles in the vicinity of intersections along the route, change traffic signal turn arrows according to the intent of the emergency vehicle to turn (based on use of the directional signal and so on) at intersections where turns are planned, and determine in real time when the emergency vehicle passes through the intersection to terminate FAST control quickly. V2V/I2V could be used to encourage general vehicles in the vicinity to drive with an understanding of the route and presence of the emergency vehicle as well as the execution of FAST control.

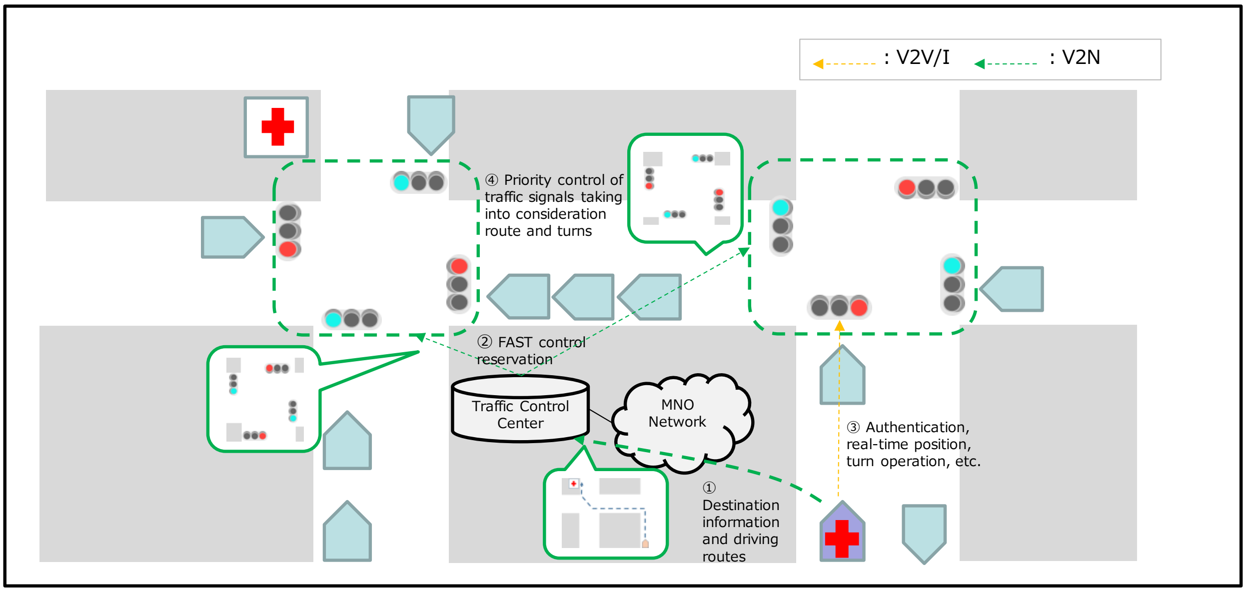


Figure 2.10 Overview of Fast Emergency Vehicle Preemption Taking into Consideration Driving Routes and Vehicle Information

Route Determination Methods
(1) Cases where the route is set by the vehicle
In cases where the route is calculated by the vehicle using FAST control, it is necessary to have information concerning intersections where FAST is supported, real-time traffic congestion information, and up to date map information, and it would be necessary to establish an operating system for distributing this information using wide area communications. In addition, it will be necessary to develop devices that can use this information to calculate the route on the vehicle side. It is also necessary to consider that updates of FAST-compatible intersection databases and calculation algorithms will be needed and that there may be variations among manufacturers.

(2) Cases where the route is set by a server
In cases where the route is calculated by a server, an environment that connects traffic control center and other servers will be needed so that the information necessary for calculating the route can be obtained. Vehicles will transmit information on destinations using wide area communications, and after the server calculates the route, the information can be transmitted to the vehicle and the traffic control center.

Performance
Wide area communication is used to transmit route information and general current position, and there is a possibility that latency on the order of several seconds can be tolerated. With regard to the range of service provision, it is necessary to cover the starting point of emergency travel (in the case of an ambulance, the site of the incident), and if the existing cellular network is used, it is also necessary to consider how to deal with the differences in service areas of each mobile operator. It is necessary to consider handling and countermeasures in cases where performance requirements are not satisfied (such as when there is communications congestion or a hardware or network failure). Depending on the wide area communication implementation method, it will also be necessary to consider the accuracy of location information.

Short range communication is used for security measures and communication of the intent to turn left or right, and it may be possible to tolerate latency on the order of several hundred ms, but it is necessary to design the system by taking into consideration not only the wireless section, but also the transmission latency on wired section and server processing time. It is necessary to consider handling and countermeasures in cases where performance requirements are not satisfied (such as when there is communications congestion or a hardware or network failure).

Standardization
To provide this use case, standardization of message formats, communications protocols, and so on is necessary for routes, authentication, and advanced signal control, standardization of the interface for connecting the networks of each mobile operator with traffic control centers, databases of FAST-compatible intersections, and so on as well as investigation of testing and authentication to ensure interconnectivity will be needed. Systems and organizations relating to operation, maintenance, management, and so on of these standards and tests are also needed.

Security and Privacy
Guaranteeing the authenticity information and who has responsibility for doing so will be important. To prevent the distribution of information from unauthenticated organizations or tampered information, ensuring security not only in communications but also in all phases of device manufacture, sale, and so on will be important.

2.2.4 Use case 4: Accident Site Status Recording and Reporting Service

Description
Cameras, sensors, and other devices have been installed to confirm the status of traffic at important intersections and at other sites, and with the proliferation of ADAS systems and automated driving vehicles, vehicles equipped with cameras or radar and other sensors will increase. This means that by using information from vehicle sensors, it will be possible to expand the scope of determination of the status of roads. If communication is not used, it will be possible to detect abnormalities within the detection area by using sensor information from one’s own vehicle, but it will not be possible to obtain information from outside the detection area. On the other hand, it will be possible to provide information on abnormal conditions to vehicles that are far from an accident site by collecting, analyzing, and distributing sensor information from other vehicles using communication. In addition, it will also be possible to provide information to vehicles that are not equipped with sensors for ADAS or automated driving but are equipped with communications devices (connected cars), and therefore, it will be possible for traffic to proceed smoothly past the site of an accident by providing notice over a wide range before the accident site. In other words, by using communications, if abnormal conditions that occur on roads, the location, causes, and so on can be identified by using communications and notification can be provided in a timely manner.

It is anticipated that the communications formats will be both short range communications (V2V) and wide area communications (V2N). With V2V, use cases where notice of information is provided to vehicles behind one’s own vehicle when an abnormal situation is detected or emergency braking is employed are anticipated. It is expected that this will be used as a trigger for information distribution and V2N information collection such as detecting the occurrence of an abnormal situation by surrounding vehicles that receive the notification information and determining which vehicle is in a positional relationship suitable for recording the situation. It is also expected that V2N will be used for both information collection and distribution. In the case of collection, collection by devices (servers) installed over a wide range of the network is possible. For example, by aggregating data on a high-performance server, more detailed image analysis will be possible, and this will enable identification of attributes such as the type and scale of the abnormal situation. In addition, by collecting information over a wide area, it will be possible to predict the occurrence of traffic congestion caused by incidents other than collisions such as falling objects or a parked vehicle.

In such cases, if the server determines that the likelihood of occurrence of an abnormal situation is high, it will collect information by directing infrastructure sensors and vehicles in the vicinity to gather information. By analyzing that information, it will be able to detect the occurrence of abnormal situations and their attributes with a higher degree of accuracy. Moreover, if V2N communication is used, information on the abnormal situation detected by a vehicle or the server can be distributed to appropriate recipients according to the attributes of that situation. For example, in cases where traffic congestion due to an abnormal situation is predicted, this information can be distributed via V2N to vehicles driving several kilometers before the site, and vehicles that receive that information can use it to a different route or take other measures. In addition, depending on the attributes of the abnormal situation, information can be provided to other relevant parties including police, fire departments, road managers, and insurers, etc.

For distributing information to related parties, in addition to distribution using fixed lines, distribution via V2N to mobile units (patrol cars, road management vehicles, etc.) is also anticipated.

Methods of Detecting Abnormal Situations
For this system, the methods of detecting the occurrence of abnormal situations are important. For this investigation, the following two detection methods are anticipated.

(1) Cases where determinations are made based on probe data from vehicles
Probe data collected from connected cars is analyzed, and situations that differ from the norm are detected by comparison to probe data during normal times at that time and location. If probe data from vehicles close to the occurrence of the abnormal situation is available, higher precision detection will be possible.

