FY 2021 “Cross-ministerial Strategic Innovation Promotion Program (SIP) Phase 2 - Automated Driving (Expansion of Systems and Services) A Study on V2X Communication for Achieving Use Cases of Cooperative Driving Automation”

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NEC Corporation

This report documents the results of Cross-ministerial Strategic Innovation Promotion Program (SIP) 2nd Phase, Automated Driving for Universal Services (SIP-adus, NEDO management number: JPNP18012) that was implemented by the Cabinet Office and was served by the New Energy and Industrial Technology Development Organization (NEDO) as a secretariat.

Contents

1. Overview

1.1 Purpose of project

Currently, research, development, demonstration, and implementation of automated driving are being conducted by domestic and foreign research institutes, automotive-related companies, ITS-related companies, and others. In Japan, in addition to studies at various research institutes and companies, automated driving is being taken up as one of the themes of the Strategic Innovation Program (SIP) as research and development related to the cooperative area. In SIP phase 2, in order to overcome a wide range of technological issues for the practical application of automated driving, development is being promoted as the cooperative area, focusing on the development of basic technologies necessary to create an environment in which automated vehicles can drive and to ensure their safety. And in the course of work such as studying development of the driving environment, efforts are being made to determine the format of road traffic information and communication requirements necessary for automated driving and to standardize them. In addition to autonomous (own vehicle alone) driving that has been the subject of research and development to date, we believe that the study of cooperative driving automation using V2X communication (communication between the vehicle and the outside (vehicle, roadside infrastructure, and center)) will become more important as work such as studying the development of the driving environment. In order to realize cooperative driving automation, it is necessary to verify the technical feasibility of V2X communication, and, based on the assumption of communication technologies that are expected to evolve in the future, to formulate and share a roadmap of specific required specifications for radio communication technology, and then work on studies at individual research organizations and companies.

Cooperative driving automation use cases in which V2X is expected to be utilized were studied as part of the Study on Communication Technologies for Automated Driving Systems conducted as the second phase of the Cross-Ministerial Strategic Innovation Promotion Program (SIP) in 2019. And the Task Force on V2X Communication for Cooperative Driving Automation (hereinafter, the “TF”) has formulated 25 use cases as “SIP Cooperative Driving Automation Use Cases” (September 2020). Based on the specific communication requirements for cooperative driving automation use cases, and taking into account the results of the study of issues with the existing ITS communication technology (700 MHz band ITS), which is conducted separately from this R&D theme, we will examine measures to address the issues by the using cellular V2X system (mainly 5G-based Uu and PC5 communication), including utilization of a new frequency band (5.9 GHz band) and verify technical feasibility. The results of this study will be combined with the results of a study of compatibility in cooperative driving automation use cases for existing ITS communication technology (700 MHz band ITS), which will be conducted separately from this R&D theme, and the results of the verification of technical feasibility. And each use case based on the assumption of communication technologies that are expected to evolve in the future and specific requirement specifications for each radio communication technology will be established as a roadmap.

1.2 Project overview/goals

This project was, for the use cases of cooperative driving automation expected to use V2X created at the study by the TF, to formulate a roadmap for the social implementation of communication technologies necessary for realizing an automated driving society, taking into account the examination, verification, and demonstration of technical feasibility of communication, such as specific requirements for radiocommunication technology.

Specific results are described in parts2 and later.

(1) Arrangement of issues of V2X communication technology to meet communication requirements and verification of compatibility by existing radio communication system (cellular V2X system)
- Evaluation of compatibility in wide-area communication
- Evaluation of compatibility in narrow-area communication

(2) Verification of validity through drafting countermeasures to solve problems and evaluation through demonstration experiments
- Examination of problems and countermeasures for wide-area communication
- Examination of problems and countermeasures for narrow-area communication
- Evaluation of the appropriateness of countermeasures
- Validation of evaluation results

(3) Formulation of a roadmap for the social implementation of communication technologies necessary for realizing an automated driving society
- Survey of trends necessary for roadmap formulation
- Draft roadmap for communication requirements for cooperative driving automation

1.3 Promotion of R&D

R&D for this project was conducted according to the following flow.

The center and left flows shown in the figure are our area of responsibility. The flow on the right side is the scope of another commissioned research theme, “Study on communication protocols for achieving Use Cases for Cooperative Driving Automation Evaluation related to 700 MHz band ITS” and is the area of responsibility of Kyocera Corporation, which it was commissioned to. Research and development were carried out in close collaboration between the two companies.

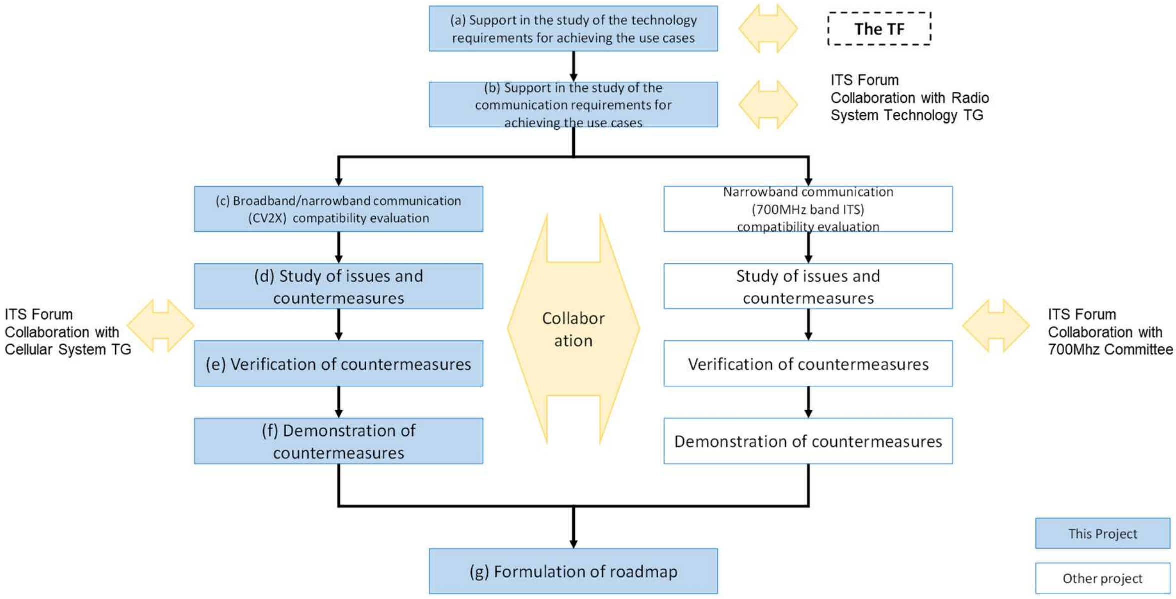

Fig. 1.3-1 Promotion of R&D

In promoting research and development, we participated in meetings of the TF and the ITS Info-communications Forum (hereinafter, the “ITS Forum”), reporting on the status of the study and holding discussions with the participating members. At that time, the following tasks were also carried out as the secretariat of the meetings.

- Support for preparation of meeting study materials

The status of participation in the meeting is covered in "6. TF ITS Forum activities record".

2. Arrangement of issues of V2X communication technology to meet communication requirements and verification of compatibility by existing radio communication systems

In this research, the following two communication formats of vehicle-to-everything (V2X) communication were studied.

- Wide-area communication
  Communication that provides information to vehicles in a wide area and collects information from vehicles via a telecommunications carrier's communication network (V2N: Vehicle to Network)
- Narrow-area communication
  Communication between vehicles (V2V: Vehicle to Vehicle) and between vehicles and infrastructure facilities such as roadside units (RSU) (V2I: Vehicle to Infrastructure) through direct communication without the need for a telecommunications carrier

An image of the radio communication studied is shown in Fig. 2-1.