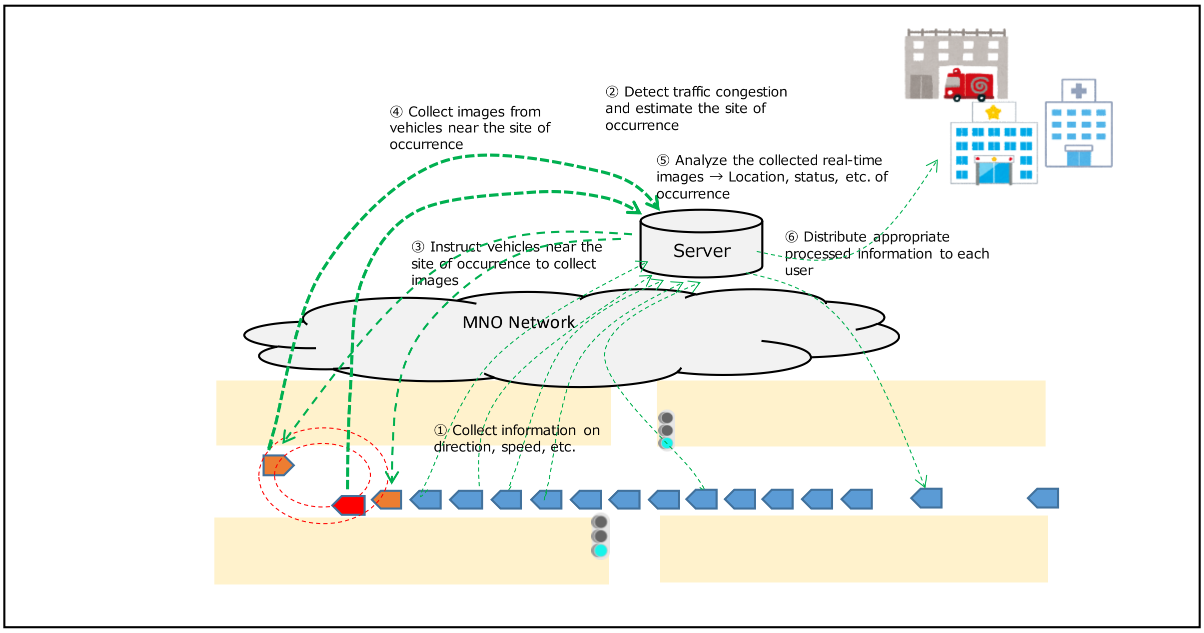


Figure 2.11 Example of Abnormality Detection Using Probe Data

(2) Cases where vehicle abnormal situation detection systems are used
Automated emergency notification systems (E-call) that use onboard sensors to detect air bag deployment and/or acceleration over a certain threshold and provide notice to a center and emergency electronic brake light (EEBL) systems that detect emergency braking and provide notice to nearby vehicles are already in practical use. By using this information to detect the occurrence of abnormal situations, it is possible to accurately detect position information. On the other hand, it is possible that traffic congestion caused by avoidance of falling objects on the road without emergency braking will not be recognized as abnormal.

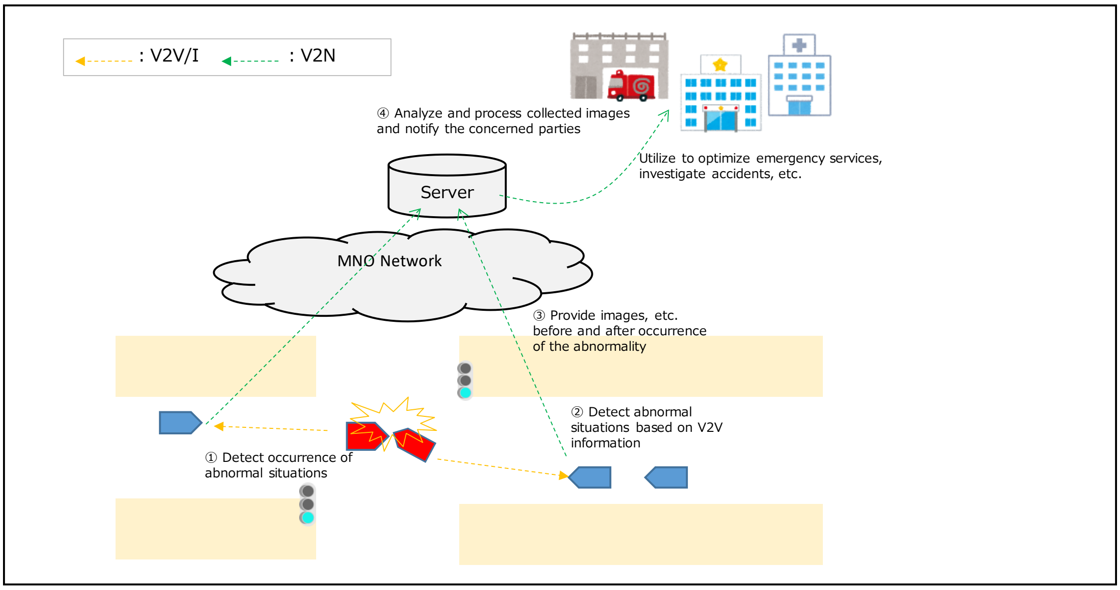


Figure 2.12 Example of Abnormality Detection Using V2V

Performance
EEBL and other such systems require low latency in cases where information concerning the occurrence of an abnormal situation is to be provided to nearby vehicles, but it may be possible to increase the permissible latency according to the distance from the vehicle receiving the information to the accident site. In cases where V2N is used to broadly collect and distribute information, the latency time can be defined individually according to the application.

In other words, in cases where notice of the occurrence of an accident is distributed with low latency, different latency times can be set in cases where detailed information on the results of analysis of information collected from the vicinity of the accident site and analyzed (accident cause, type, predicted effects, etc.). In addition, it is necessary to consider how to handle cases where performance requirements cannot be satisfied such as when there is communications congestion or a hardware or network failure, and in cases where V2N is used, how to deal with differences in the service areas of each mobile operator.

Standardization
In cases where vehicle probe data or data that is currently used for identification purposes such as E-call communications is used to detect the occurrence of accidents or traffic congestion, standardization of protocols and message formats to achieve that will be necessary.

In cases where information is collected from the site where an abnormal situation occurred in response to instructions from a server, it will be necessary to standardize the specifications of and formats data to be exchanged.

It will also be necessary to create mechanisms relating to communications in cases where there are both companies and public agencies (police, fire departments, road managers, insurers, etc.) that receive the results of analysis of collected information.

Security and Privacy
Guaranteeing the authenticity information and who has responsibility for doing so will be necessary, and therefore, when collecting information, it will be necessary to take measures such as imposing certain restrictions on information from unauthenticated users and organizations. When distributing information, it will also be necessary to take measures to prevent the distribution of information from unauthorized organizations.

In addition, enactment of legislation for using various applications (provision to police and insurers) that employ image data collected from infrastructure cameras and vehicles will be needed.

Other
It is anticipated that (1) analysis of vehicle probe data and (2) use of existing systems such as E-call and EEBL will be used to detect abnormal situations with this use case, but it will be necessary to create mechanisms for the shared use of this data and to create schemes for the installation and operation of data analysis servers. In addition, users of the provided information will incur costs for device installation and communications expenses. It is believed that widespread adoption of such a system will require the creation of business models that can maintain the motivation of participants that provide information and that collect, analyze, and distribute information.

2.2.5 Use case 5: Platooning Security, Authentication, and Billing

Description
Platooning requires only highly reliable vehicles participate in a platooning, where the high reliable means the performance of vehicle sensors, breaks, and automated driving programs are ensured by the assessment or inspection because the distances between vehicles is short and the behavior of the lead vehicle is closely followed by following vehicles. Also, it is anticipated that following vehicles has better fuel efficiency compared with the lead vehicle thanks to lower air resistance and therefore, mechanisms for equalizing transportation costs (exchange of billing information) among the vehicles participating in a platoon may lead to ensuring fairness among users. In such cases, it is anticipated that wide-area communication is used for authentication of participation in a platoon and billing information management, and short range communication is used for identification of platoon partners, reliable information such as position accuracy, following control, fuel efficiency improvement effects, calculation and verification of billing information, and so on.

Performance
Latency on the order of several seconds or even more may be sufficient for wide-area communication because the vehicle authentication for platoon participation and collection of billing information raised in this use case are unrelated to platoon driving operations. On the other hand, platooning may start or end at various locations, and consequently, these information exchange requires to cover a wide area. Based on the latency requirements and need for wide area communication, it is expected that existing cellular systems can be used. With respect to short range communication, there is a high need for real-time communication for identification of the lead vehicle and vehicle platooning control (it will depend on the implementing vehicle, but for example, on the order of a 100 ms cycle), and if vehicle platooning control is possible, the performance needed for such usage would be sufficient.

Standardization
In cases where platooning is performed by individual operating companies or specific application programs, there may be the possibility that standardization is not required as a competitive field. In cases where platooning is performed by different operating companies or different application programs, provision of this use case will require standardization of message formats, communication protocols, and so on as well as investigation of testing and authentication to ensure interconnectivity. It is necessary to investigate standardization and legislation concerning what kinds of conditions must be satisfied such as vehicle sensors, brakes, and automated driving programs as well as billing conditions for determining whether or not a vehicle is able to participate in platooning.