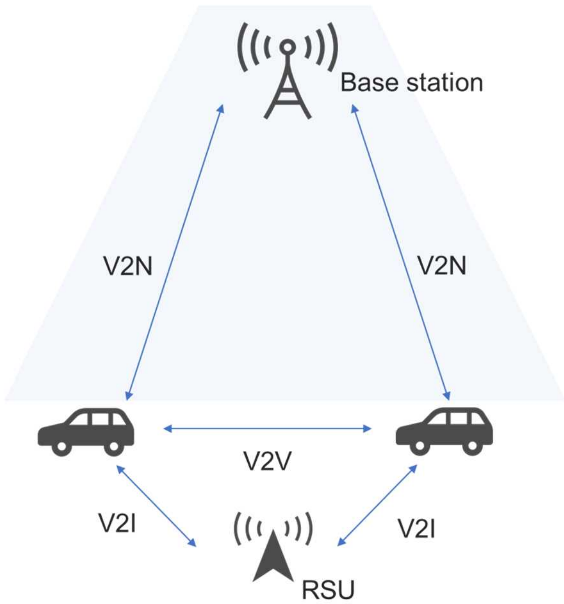

Fig. 2-1 Image of radio communication studied

According to the definition by the TF, a "cooperative driving automation system" is "a system that enables more advanced driving automation by utilizing traffic environment information obtained through communication based on an autonomous driving system." In defining a "cooperative driving automation system," the TF classified information obtained using communications to achieve high-level driving automation into three categories: "information outside the detection range of on-board sensors," "information of one's own vehicle," and "V2V and I2V interaction". Based on these categories, the cooperative driving automation use cases were organized into the following three categories:

(1) Use cases in which information outside the detection range of on-board sensors must be obtained
(2) Use cases in which information of one's own vehicle must be provided
(3) Use cases in which V2V and I2V interaction must be ensured

The 25 use cases[1] of cooperative driving automation formulated by the TF, organized by functional category from (1) to (3) above, are shown in Table 2-1, Table 2-2, and Table 2-3.

Table 2-1 Overview of use cases: (1) Use cases in which information outside the detection range of on-board sensors must be obtained (1/2)

Classification by function	Use case	Overview	Communication format
a. Merging / lane change assistance	a-1-1. Merging assistance by preliminary acceleration and deceleration	Information such as the speed of vehicles traveling on the mainline at the measurement points on the mainline and the estimated time of arrival at the merge point is provided from the infrastructure to merging vehicles to support preliminary acceleration and deceleration.	V2I
	a-1-2. Merging assistance by targeting the gap on the mainline	Continuously measured information on the location and speed of vehicles traveling on the mainline is continuously provided from the infrastructure to merging vehicles to assist in merging by targeting gaps between vehicles traveling on the mainline.	V2I
b. Traffic signal information	b-1-1. Driving assistance by using traffic signal information (V2I)	Current traffic signal color and traffic signal phase and timing information (the next traffic signal color and the time until change), etc., at intersections is provided by the roadside infrastructure to vehicles that enter intersections to assist deceleration and stopping, and thereby avoid a dilemma.	V2I
	b-1-2. Driving assistance by using traffic signal information (V2N)	Traffic signal phase and timing information (the next traffic signal color and the time until change), etc., of traffic signals at intersections is provided via a network to vehicles that enter intersections to assist deceleration and stopping, and thereby avoid a dilemma.	V2N
c. Lookahead information: Collision avoidance	c-1. Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly	Sudden braking information as well as location and speed information are provided by the suddenly decelerating vehicle to following vehicles to encourage them to stop or slow down in advance, thereby preventing pileups.	V2V
	c-2-1. Driving assistance based on intersection information (V2V)	Location and speed information of vehicles that approach intersections is provided by approaching vehicles to other vehicles that approach or pass through intersections to assist them to pass through or make a right turn at intersections with many blind spots.	V2V
	c-2-2. Driving assistance based on intersection information (V2I)	Location and speed information of vehicles that approach intersections, which is obtained from roadside sensors or vehicles, is provided by the infrastructure to other vehicles that approach or pass through intersections to assist them to pass through or make a right turn at intersections with many blind spots.	V2I
	c-3. Collision avoidance assistance by using hazard information	Emergency hazard information is sent to following vehicles when an autonomous driving vehicle performs emergency deceleration or emergency lane change, thereby supporting smooth avoidance control for following vehicles.	V2V

[1]Source: SIP Cooperative Driving Automation Use Cases - 2019 Task Force on V2X Communication for Cooperative Driving Automation Activity Report-

Table 2-1 Overview of use cases: (1) Use cases in which information outside the detection range of on-board sensors must be obtained (2/2)

Classification by function	Use case	Overview	Communication format
d. Lookahead information: Trajectory change	d-1. Driving assistance by notification of abnormal vehicles	Event information (broken down vehicle, accident vehicle, etc.) and location information (section located, lane) of abnormal vehicles stopped on the road is provided from the infrastructure to surrounding vehicles or from abnormal vehicles to surrounding vehicles to support early lane change and trajectory change.	V2I V2N
	d-2. Driving assistance by notification of wrong-way vehicles	Information on the location and speed of wrong-way vehicles and the presence of the wrong-way vehicles is provided from the infrastructure to surrounding vehicles to encourage them to change lanes, etc., in advance to assist in collision avoidance.	V2I V2N
	d-3. Driving assistance based on traffic congestion information	Traffic congestion information obtained from vehicles in congestion is provided from the infrastructure to surrounding vehicles to assist driving.	V2I V2N
	d-4. Traffic congestion assistance at branches and exits	Information (location and speed) on shoulder congestion is provided from the infrastructure to mainline vehicles to assist them in entering branches.	V2I V2N
	d-5. Driving assistance based on hazard information	Obstacle, construction, congestion and other information is provided from the infrastructure to surrounding vehicles to assist driving.	V2I V2N
e. Lookahead information: Emergency vehicle notification	e-1. Driving assistance based on emergency vehicle information	Information on the direction of movement and speed of emergency vehicles and their planned route (planned travel lane) is provided from emergency vehicles to surrounding vehicles to encourage surrounding vehicles to slow down or stop, etc., to support smooth passage of the emergency vehicle.	V2I V2V V2N

Table 2-2 Overview of use cases: (2) Use cases in which information of one's own vehicle must be provided

Classification by function	Use case	Overview	Communication format
f. Information collection / distribution by infrastructure	f-1. Request for rescue (e-Call)	Rescue information is sent from vehicles involved in accident or other abnormal vehicles to the infrastructure to request rescue.	V2N
	f-2. Collection of information to optimize the traffic flow	Information on the location and speed of the traveling vehicles is collected via the infrastructure for traffic volume analysis and optimization.	V2I V2N
	f-3. Update and automatic generation of maps	Information collected by vehicles is collected by the infrastructure to update and automatically generate map data.	V2N
	f-4. Distribution of dynamic map information	Dynamic map information is provided from the infrastructure to vehicles.	V2N

Table 2-3 Overview of use cases: (3) Use cases in which V2V and I2V interaction must be ensured

Classification by function	Use case	Overview	Communication format
a. Merging / lane change assistance	a-1-3. Cooperative merging assistance with vehicles on the mainline by roadside control	Information on the location and speed of vehicles traveling on the mainline measured in a planar manner is provided from the infrastructure to merging vehicles and instruction on adjusting interval between vehicles, etc., is given from the infrastructure to vehicles traveling on the mainline to assist in merging.	V2I
	a-1-4. Merging assistance based on negotiations between vehicles	When merging onto a congested mainline, the mainline vehicle and the merging vehicle communicate their location and speed information, request to adjust interval between vehicles, etc., to support merging through vehicle-to-vehicle negotiation.	V2V
	a-2. Lane change assistance when the traffic is heavy	When changing lanes to a congested lane, location, and speed information as well as lane change intentions are communicated between vehicles to assist in lane changes.	V2V
	a-3. Entry assistance from non-priority roads to priority roads during traffic congestion	At intersections without traffic signals, information on location and speed, as well as the intention to enter, is communicated between vehicles near the intersection to provide driving assistance for entering priority roads from non-priority roads.	V2V
g. Platooning / adaptive cruise control	g-1. Unmanned platooning of following vehicles by electronic towbar	Operational information and other information on platooning vehicles is communicated between the trucks forming the column to support platooning (electronic towbar).	V2V
	g-2. Adaptive cruise control and manned platooning of following vehicles using adaptive cruise control	Location, speed, driving operation information of the vehicle ahead, etc., are communicated to the vehicle behind to support adaptive cruise control.	V2V
h. Remote control	h-1. Operation and management of mobility service cars	In traffic environments where avoidance is difficult with an autonomous driving system, video information, etc., from the mobility service cars and remote control instructions from the operation manager are communicated between the operation manager and the mobility service car to operate and manage the vehicle from a remote location.	V2N

Related organizations that cooperated with the ITS Forum's Radio System Technology Task Group (hereinafter, the "TG") in studying communication scenarios and communication requirements for cooperative driving automation use cases is shown in Table 2-4 Communication requirements and communication scenarios were formulated based on discussions with the related organizations.