Security and Privacy
It is necessary to investigate the level of security and privacy that should be insured among the vehicles participating in a platooning. In cases where participation is limited to a single operating company or the like, more information can be shared, and in the case of platooning among arbitrary vehicles, it will be necessary to share information with greater consideration for security and privacy. With regard to vehicle authentication and billing in relation to platooning under this use case, in the case of wide area communication between vehicles and a server on a network, each vehicle and the server can communicate with each other by unicast to prevent interception by other vehicles, and security and privacy can be protected in the same way as ordinary cellular communications.

Chapter 2.2 Summary

In combined wide area communication use cases, compared to cases of using short range communication or wide area communication alone, it is expected that benefits such as improved quality of service from the seamless provision of services and improved service feasibility can be achieved.

The technical issues to be addressed to achieve such systems will require to address the issues of both short range communication and wide area communication and development of applications for their use together, and consequently, there are many issues. It may be possible to solve technical issues by creating designs that satisfy service requirements, conducting necessary verification, and embedding applications. On the other hand, combined use will result in a broader range of service related parties (parties who issue, analyze, and distribute information, beneficiaries, and so on), and as a result it may be difficult to create service systems and business models. In cases where the information providers and primary beneficiaries are not the same in particular, user acceptance and business aspects will be issues. In all cases, deliberation and investigation through close cooperation among the relevant parties will be essential.

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.

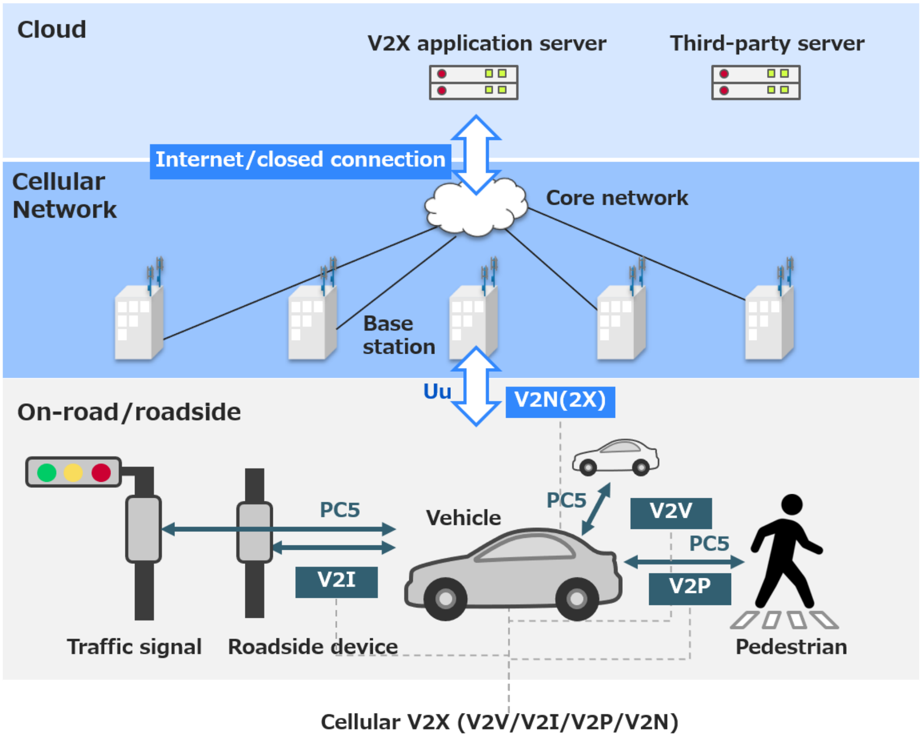


Figure 3.1 Overall Structure of Cellular V2X (re-posted)

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[6] 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.

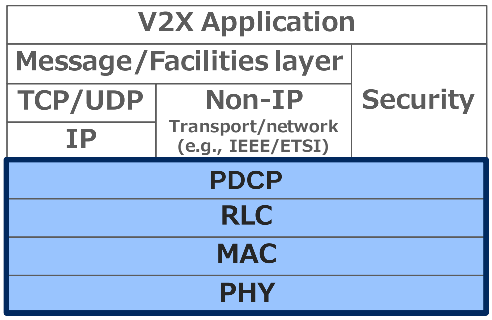


Figure 3.2 Short Range Communication Protocol Stack

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.

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

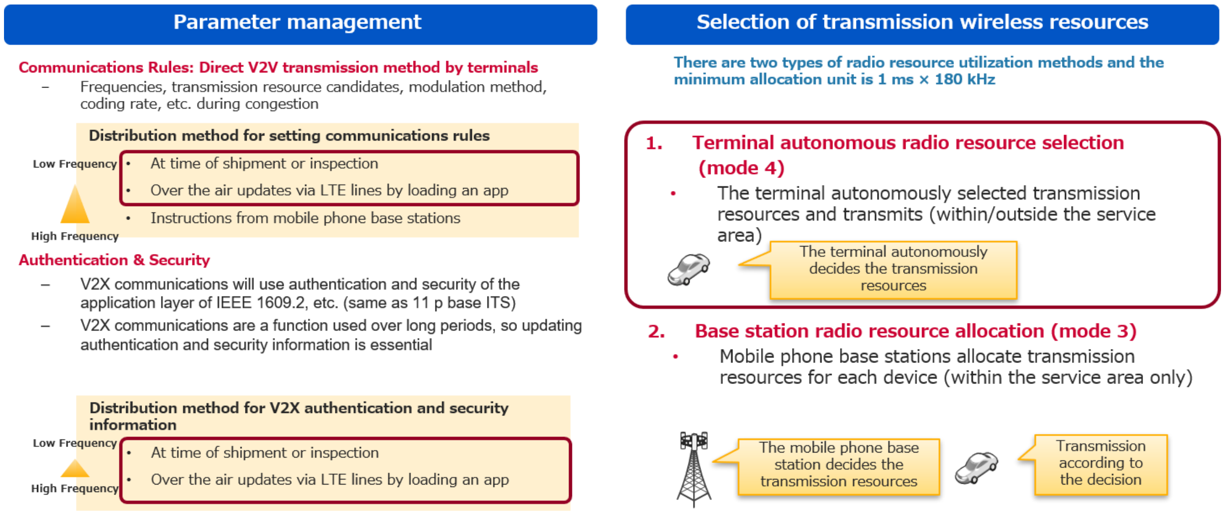


Figure 3.3 Types of Short Range Communication Operations

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 [40], 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 automated 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.

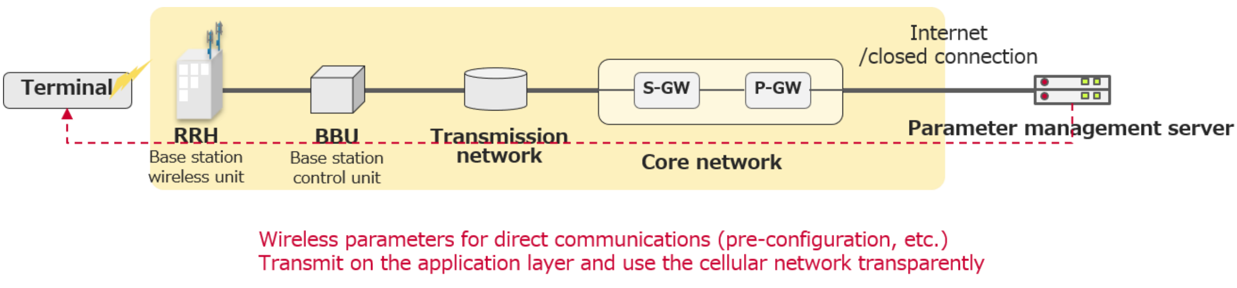


Figure 3.4 Distribution of Short Range Communication Parameters via Cellular Network

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 positioning 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 [41]. 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 [42] 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 [43] and [44].

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 [14]. 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.

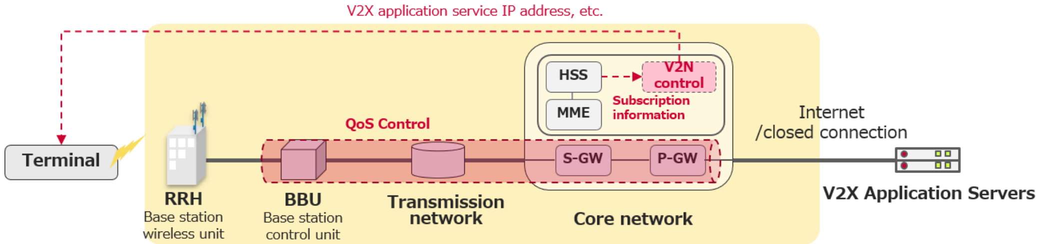


Figure 3.5 Example of a Cellular V2X System Architecture

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.