Table 2-4 Use cases and related organizations that cooperated

Classification by function	Use case	Related organization
a. Merging / lane change assistance	a-1-1. Merging assistance by preliminary acceleration and deceleration	National Institute for Land and Infrastructure Management
	a-1-2. Merging assistance by targeting the gap on the mainline	National Institute for Land and Infrastructure Management
b. Traffic signal information	b-1-1. Driving assistance by using traffic signal information (V2I)	UTMS Society of Japan
	b-1-2. Driving assistance by using traffic signal information (V2N)	UTMS Society of Japan
c. Lookahead information: Collision avoidance	c-1. Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly	
	c-2-1. Driving assistance based on intersection information (V2V)	ITS Connect Promotion Consortium
	c-2-2. Driving assistance based on intersection information (V2I)	UTMS Society of Japan
	c-3. Collision avoidance assistance by using hazard information	Japan Automobile Manufacturers Association
d. Lookahead information: Trajectory change	d-1. Driving assistance by notification of abnormal vehicles	National Institute for Land and Infrastructure Management
	d-2. Driving assistance by notification of wrong-way vehicles	
	d-3. Driving assistance based on traffic congestion information	National Institute for Land and Infrastructure Management
	d-4. Traffic congestion assistance at branches and exits	National Institute for Land and Infrastructure Management
	d-5. Driving assistance based on hazard information	National Institute for Land and Infrastructure Management
e. Lookahead information: Emergency vehicle notification	e-1. Driving assistance based on emergency vehicle information	ITS Connect Promotion Consortium
f. Information collection / distribution by infrastructure	f-1. Request for rescue (e-Call)	Japan Mayday Service Co., Ltd.
	f-2. Collection of information to optimize the traffic flow	SIP Probe information utilization contractor
	f-3. Update and automatic generation of maps	SIP map update contractor
	f-4. Distribution of dynamic map information	Zenrin Co. Ltd.
a. Merging / lane change assistance	a-1-3. Cooperative merging assistance with vehicles on the mainline by roadside control	Japan Automobile Manufacturers Association
	a-1-4. Merging assistance based on negotiations between vehicles	Japan Automobile Manufacturers Association
	a-2. Lane change assistance when the traffic is heavy	Japan Automobile Manufacturers Association
	a-3. Entry assistance from non-priority roads to priority roads during traffic congestion	Japan Automobile Manufacturers Association
g. Platooning / adaptive cruise control	g-1. Unmanned platooning of following vehicles by electronic towbar	Platooning demonstration testing contractor
	g-2. Adaptive cruise control and manned platooning of following vehicles using adaptive cruise control	Platooning demonstration testing contractor
h. Remote control	h-1. Operation and management of mobility service cars	National Institute of Advanced Industrial Science and Technology

For the 25 use cases of cooperative driving automation formulated by the TF, the following assumptions are made when the TG considers the technical requirements, communication scenarios, and communication requirements assumed to realize cooperative driving automation[2].

1) Basic conditions

Assume as own vehicle the cooperative driving automation system defined in the SIP Cooperative Driving Automation Use Case, a "system that enables safer and smoother automated driving control by providing information outside the detection range of on-board sensors and information of one's own vehicle, as well as communicating V2V and I2V interaction, based on an autonomous driving system".

Assume other vehicles in the vicinity to be "cooperative driving vehicles" that are driving automatically with the cooperative driving automation system, and assume vehicles not equipped with a cooperative driving automation system and that are driven by the driver (including vehicles driven by the driver without using a cooperative driving automation system) or vehicles that are driving automatically with an autonomous driving system to be "V2X non-supported vehicles".

2) Utilization of high-precision 3D map information

All roadside infrastructure supporting the cooperative driving automation system and all vehicles equipped with the cooperative driving automation system shall have high-precision 3D map information that is static information that can be linked to dynamic data.

In order to utilize dynamic maps (see Fig. 2-2) that align high-precision 3D map information and dynamic data (quasi-static information, quasi-dynamic information, and dynamic information) in accordance with established tying rules, the radio system must be designed so that multiple communication scenarios for the SIP cooperative driving automation use cases can be coordinated and executed simultaneously. In each of the use cases under consideration, it is necessary to take into account the cases where dynamic data cannot be obtained using other communication scenarios.

FY 2020 "Cross-ministerial Strategic Innovation Promotion Program (SIP) Phase 2 - Automated Driving (Expansion of Systems and Services) Study Investigation of CRPs in High-Precision 3D Maps" is to be taken into account in this study (CRP: Common Reference Point).

The relationship between APs (Anchorage Points) and CRPs can be either rule-based or table-based placement, but this relationship is assumed to be obtained by the vehicle in advance or by V2N or V2I in advance, and no V2N or V2I notification is assumed for each use case.

[2] Source: Study report on communication scenarios and requirements for "SIP Use Cases for Cooperative Driving Automation" (RC-017)

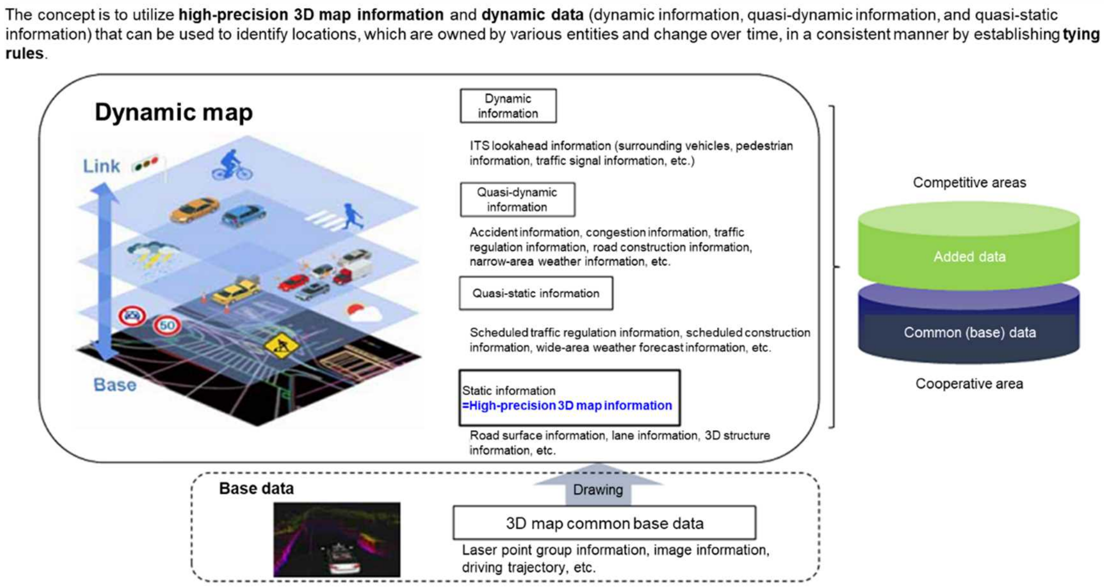

Fig. 2-2 Image of dynamic map construction[3]

3) Definition of delay

The definition of delay in this section is given in Fig. 2-3, which describes the relationship of delay in each part of the system, and in Table 2-5, which defines the allowable delay of the radio communication section