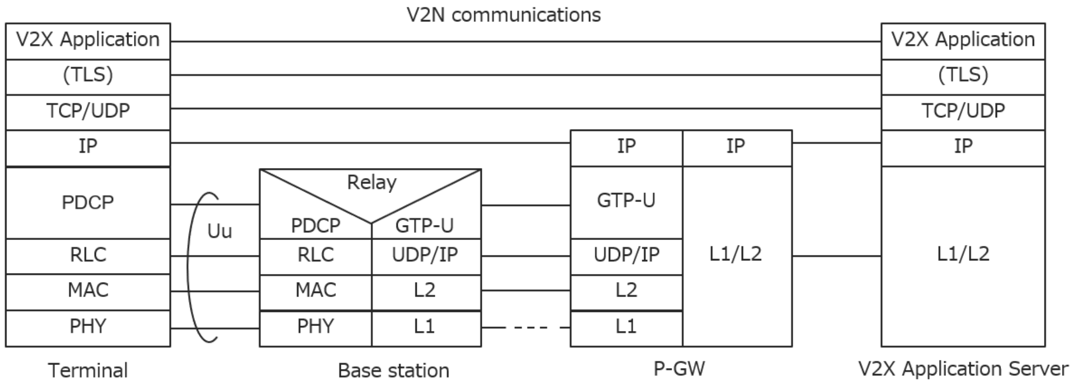


Figure 3.6 Example of the V2N Protocol Stack

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.

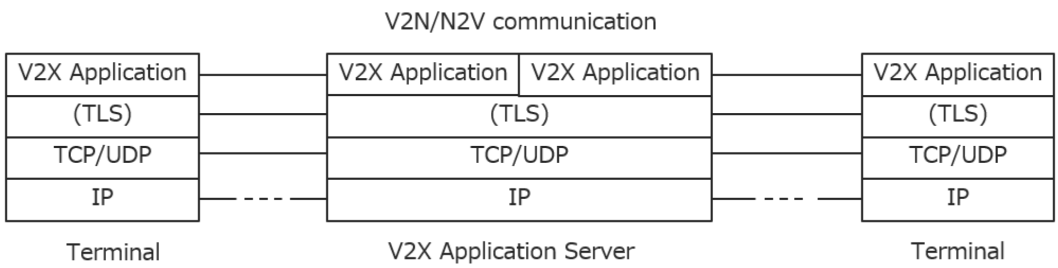


Figure 3.7 Example of the V2N2V Protocol Stack (Layers below IP Omitted)

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.

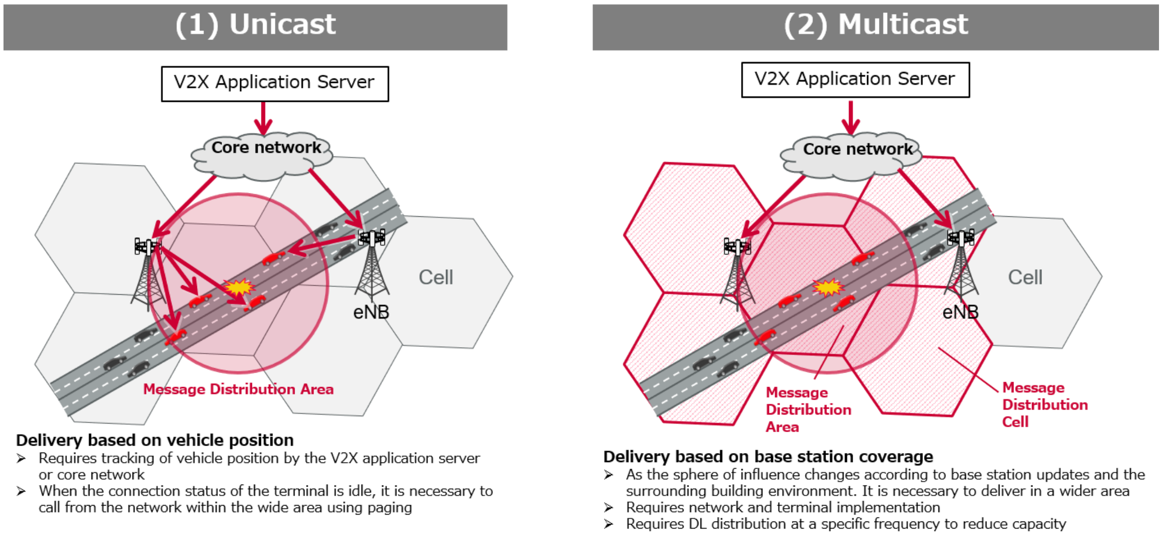


Figure 3.8 Geo-messaging in V2N DL Distribution

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 Figure 3.9. 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.

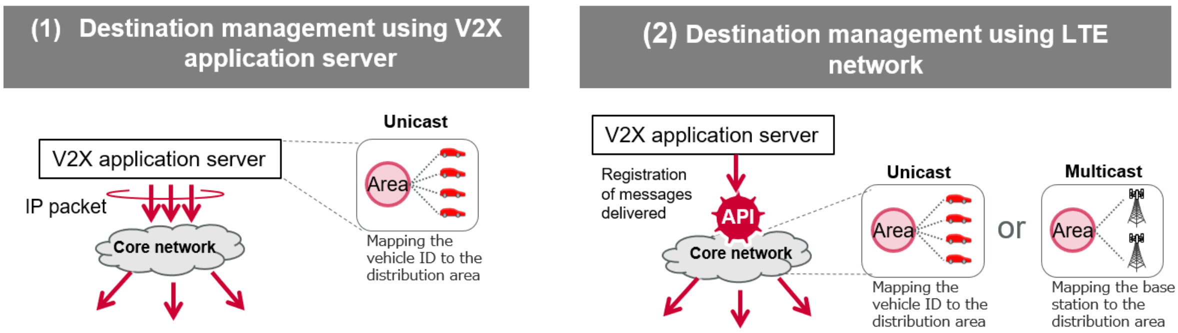


Figure 3.9 Example of Destination Management Function Allocation

3.3.4 Security

The 3GPP specifications support encryption on the PDCP layer for cellular communication part as security [45]. 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 [46]. 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 [47]. 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.

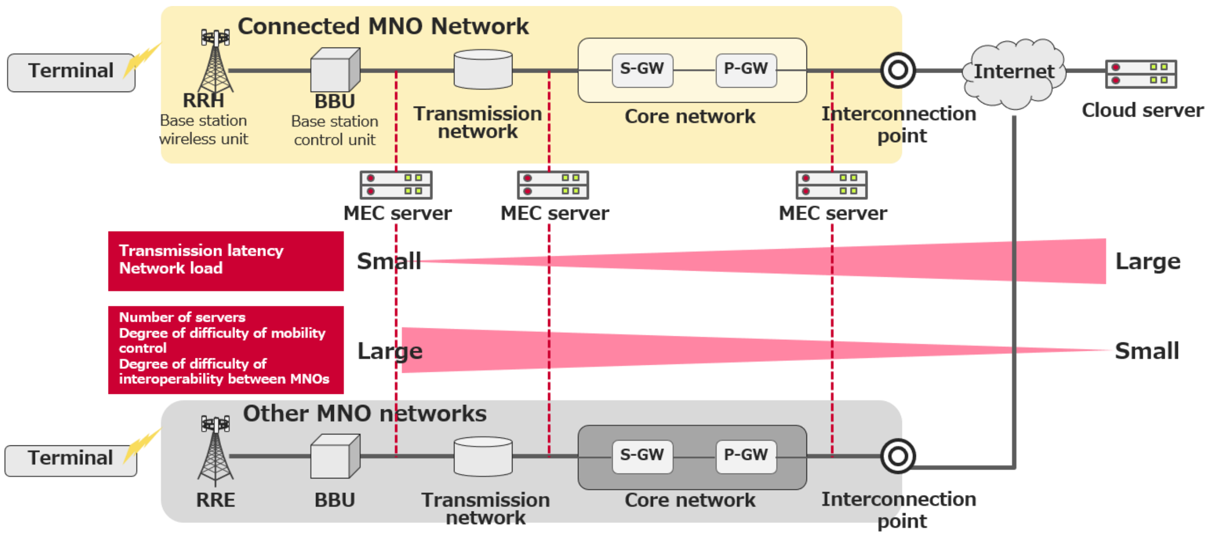


Figure 3.10 Example of MEC Server Physical Connection

In use cases where both short range communication (V2I) and wide area communication (V2N) are used, it will be necessary to investigate connection points between local servers connected to roadside units and individual MNO networks. Interconnection points ranging from sites close to base stations to cloud server formats are anticipated, but in these cases too, issues the same as those with connection of MEC servers in MNO networks may also arise, and it is believed that it may be desirable to consider cloud server formats and formats that install MEC servers outside existing P-GW.