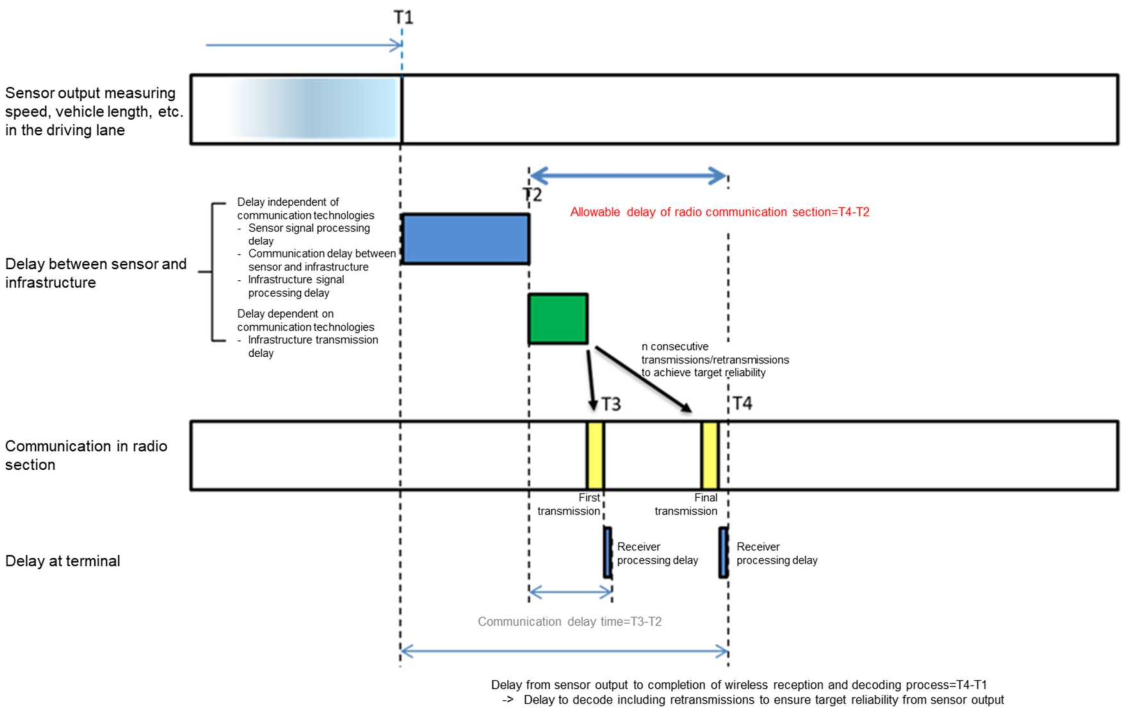

Fig. 2-3 Relationship of delay in each part of the system

[3]Source: FY 2020 SIP results report [Study Investigation of CRPs in High-Precision 3D Maps].pdf

Table 2-5 Allowable delay of radio communication section

Delay section	Sections in figure	Explanation
Allowable delay of radio communication section	T4-T2	The maximum delay time allowed by the radio access layer for the system to achieve the required reliability (including transmission waiting time and consecutive transmission/retransmission time at radio access layer). Used for comparison of radio access methods, etc.

In the radio access layer, retransmission/consecutive transmission is performed as necessary to achieve the required reliability (error rate and propagation distance) for each message from the upper layers, as described in Fig. 2-3.

The radio access layer shows the contents described in ITS FORUM RC-015 Guideline for Experiments of Communications System for Use Cases of Automated Driving on Expressways, and continuous transmission/consecutive processing is performed at Layer 7 in the ITS FORUM RC-005 reference method, for example, and at Layer 2 including MAC sub-layer in LTE-V2X.

Messages that exceed the allowable delay of radio communication section are considered to not have arrived regardless of the decoding result.

The delay (T4-T1) from the sensor output to the completion of the reception and decoding process by radio must be used to study the required communication area, distance, etc., of the system.

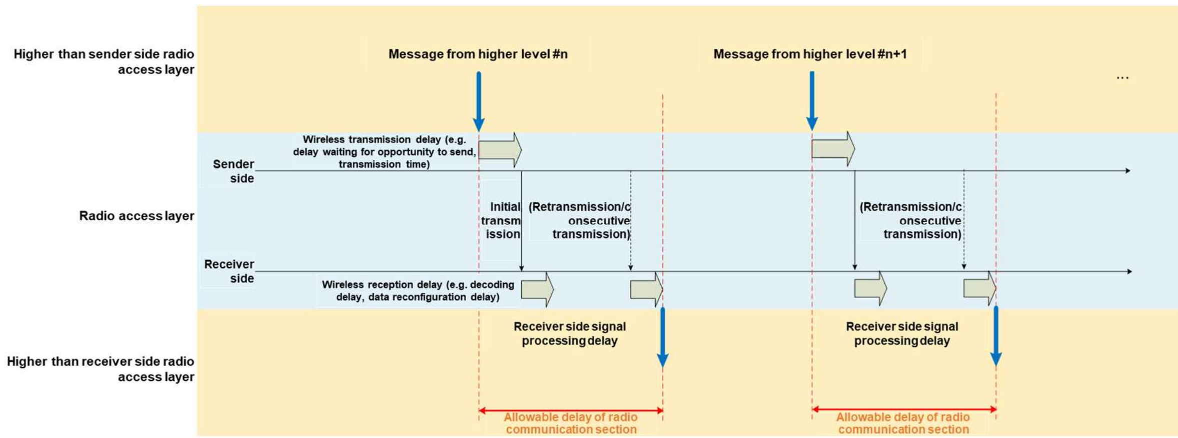

Fig. 2-4 Delay relationships between layers

4) Communication quality regulations

The definition of communication quality handled in this section is specified as the Packet Arrival Rate (PAR) per message in the allowable delay of radio communication section shown in “3) Definition of delay”.

5) Multiplexing of information elements

In this section, information elements are described under the assumption that messages are generated for each use case or type of information element, and that at least each message can be sent and received independently in the radio access layer.

In the following cases, multiplexing of information elements/messages at either layer is conceivable.

a) When multiple information elements/messages of different types occur on the sender side in the same use case

As an example, in the merging support use case a-1-3., a situation may arise where information that is sent periodically in the roadside infrastructure, such as location messages, and information that is sent at specific events/sequences, such as control/agreement communication sequences, is occurring.

b) When multiple information elements/messages of different recipients occur on the sender side in the same use case

As an example, in the merging support use case a-1-3., a situation may arise where the roadside infrastructure implements control procedures for multiple vehicles in parallel, resulting in multiple control information.

c) When multiple information elements/messages for different use cases occur on the sender side

As an example, a situation may arise where a location message for merging support use case a-1-3. and a message required for traffic congestion assistance at branches and exits use case d-4. are occurring simultaneously in the roadside infrastructure.

The following methods can be considered for handling cases in which multiple information elements of different types, recipients, and use cases occur simultaneously, as described above. Since applicable methods may differ depending on the capability of the radio access layer, it is necessary to consider methods that take into account the capability of the radio access layer.

- Method 1: Multiple information elements/messages are multiplexed at the layers described in this section.
  - Method 1a: The message format shall be such that a single message can contain multiple information elements of different types and for different recipients.
  - Method 1b: A single message contains information elements for one type or recipient, but sublayers that multiplex those multiple messages are provided in the layers described in this section.
- Method 2: Multiple information elements/messages are multiplexed at the radio access layer prior to transmission over the radio communication channel.
- Method 3: Information elements/messages are not multiplexed at the radio access layer before sending, but multiplexing is done by multiple access of radio communication channels using different times, frequencies, etc.
- Method 4: Low-priority information elements/messages and information elements/messages with sufficient waiting time are discarded or sent delayed.

Method 1 requires consideration of message composition within the scope of this section.

Method 1a has the advantage of reducing the amount of information radio sent compared with other methods, because the part that can be shared among information elements (e.g., common information) only needs to be communicated once, but it requires consideration of each information element and the message structure becomes complex, and if a response message is required, it is necessary to notify which part of the request is responded (e.g., by an identifier assigned for each request).

Methods 1 and 2 require the ability to handle larger packet sizes at the radio access layer than Scheme 3.