In light of the characteristics described above, in cases where use of MEC is considered in the use cases described in Chapter 2, it will be necessary to investigate the compatibility of installation sites with those use cases.
Figure 3.10 examines the following three patterns of installation sites. In pattern 1, the MEC servers installed immediately below the base station, and transmission latency is the smallest, but the number of servers needed and costs are the highest, and interconnection among MNOs and with external servers is difficult. In pattern 2, the servers are installed on the outside of the P-GW, and connection among MNOs is relatively easy. In addition, cases where a dedicated line is installed on an external server to construct a closed network can also be classified under this pattern. In pattern 3, cloud servers could be installed in Japan to achieve low latency. In this case, it is expected that connection to the cloud server will be via the Internet.

The approximate one-way transmission latency at each installation position is estimated to be several ms when directly under the base station, 20 to 30 ms when outside the P-GW, and about 50 ms for a cloud server [48], [49]. Here, transmission latency means the communication latency time not including the wireless segment. Depending on the application processing time in each use case, network configuration, and congestion conditions, latency of 100 ms or more may occur in addition to the transmission delay. In addition, it is also necessary to consider processing times in use cases that require identification of information distribution recipient vehicles and so on.

With regard to the use cases that anticipate the use of wide area communication in Chapter 2, the suitability of MEC installation sites is considered. For use cases where latency of several seconds or more is acceptable (lane change support, route selection, route re-selection, information on the presence of groups of vehicles near a highway exit, information on roadway hazards, platoon security, authentication, and billing), cloud servers may be suitable.

Next, in the case of use cases where systems outside MNO networks provide information to vehicles (use of traffic signal information: provision of information from signal control centers, FAST that takes into consideration emergency vehicle routes, accident site recording and reporting services), installation of MEC servers immediately below base stations would not be feasible from the perspective of interconnection with external servers. Because of this, it is believed that a format that adopts VPN connection with external cloud servers via the Internet would be possible. On the other hand, in cases where connection to the Internet would not be permissible from the perspective of security, MEC servers outside the P-GW could be used to create a closed network.

In use cases where the permissible latency of several hundred ms and use of both short range communication and wide area communication is possible (vehicle avoidance support, traffic signal information use: provision of information from traffic signals), assuming that V2V or V2I short range communication could cover the low-latency area, possible MEC server installation sites would be a cloud server or MEC server outside the P-GW. In this case, it is expected that installation sites will be selected in light of the permissible transmission latency for each anticipated use case including application processing latency.

Use of MEC is also anticipated for 5G core in the future. In the case of 5G core, User Plane Function (UPF) has been standardized, and UPF has functions to identify packets directed to MEC addresses and to redirect them to a forwarding destination [50], [51]. UPF can be installed at an arbitrary location, and therefore, there is a high degree of freedom in MEC location with 5G core, but with regard to services provided among MNO via MEC, even if the 5G/4G network configuration and the 5G core introductions schedule are performed independently for each MNO, it is necessary to consider installation sites where service levels do not change. In cases where coordination among MNO business operators is necessary based on considerations of latency time and so on, it will also be necessary to investigate physical installation sites.

Chapter 4 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. Also, accident reduction and congestion mitigation expected from each use case are solutions to social issues with high public interest. Therefore, it is assumed the government agencies are also beneficiaries.

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.

In addition, issues were examined with respect to the use case examples added in Chapter 2.2, but the system providers and operators were different in each use case. Although the degree of difference varies for each use case, the point regarding public benefit also applies to the added use cases.

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. Server equipment costs will arise from changes to the structure of servers or changes in the number of servers according to the target services, number of users, and use volume, but it can be considered that this is fundamentally infrastructure used by all beneficiaries (referred to as “shared infrastructure”). Depending on the use format of server equipment and other factors, these expenses as a whole can be seen as costs common to all use cases, but there is also the option of seeing them as costs for only some use cases.

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. Operational and management costs can also basically be considered as common infrastructure, similar to server equipment costs. The same also applies to the allocation of costs to individual use cases.

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.

In cases where communications infrastructure dedicated to V2N, V2I, and V2V is used, the above costs can be considered as shared infrastructure. In cases where specific infrastructure is needed for certain use cases, it will be necessary to allocate costs on a use case basis.

However, when using a public network (a communication network shared with other services) as wide area communications infrastructure of cellular communications for V2N, it will be necessary to clarify the scope that will be considered shared infrastructure costs. Public network communications infrastructure costs are generally recovered from users in the form of packet communication fees, but in cases where expansion of area coverage specifically for V2N or development of V2N dedicated functions is necessary, there is a risk that the profitability of communication carriers cannot be achieved by only communication packet costs paid by users, and it will be necessary to investigate allocation as communications infrastructure.

v. Communications Packet Costs (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.

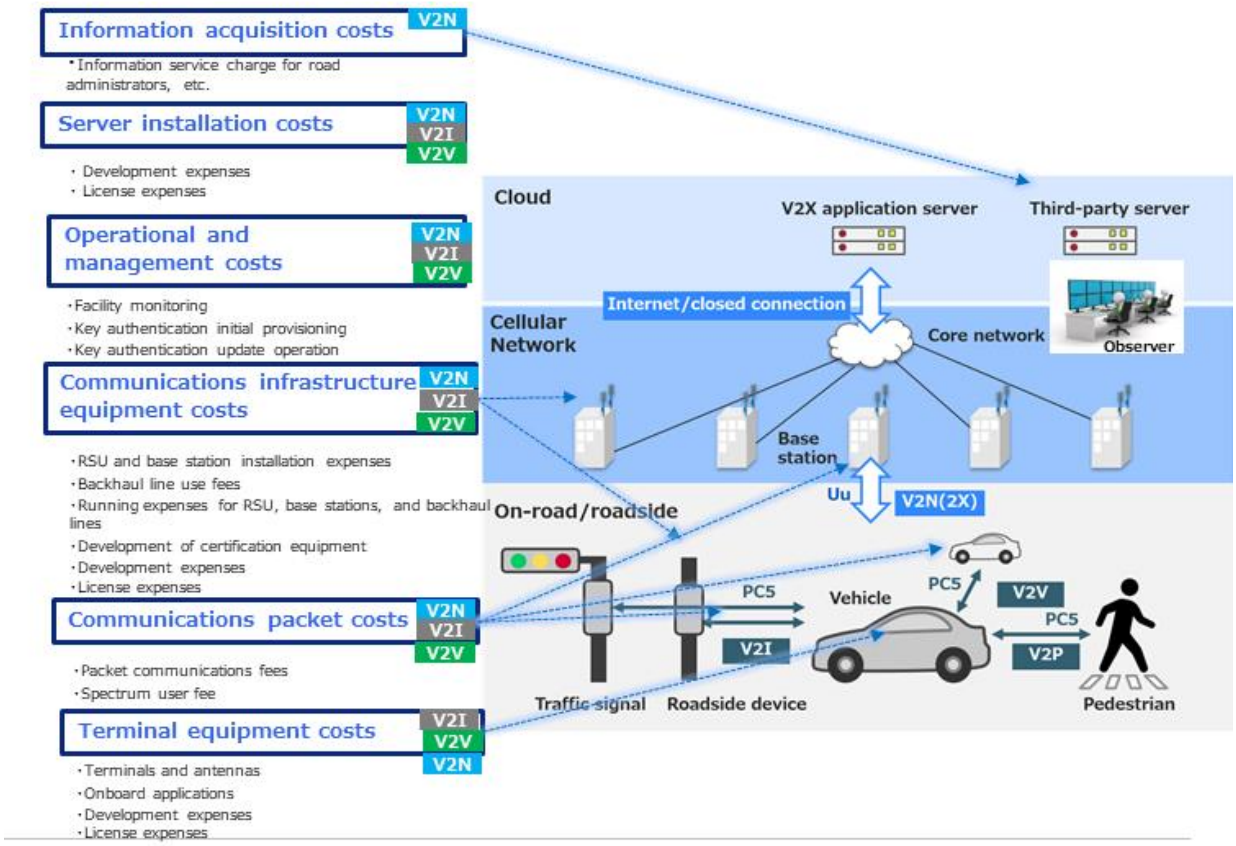


Figure 4.1 Cost Factors in Cellular V2X Business

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. With cellular V2X as well, of the cost factors listed in 4.2, with respect to the cost of shared infrastructure, public investment may be considered from the viewpoint of ensuring business continuity and promoting utilization by reducing the burdens on end-users such as drivers.

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 [52]. For example, VICS provides information such as road transit times and traffic volume to outside operators based on information from sensors installed on roads.

Based on the above, V2I/V2N business models are explained using three different types of examples. In these models, service beneficiaries, national and prefectural governments, municipalities, insurers, V2I/N service providers, communication infrastructure business, and others are anticipated as stakeholders. Drivers, transit businesses, transportation businesses, and others are expected to be service beneficiaries in the near future, and with the spread of MaaS in the future, mobility service businesses (MaaS businesses) will also become service beneficiaries, and it is possible to envision a format that mediates between passengers, who are the end-users, and various businesses. National and prefectural governments and municipalities are expected to include road managers. V2I/N service providers or businesses that provide V2I/N services to beneficiaries, and in cases where they bear infrastructure investments, various formats where operation is outsourced by national and prefectural governments, municipalities, and other parties are possible. Similarly, various formats can be considered for communication infrastructure businesses, and it will be necessary to define these more specifically in the future.