Method 3 requires more accesses to the radio communication channel than the other methods. And method 3 can also change the reliability and arrival distance of each message by changing the degree of error correction and transmission power.

In method 4, the information element/message may not be able to meet the allowable delay time of radio communication section.

2.1 Evaluation of compatibility in wide-area communication

In considering compatibility of cooperative driving automation use cases using wide-area communication, this section describes as understanding of the use cases the technical requirements necessary to realize use cases using wide-area communication and the communication scenario and communication requirements. It also describes the organization of use cases to be considered.

Wide-area communication is assumed to be realized by unicast, which is one-to-one communication using communication networks of telecommunication carriers (MNO network), but in the future, broadcast that can simultaneously distribute information to all vehicles in the base station area (MBMS: Multimedia Broadcast Multicast Service, etc.) will also be considered and studied.

There may also be management servers that play the following roles, and that these management servers will be located such as in each area to distribute the load.

- Manage information sent periodically from the vehicle
- Analyze and determine events based on information obtained from the vehicle
- Determine the information that needs to be distributed to vehicles based on the determined events and identify the areas where it should be distributed

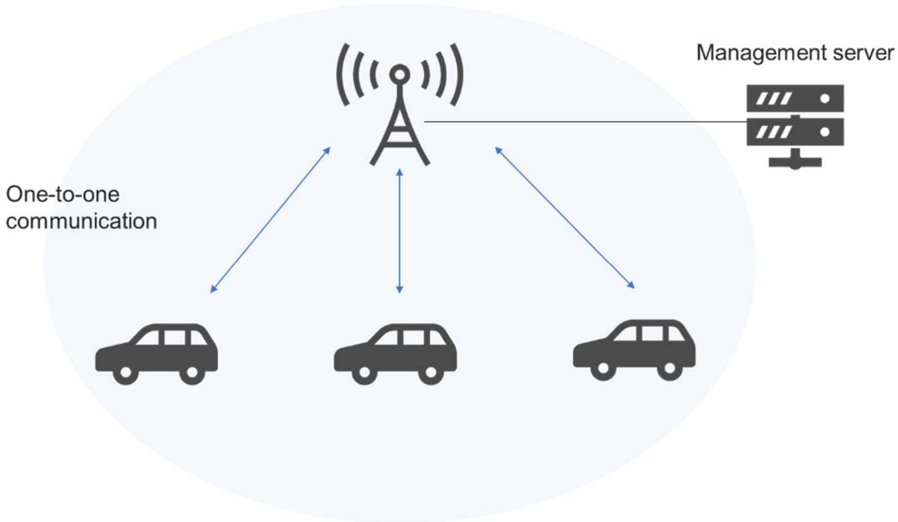

Fig. 2.1-1 Unicast

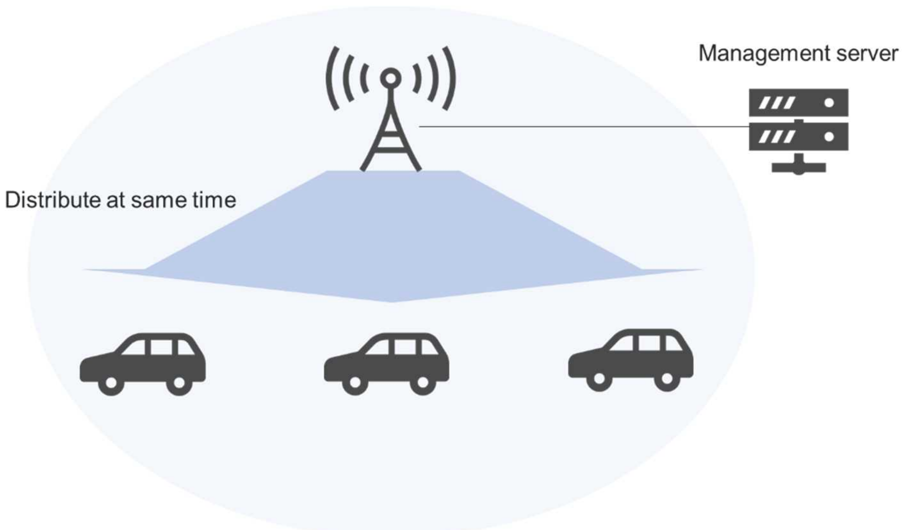

Fig. 2.1-2 Broadcast

2.1.1 Understanding of use cases

Of the 25 use cases of cooperative driving automation shown in Table 2-1 to Table 2-3, those classified as “realized using wide-area communication” are as follows.

1) b. Traffic signal information
- b-1-2. Driving assistance by using traffic signal information (V2N)

2) d. Lookahead information: Trajectory change signal information
- d-1. Driving assistance by notification of abnormal vehicles
- d-2. Driving assistance by notification of wrong-way vehicles
- d-3. Driving assistance based on traffic congestion information
- d-4. Traffic congestion assistance at branches and exits
- d-5. Driving assistance based on hazard information

3) e. Lookahead information: Emergency vehicle notification
- e-1. Driving assistance based on emergency vehicle information

4) f. Information collection / distribution by infrastructure
- f-1. Request for rescue (e-Call)
- f-2. Collection of information to optimize the traffic flow
- f-3. Update and generation of maps
- f-4. Distribution of dynamic map information

5) h. Remote control
- h-1. Operation and management of mobility service cars

Points to consider (communication requirements, etc.) noted by the TF regarding these use cases are described in Table 2.1.1-1.

Table 2.1.1-1 Points to consider (communication requirements, etc.) on use cases using wide-area communication (1/4)

Classification by function		b. Traffic signal information	d. Lookahead information: Trajectory change	
Use case		b-1-2. Driving assistance by using traffic signal information (V2N)	d-1. Driving assistance by notification of abnormal vehicles	d-2. Driving assistance by notification of wrong-way vehicles
Communication		V2N	V2I, V2N	V2I, V2N
Connection type		One-to-many	One-to-many	One-to-many
Control use		Speed adjustment, stop	Lane change, trajectory change	Lane change, trajectory change, evacuation to shoulder
Immediate response		Necessary	Unnecessary	Unnecessary
Data section / information content	Message	Traffic signal phase and timing information	Event information on abnormal vehicles	Presence of wrong-way vehicles
	Sensor data	-	Location	Location, speed, lane section of wrong-way vehicles
	Rich content	-	-	-
Data volume		Small	Small	Small

Table 2.1.1-1 Points to consider (communication requirements, etc.) on use cases using wide-area communication (2/4)

Classification by function		d. Lookahead information: Trajectory change		
Use case		d-3. Driving assistance based on traffic congestion information	d-4. Traffic congestion assistance at branches and exits	d-5. Driving assistance based on hazard information
Communication		V2N	V2I, V2N	V2I, V2N
Connection type		One-to-many	One-to-many	One-to-many
Control use		Trajectory change, speed adjustment, stop	Speed adjustment, trajectory change	Trajectory change, lane changes, automated driving control support level change
Immediate response		Unnecessary	Unnecessary	Unnecessary
Data section / information content	Message	Congestion status	Shoulder congestion status (toward branch)	Obstacle information
	Sensor data	-	Speed, location	Location
	Rich content	-	-	-
Data volume		Small	Small	Small

Table 2.1.1-1 Points to consider (communication requirements, etc.) on use cases using wide-area communication (3/4)

Classification by function		e. Lookahead information: Emergency vehicle notification	f. Information collection / distribution by infrastructure	
Use case		e-1. Driving assistance based on emergency vehicle information	f-1. Request for rescue (e-Call)	f-2. Collection of information to optimize the traffic flow
Communication		V2I, V2N, V2N	V2N	V2I, V2N
Connection type		One-to-many	One-to-one	One-to-one
Control use		Speed adjustment, lane change, stop (shoulder)	Report to authorities	-
Immediate response		Unnecessary	-	-
Data section / information content	Message	Emergency vehicle approach information	Request for rescue	-
	Sensor data	Location, speed	Location	Location, speed
	Rich content	-	-	-
Data volume		Small	Small	Small

Table 2.1.1-1 Points to consider (communication requirements, etc.) on use cases using wide-area communication (4/4)

Classification by function		f. Information collection / distribution by infrastructure		h. Remote control
Use case		f-3. Update and generation of maps	f-4. Distribution of dynamic map information	h-1. Operation and management of mobility service cars
Communication		V2N	V2N	V2N
Connection type		One-to-one	One-to-many	One-to-one
Control use		-	Trajectory change	Remote control
Immediate response		-	-	Necessary
Data section / information content	Message	-	-	Remote control instructions
	Sensor data	Location	-	Location, speed
	Rich content	Onboard camera video	Road data, feature location, etc.	Onboard camera video
Data volume		Large	Large	Large

Also, images of realizing each use case are described.