(1) Automobile insurance model

In this model, insurers tie up with V2I/N service providers and collect costs relating to V2I/N service as a part of insurance premiums. It is expected that insurers will be able to more accurately calculate accident risks than in the past through the provision of information on environments in the vicinity of vehicles collected through V2X. With telematics insurance, which has been attracting attention in recent years, information on the behavior of one's own vehicle, images from drive recorders, and so on are collected by cellular communication to refine accident risk calculations based on the information, and if this model is added and applied, further refinement of accident risk calculations can be expected. With this model, if the penetration rate of V2I/N services is low and it is difficult to improve risk calculations, there will be an issue in that introduction incentives will have difficulty working. Because of this, voluntary implementation of measures to promote further penetration such as road managers and local governments receiving information from V2I/N service providers to improve road management and city planning and provide information volumes as compensation and subsidizing initial investments in communications infrastructure and V2I/N service infrastructure.

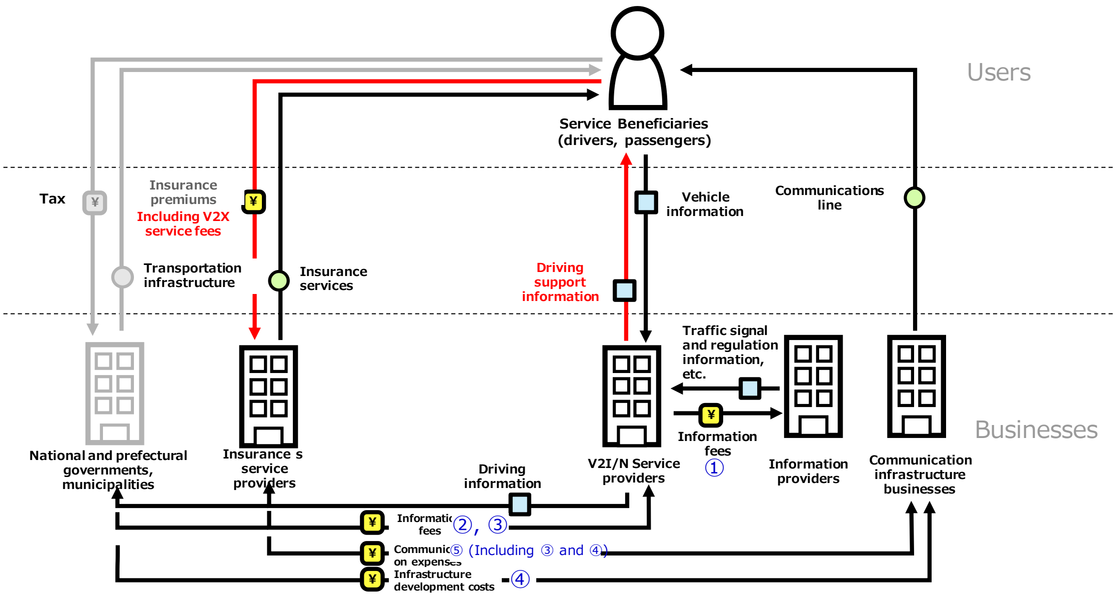


Figure 4.2 Example of Automobile Insurance Model (blue text indicates factor numbers)

(2) Tax model

With V2X, it is desirable that all traffic participants participate in V2X communications and traffic accidents are reduced. In this model, this public nature of V2X is a focus of attention, and it is assumed that services will be provided using taxes as a revenue source. Here a format is described whereby the communication infrastructure relating to V2I/N is developed as a part of transportation infrastructure and a portion is outsourced to communication infrastructure companies. To carry out this model, it would be necessary to clarify the social value and to form a consensus by demonstrating that V2I/N can reduce traffic congestion and traffic accidents or accelerate the spread of automated driving.

(3) Example of MaaS/automated driving model

Under this model, V2I/N services are provided in limited region such as smart cities for the rapid establishment of MaaS using level 4 automated driving (unmanned driving). Transportation service fees received from passengers who receive the transportation services from MaaS service providers serve as the source of business capital. A format whereby some V2X infrastructure is developed through private investment with the addition of V2I/N service costs is shown as an example. For this model, early realization of level 4 automated driving using V2I/N services is an essential assumption, and it is necessary to consider further the significance of infrastructure connected & automated driving.

The relationships among the three models described above are not exclusive and structures where they coexist are conceivable. Among the three models, the automobile insurance model (1) and tax model (2) are premised on the provision of services regardless of region, while the MaaS/automated driving model (3) assumes the provision in limited areas of services more advanced than those provided under models (1) and (2). For this reason, if the MaaS/automated driving model were introduced, it could be present in limited areas (such as smart cities) with the services described in models (1) and (2), and it would be possible to provide multiple V2I/N services using different business formats. In addition, it would be necessary to consider the feasibility including profitability of nationwide expansion of V2I/N services based on the MaaS/automated driving model launched in a limited area.

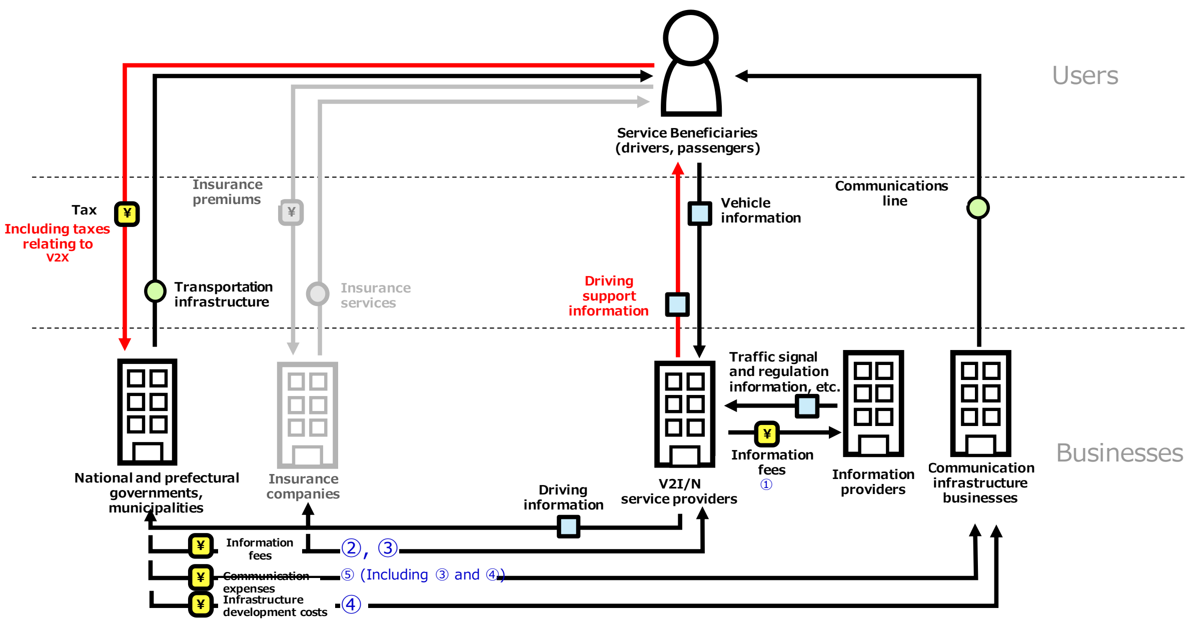


Figure 4.3 Example of Tax Model (blue text indicates factor numbers)

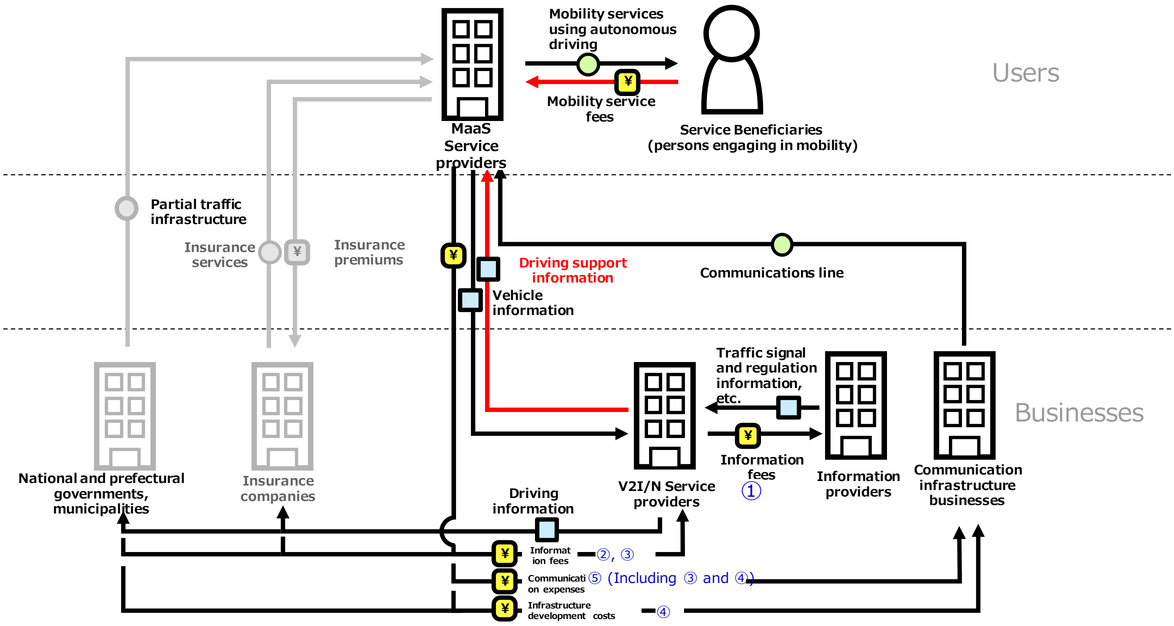
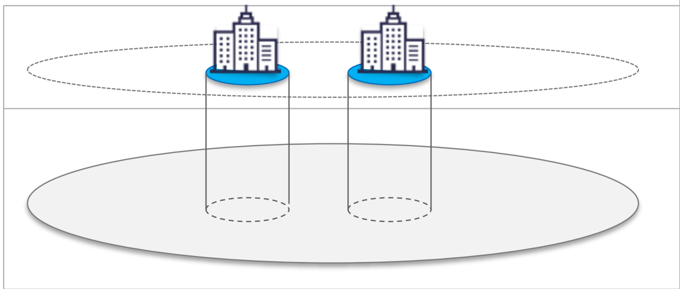


Figure 4.4 Example of MaaS/Automated Driving Model (blue text indicates factor numbers)



	V2X Service Area	Business Model
	Smart City (limited areas)	MaaS/Automated driving model
	Nationwide (including smart cities)	Automobile insurance model Tax model

Figure 4.5 Business Model with Both V2X Services in Unlimited Areas and V2X Services in Limited Areas

Chapter 5 Organization of Issues

The main issues identified in prior chapters are organized in Table 5.1. As a result of conducting investigations (investigated in Version 1 of the report) based on the use case examples that focus on the interval of information updates in Chapter 2.1, it was determined that the issues of the use cases using V2V communications and of the use cases using V2N or V2I communications 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 cases, where information may be obtained from vehicles, clarifying the division of roles between V2V and V2N is an issue, and in use cases, 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.

In addition, when updating this report to Version 2.0, issues were investigated with regard to the use case examples involving combined use of short range communications and wide area communications added in chapter 2.2, but there are many parties involved in the services, which increases the difficulty of building systems and business models, and there are cases where the information providers and primary beneficiaries are not the same, and it was determined that it is necessary to further investigate user acceptance and business feasibility.

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

Perspective		Issue
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)
		Development of structures and business models in cases where there are many parties involved in services
		Acceptance by users and business feasibility in cases where information providers and the primary beneficiaries are not the same
	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.)

Chapter 6 Summary

In this document, with regard to issues concerning the advancement of ITS and automated driving using cellular communications technologies (cellular V2X), use case examples that could take advantage of cellular V2X were selected and organized, and matters and issues necessary for realization from the perspectives of both communication architecture and business model were considered.

As examples of use cases, in Version 1.0 the focus is on the update interval of information. A comparison was made with dynamic maps, which are widely discussed for developing automated driving, and the examples were organized by associating them with locatable information that changes over time (dynamic information, quasi-dynamic information, quasi-static information, and static information), and the items, issues, and so on are necessary for realization were considered.

As a result of analysis in Version 1.0 and subsequent versions of research and development and policy discussion being conducted in Japan and overseas, it was concluded that there are many cases that overlap with the use cases focusing on the update interval of the information mentioned above and that the independent use of any of V2V, V2I, and V2N is assumed. The focus was then placed on the combination of both short range communication (V2V, V2I) and wide area communication (V2N) used for cellular V2X (combined use of wide area communication), with each complementing the other’s strengths and weaknesses to additionally investigate use cases that continuously provide optimal information according to the distance, time, etc. and demonstrate high added value as well as use cases that can improve service feasibility.

Next, the issues identified from the examination of use case examples were organized from the viewpoints of communication, information, and services. The issues were nearly the same for that use cases that focus on the update interval of information in Version 1.0 and the use cases that use both short range communication and wide area communication, but in the case of combined wide area communication use cases, the number of parties involved in the services often increases, which increases the difficulty of creating systems and business models, and there are also use cases in which the information provider and the main beneficiaries are not the same. It was determined that there is need for further investigation on acceptability and business feasibility.

As various services are being investigated for the advancement of ITS and automated driving, the necessary communications performance and regulatory systems, as well as the impact on business, are being discussed. There are significant appeals to using wide area communications (V2N) and short range communications (V2V, V2I, and V2P) or both 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 automated 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 a technology that uses cellular communications such as LTE and 5G NR 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 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 16 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. In general, NR is often recognized as a representative 5G wireless interface.
NR, 5G NR	The new wireless access technology standardized by 3GPP for 5G. Only wide area communications via base stations have been standardized in Release 15, and short range communications is standardized in Release 16.
NR V2X	Wide area and short range communication based on NR in cellular V2X.
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 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.
Communication latency time	In communication-related materials such as ITU-R and 3GPP, the communication latency often means the shortest latency time in one direction under the condition that the communication device is in active state and the light load on the wired or wireless communication links. Further consideration is necessary on the systemic latency on the following points 1) data generation frequency and latency in the sensors and communication data generation units, 2) the effects and variation under heavy loads on wired and wireless communication links, 3) the time required for the retransmissions to ensure reliability, and 4) whether the communication units is always active or not.

Information update interval		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 communications can be used with other
		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	communications or individually.
●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	

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 [53], [54].

Link Design (1 of 2)

Challenges

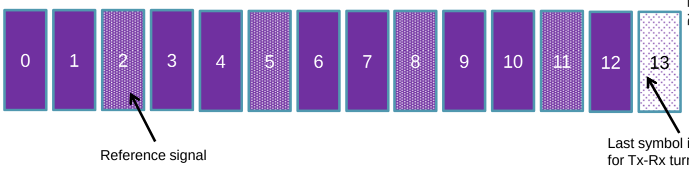
- ITS spectrum @ 6 GHz
- High speed
  - Max vehicle speed of 250 kph ⇔ max relative speed is 500 kph
  - At 6 GHz, 2700Hz Doppler shift ⇔ channel variation within a subframe
- High frequency offset
  - Up to 0.3ppm frequency offset
  - At carrier frequency of 6GHz ⇔ 1800Hz
- Focused on enhancing sidelink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

2

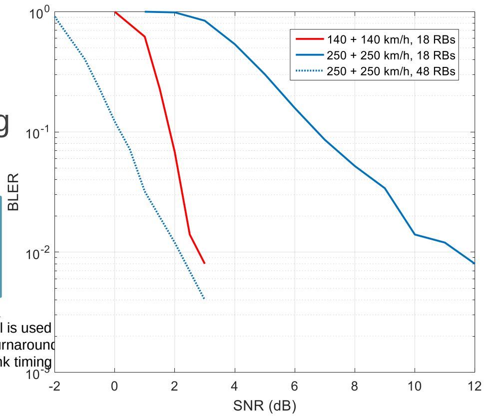
Link Design (2 of 2)

Solutions

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



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



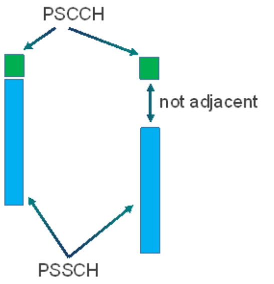
300 bytes, QPSK, two Tx, random frequency error