1) b. Traffic signal information

- b-1-2. Driving assistance by using traffic signal information (V2N)

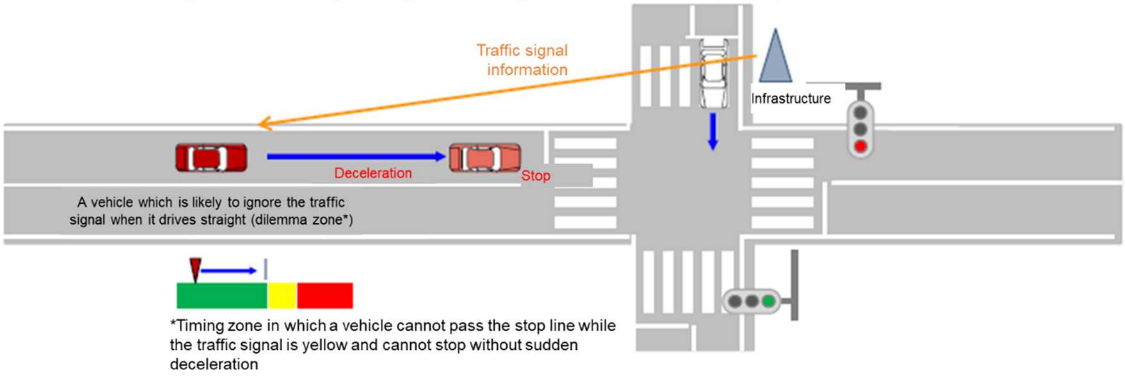

Fig. 2.1.1-1 b-1-2. Driving assistance by using traffic signal information (V2N)