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

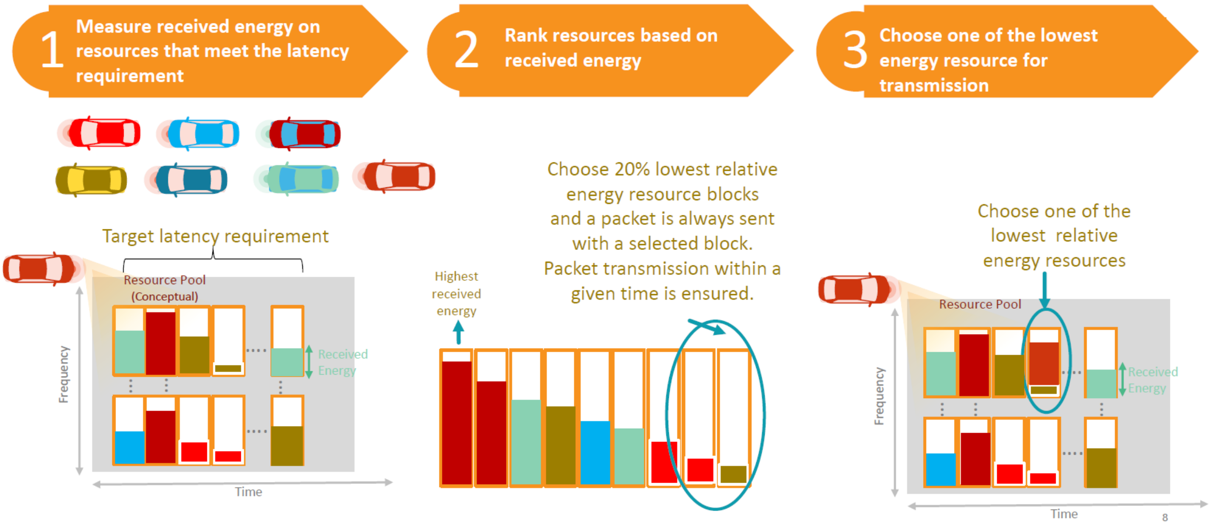
Modes 3 and 4 - Default is Mode 4

- 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 Configuration Parameters Consideration for LTE-V2X Operation

This appendix describes important considerations for system configuration in LTE-V2X operation associated with the system requirements, (pre-)configuration parameters and provision method of the traffic from the application layer to LTE-V2X layer.

The services to convey information to surrounding vehicles for the safety need to satisfy the reliability and the system latency determined by the service requirements. Such requirements and evaluation methods can be different among regions/countries even in the same or similar use cases, due to available bandwidth, radio propagation environment (typical number of lanes, vehicle density and so on), and communication traffic conditions. In order to support the requirements of the reliability and the system latency in each region/country, appropriate setting of (pre-)configuration parameters and proper provision of the communication traffic from the application layer to LTE-V2X layer are necessary. Following describes some of example considerations:

Congestion control and Resource selection

Congestion control and resource selection are important factors to achieve the certain performance in any radio systems.

If resource usage exceeds the capacity of the physical layer, the reliability of the traffic cannot be satisfied because of high collision rate and/or much interference. The congestion control in the application layer identifies the resource usage and it controls the amount of the traffic from the application layer to LTE-V2X layer. Proper design of the congestion control is necessary in order to support the reliability requirement by preventing over-usage of LTE-V2X layer. The congestion control mechanism based on SAE J3161/1 was evaluated with LTE-V2X PC5 [55].

Inter-channel interference happens when adjacent (sub-) channels are used by different transmission terminals because the transmission power leakages to the adjacent (sub-)channels. Co-channel interference also happens when different transmission terminals within near range uses the same channel. In LTE-V2X, the terminal measures the received signal level (RSSI) and compare it with the (pre-)configuration parameter of RSSI. The proper setting of this (pre-)configuration parameter is necessary because it controls how much resource for the transmission is available and how strong the interference occurs in transmission in a subframe. The terminal tries to avoid selecting interfered subframe by selecting 20% best subframes in terms of averaged RSSI over a subframe. Proper configuration of retransmission, probResourceKeep and one-shot transmission can also help to mitigate inter-channel or co-channel interference.

Half duplex

Half-duplex may face the situation where the transmission terminal cannot consecutively receive the signal from the other terminal in the same subframe. If this situation happens by the scheduled periodic transmission, two terminals cannot communicate each other during the scheduled period. How often this happen (probability) is determined not only by the periodicity of application traffic, length of scheduled period, available resource, the number of terminals in the communication area, and also other factors. The retransmission timing is usually randomly selected by the transmission terminal. It can reduce the probability of the collision among terminals. In LTE-V2X, the (pre-)configuration parameter of probResourceKeep, which controls how long the same resource is consecutively selected, needs to be set properly to prevent high probability of consecutive collision. Also, occasional one-shot transmission instead of periodically reserved resource transmission controlled by the application layer can also mitigate the consecutive collision.

A.4 Use cases that were not selected in chapter 2.2

No.	Use Case Title	Details	Reasons for Not Selecting
1	Re-formation of divided platoon	For situations where a platoon is divided due to vehicles going into the spaces between platoon vehicles while traveling on a highway. As a countermeasure, it would be possible to instruct the front and rear platoon vehicles to adjust speed based on the positional relationship of the divided platoon and to process the platoon information after they are able to approach each other. By using V2N, it would be possible to inform a cloud server of the position of the divided platoon and to notify platoon members where the platoon can be re-formed and speed adjustments. After the front and rear of the platoon approach, the platoon will be re-formed by identifying and authenticating the other members using V2V and exchanging information such as real-time position, acceleration, and order.	Trucks must comply with speed limits, so vehicles in the front must slow down when re-forming a platoon. In this case, the impact on traffic flow would be significant and the benefits of re-forming the platoon would be diminished. At the time of division, it may be possible to maintain contact using hands-free phones, etc. and to re-form the platoon using SA/PA.
2	Sharing location information and onboard sensor information to prevent collision with oncoming vehicles when turning right	When turning right at an intersection with poor visibility, the training vehicle and an oncoming vehicle may collide. As a countermeasure, a method of obtaining the position information of all vehicles traveling in the opposing lane or a method of detecting the presence of a vehicle out of sight by referring to information from sensors and cameras of the surrounding vehicles can be considered. By using V2V, each vehicle can distribute and obtain location information, and it is possible to detect the presence of vehicles out of sight. By using V2N, it would be possible to narrow the scope of vehicles requesting the provision of sensor and camera information based on the position, speed, etc. of each vehicle on the center side, and it would be possible to share sensor and camera information using minimal resources.	・Service that require sharing sensor and camera information among vehicles and determining the position information of all vehicles traveling in the opposing lane need to have a very high penetration rate in connected cars; this may be possible in 2030 or later. ・In Japan, a right turn (across traffic) support service using V2I that utilizes roadside sensor information has already been put into practical use, and this use will be effective at the stage that is not widely spread.
3	Merging support using mapping and coordination control of merging vehicles and vehicles in the main lane	When merging on highways or general roads, the merging vehicle will detect the vehicle in the main lane using an autonomous sensor and plan the merging timing, but if the merging lane is short or depending on the speed of the vehicle in the main lane, merging may be difficult. As a countermeasure, an infrastructure sensor near the merging point could detect the position and speed of the merging vehicle and vehicles in the main lane, and V2I could be used to inform each vehicle to adjust speed or change lanes. In addition, it would be possible to map surrounding vehicles that collect position and speed information of merging vehicles and vehicles in the main lane further away from the merging point and to adjust speed and give lane change instructions to vehicles in the main lane at a further distance.	・The accuracy of measuring the absolute position of vehicles is low and improving accuracy is an issue. ・It will be difficult to achieve the added value portion using V2N unless the penetration rate of connected cars is considerably higher, and it is expected that this will occur in 2030 or later. ・At the stage that is not widely spread, it would be desirable to take countermeasures by installing infrastructure that can continuously detect vehicles traveling in the main lane. ・It is important to investigate areas where control is expected to be effective. Considering the certainty of the estimated arrival time at the point of merging, it is assumed that it would be effective within a narrow communication range (e.g., approximately 200 m) from the starting point of the acceleration lane, and control information will be sent by V2N to vehicles further away. Attempting to do so would require verification of the effectiveness and actual conditions of the merge length (possibly shorter than the V2N range).
5	Notification of the presence of pedestrians who may suddenly enter the road	A pedestrian suddenly entering the road from a blind spot may result in a traffic accident. As a countermeasure, when the presence of a child or an elderly person on the road is detected by a vehicle sensor or camera, the information could be distributed to nearby vehicles for vehicle control and to call attention to the presence of the pedestrian in order to prevent a collision. By using V2N, it would be possible to provide information such as alerting vehicles that are far from a potential collision. By using V2V, it would be possible to provide highly reliable information with low latency when the distance to the potential collision is short.	・Pedestrian behavior is unpredictable, and therefore, vehicle control based on uncertain information is unacceptable. ・Accident prevention is becoming more effective by autonomously detecting pedestrians who suddenly enter the road based on sensor and camera information and braking.
6	Determining the presence of stationary vehicles to prevent sudden braking	If the presence of stationary vehicles such as those waiting at traffic lights, waiting to turn across traffic, or parking on the street is not noticed, there is a risk of a rear end collision or sudden braking. As a countermeasure, it would be possible to call attention to such vehicles and change lanes or routes by determining the situation in advance in real time and notifying drivers of the collision risk in advance. By using V2N, the position, speed, route information, traffic signal control information, and other information of each vehicle can be determined on a cloud server, and drivers can be alerted in real time by predicting traffic congestion and convoys. By using V2V, it would be possible to quickly warn following vehicles when sudden breaking by a vehicle in front occurs.	・In order to determine the position, speed, and route information of each vehicle, it would be necessary that the penetration rate of connected cars increases; this is expected to be achieved after 2030.

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