2) d. Lookahead information: Trajectory change signal information

- d-1. Driving assistance by notification of abnormal vehicles

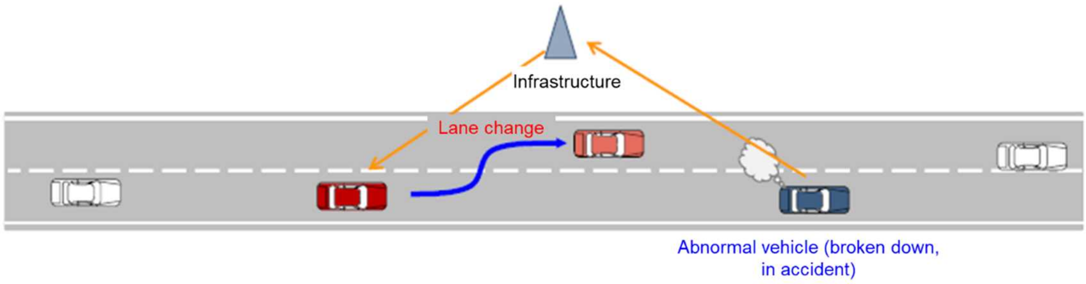

Fig. 2.1.1-2 d-1. Driving assistance by notification of abnormal vehicles

- d-2. Driving assistance by notification of wrong-way vehicles

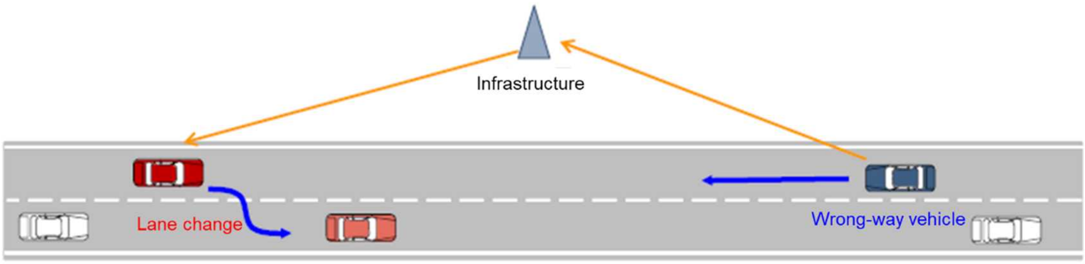

Fig. 2.1.1-3 d-2. Driving assistance by notification of wrong-way vehicles

- d-3. Driving assistance based on traffic congestion information

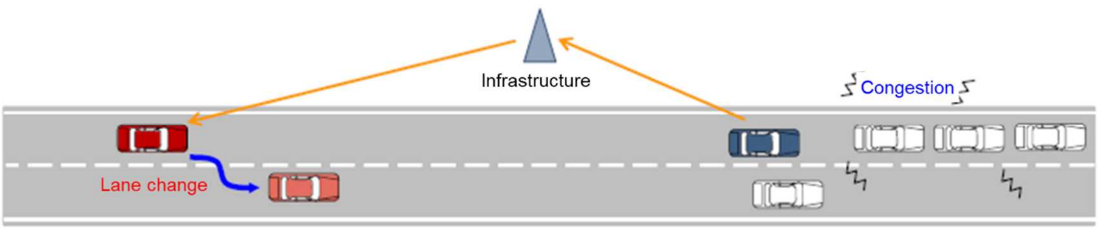

Fig. 2.1.1-4 d-3. Driving assistance based on traffic congestion information

- d-4. Traffic congestion assistance at branches and exits

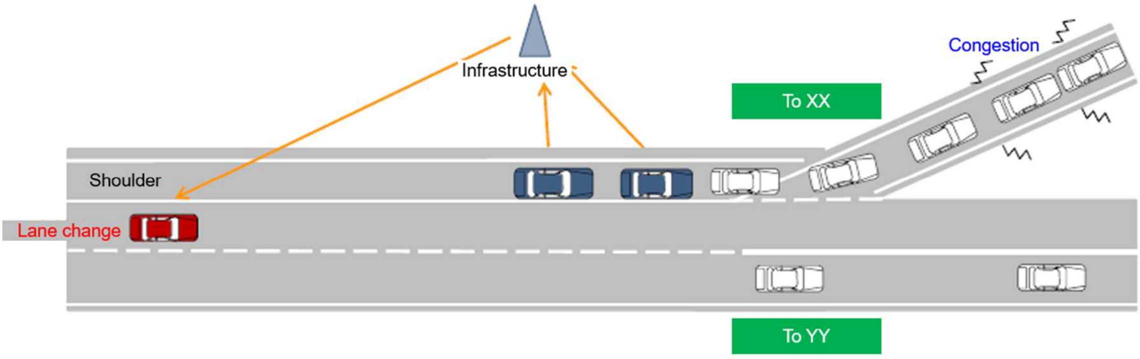

Fig. 2.1.1-5 d-4. Traffic congestion assistance at branches and exits

- d-5. Driving assistance based on hazard information

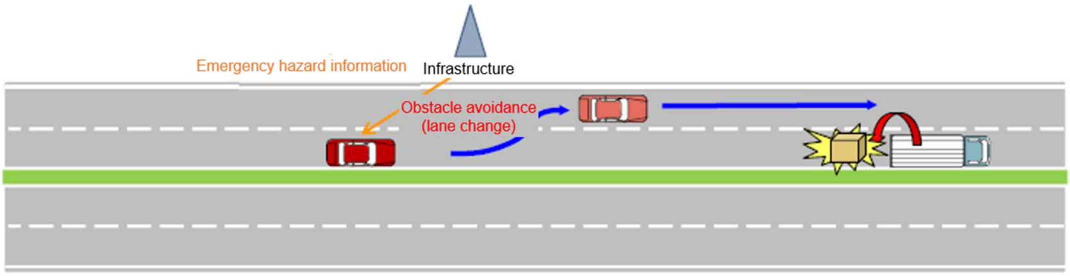

Fig. 2.1.1-6 d-5. Driving assistance based on hazard information

3) e. Lookahead information: Emergency vehicle notification

- e-1. Driving assistance based on emergency vehicle information

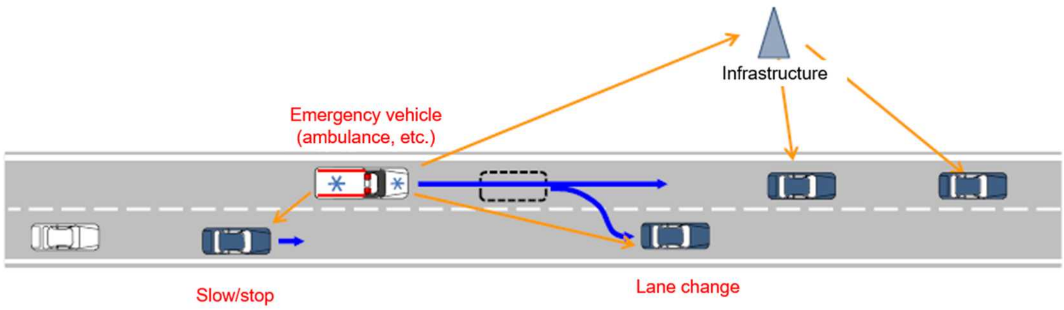

Fig. 2.1.1-7e-1. Driving assistance based on emergency vehicle information

4) f. Information collection / distribution by infrastructure

- f-1. Request for rescue (e-Call)

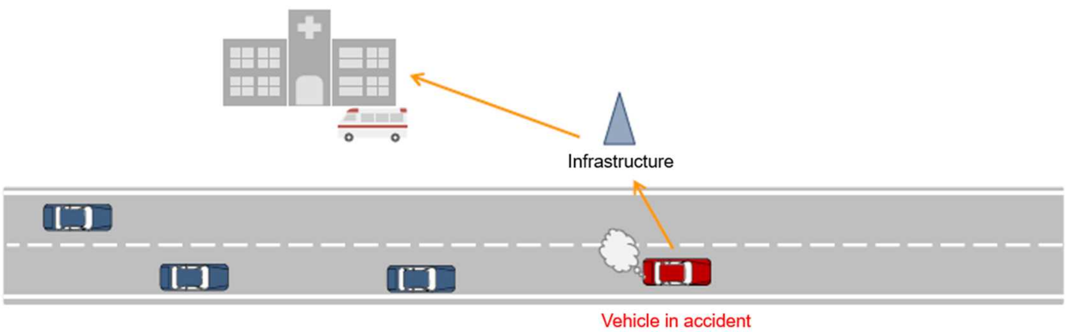

Fig. 2.1.1-8 f-1. Request for rescue (e-Call)

- f-2. Collection of information to optimize the traffic flow

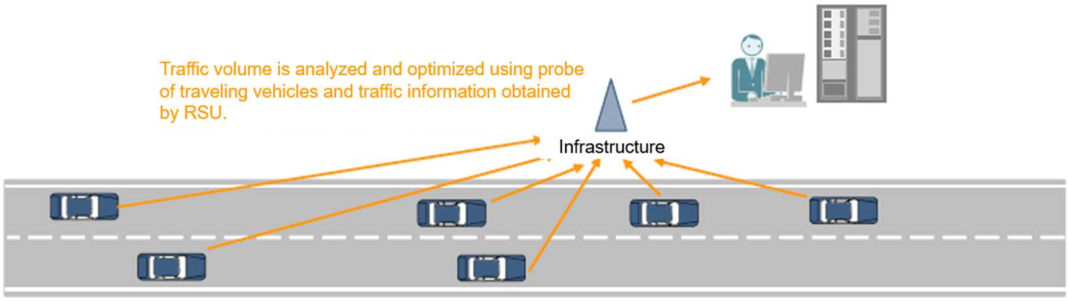

Fig. 2.1.1-9 f-2. Collection of information to optimize the traffic flow

- f-3. Update and generation of maps

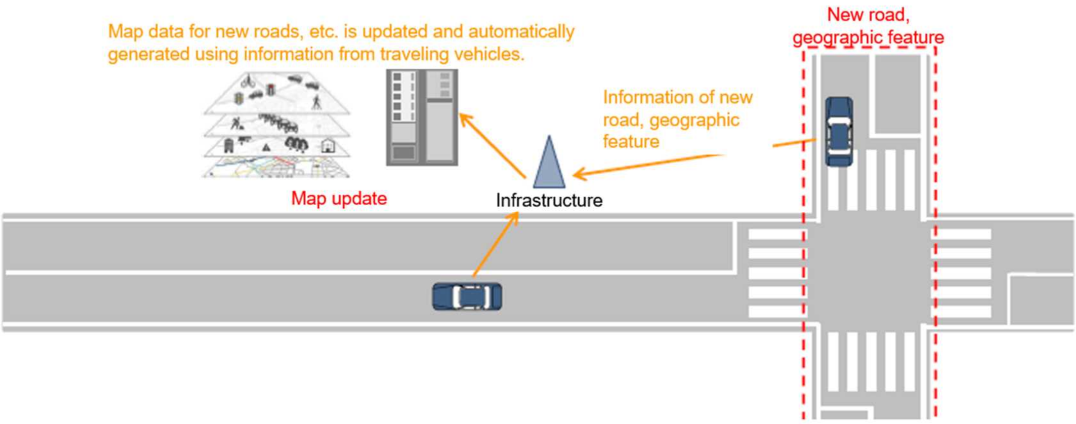

Fig. 2.1.1-10 f-2. Collection of information to optimize the traffic flow

- f-4. Distribution of dynamic map information

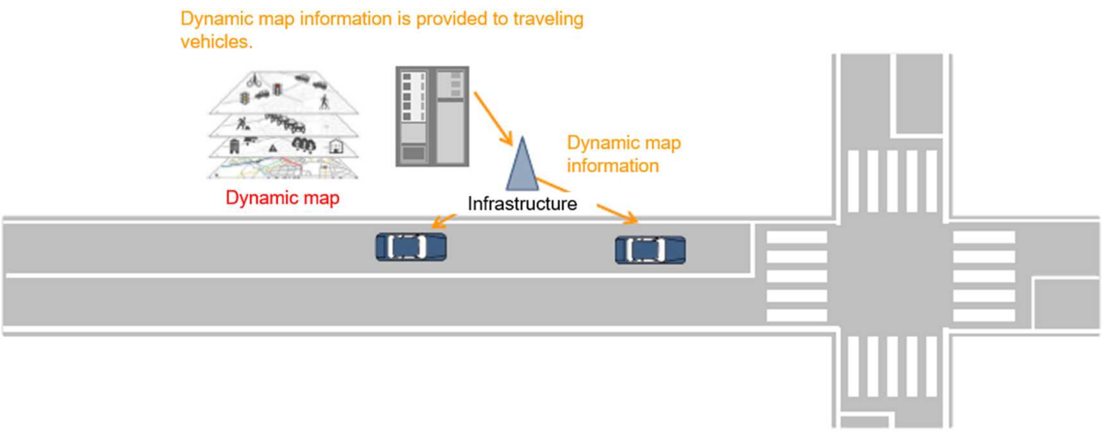

Fig. 2.1.1-11 f-4. Distribution of dynamic map information

5) h. Remote control

- h-1. Operation and management of mobility service cars

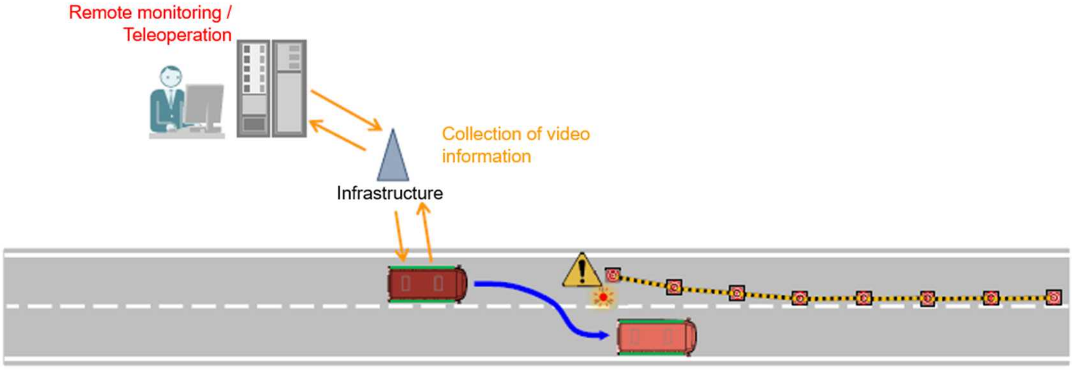

Fig. 2.1.1-12 h-1. Operation and management of mobility service cars

(1) Technical requirements

In the use cases formulated by the TF, the technical requirements for realizing the use cases using wide-area communications are described in Table 2.1.1-2.

Table 2.1.1-2 Technical requirements of use cases using wide-area communication (1/2)

Use case	Technical requirements
b-1-2. Driving assistance by using traffic signal information (V2N)	The location information of the cooperative driving vehicle is sent from the vehicle to the management server (signal information center, distribution center, etc.). Traffic signal phase and timing information (the next traffic signal color and the time until change), etc., of traffic signals at intersections is provided by the management server to vehicles that enter intersections to assist deceleration and stopping, and thereby avoid a dilemma.
d-1. Driving assistance by notification of abnormal vehicles	Event information (broken-down vehicle, accident vehicle, etc.) and location information (section located, lane) of abnormal vehicles stopped on the road are sent from the abnormal vehicle to the management server. The management server provides information on abnormal vehicles to surrounding vehicles to assist them in making lane changes and trajectory changes earlier.
d-2. Driving assistance by notification of wrong-way vehicles	The location and speed of the wrong-way vehicles and information on the presence of the wrong-way vehicles are sent from the wrong-way vehicle to the management server. Information on wrong-way vehicles is provided from the management server to surrounding vehicles to encourage them to change lanes, etc., in advance to assist in collision avoidance.
d-3. Driving assistance based on traffic congestion information	Information on congestion status is sent from vehicles in congestion to the management server. Information on congestion status is provided from the management server to surrounding vehicles to assist driving.
d-4. Traffic congestion assistance at branches and exits	Information on shoulder congestion status (location and speed) is sent from vehicles in congestion to the management server. Information on congestion status is provided from the management server to surrounding vehicles to assist them in entering branches.
d-5. Driving assistance based on hazard information	Obstacle, construction, congestions, and other information is provided from the management server to surrounding vehicles to assist driving.

Table 2.1.1-2 Technical requirements of use cases using wide-area communication (2/2)

Use case	Technical requirements
e-1. Driving assistance based on emergency vehicle information	Information on the direction of movement, speed, and planned route (planned travel lane) of emergency vehicles is sent from the emergency vehicle to the management server. Information on emergency vehicles is provided from the management server to surrounding vehicles to encourage surrounding vehicles to slow down, stop, etc., to support smooth passage of the emergency vehicle.
f-1. Request for rescue (e-Call)	An abnormal vehicle, such as a vehicle involved in an accident, automatically or manually by an occupant sends a request for rescue to the management server (rescue service provider, etc.) with the event, location information, etc., to request rescue. After message communication is completed between the abnormal vehicle and the rescue service provider, further detailed information is collected through voice communication and utilized for rescue.
f-2. Collection of information to optimize the traffic flow	Messages with data on the location and speed of the traveling vehicle are sent from the autonomous vehicle to the management server (automobile manufacturer, traffic information provider, etc.) via public communication network and collected for analysis and optimization of traffic volume.
f-3. Update and generation of maps	If a change is detected in the collected detection target information and the map information held while driving, the map information (information on the change) is sent from the vehicle to the management server (automobile manufacturer, map information provider, etc.).
f-4. Distribution of dynamic map information	Difference updating of static maps due to changes in geographic features, etc., is covered. Map information is sent to a management server (information distribution center server) while the automated vehicle is in motion. The management server sends map tile data with the update to the vehicle and performs a difference update of the static map on the route to be traveled.
h-1. Operation and management of mobility service cars	In traffic environments where avoidance is difficult with an autonomous driving system, video information, etc., from mobility service cars is sent to the management server (operation manager). Remote control instructions from the management server are sent between mobility service cars and to operate and manage the vehicles from a remote location.

(2) Communication requirements

Communication requirements based on communication scenarios are shown in Table 2.1.1-3.

Table 2.1.1-3 Communication requirements of use cases using wide-area communication (1/4)

Classification by function	b. Traffic signal information	d. Lookahead information: Trajectory change	
Use case	Driving assistance by using traffic signal information (V2N)	Driving assistance by notification of abnormal vehicles	Driving assistance by notification of wrong-way vehicles
No.	b-1-2.	d-1.	d-2.
Message name	-	-	-
Communication format	V2N	V2N	V2N
Communication counterpart	Non-specified vehicles	Non-specified vehicles present in areas where hazard information can be effectively used	Non-specified vehicles present in areas where hazard information can be effectively used
Target area (minimum range)	Service area is range covered by cellular	Event occurrence point to 1 km (provisional)	Event occurrence point to 2 km (provisional)
Number of transmitting vehicles per area	RSU installation model (See https://www.soumu.go.jp/main_content/000455914.pdf Part 4.2)	Uplink: Number of abnormal vehicles (ordinarily 1 vehicle) Downlink: 285 (unicast assumed)	Uplink: Number of abnormal vehicles (ordinarily 1 vehicle) Downlink: 567 (unicast assumed)
Required communication distance	Passenger vehicles: Approx. 138.5 m (provisional) Large vehicles: Approx. 206.3 m (provisional) (yellow 4 sec. 60 km/h) Note, 700 MHz band system request value is 240 m	From 255 m to 1 km upstream from the event occurrence point (provisional) As service provision range	From 510 m to 2 km upstream from the event occurrence point (provisional) As service provision range
Maximum relative speed	70 km/h	20 km/h to 120 km/h	20 km/h to 120 km/h
Maximum data size*1	About value in 700 MHz band system	715 bytes (465+250)	715 bytes (465+250)
Cyclic or acyclic	Under consideration	Cyclic	Cyclic
Transmission cycle*2	Under consideration	Minimum 7.65 sec.	Minimum 7.65 sec.
PAR per packet*3	Under consideration	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)
Allowable delay of radio communication section	Consideration needed throughout system-wide delay	Not specified	Not specified

Table 2.1.1-3 Communication requirements of use cases using wide-area communication (2/4)

Classification by function	d. Lookahead information: Trajectory change		
Use case	Driving assistance based on traffic congestion information	Traffic congestion assistance at branches and exits	Driving assistance based on hazard information
No.	d-3.	d-4.	d-5.
Message name	-	-	-
Communication format	V2N	V2N	V2N
Communication counterpart	Non-specified vehicles present in areas where hazard information can be effectively used	Non-specified vehicles present in areas where hazard information can be effectively used	Non-specified vehicles present in areas where hazard information can be effectively used
Target area (minimum range)	Event occurrence point to 1 km (provisional)	Event occurrence point to 1 km (provisional) and one branch or exit previous upstream to 1 km upstream	Event occurrence point to 1 km (provisional)
Number of transmitting vehicles per area	Uplink: Number of abnormal vehicles (ordinarily 1 vehicle) Downlink: 285 (unicast assumed)	Uplink: Number of abnormal vehicles (ordinarily 1 vehicle) Downlink: 570 (unicast assumed)	Downlink: 285 (unicast assumed)
Required communication distance	From 255 m to 1 km upstream from the event occurrence point (provisional) As service provision range	From 255 m to 1 km upstream from the event occurrence point (provisional) As service provision range	From 255 m to 1 km upstream from the event occurrence point (provisional) As service provision range
Maximum relative speed	20 km/h to 120 km/h	20 km/h to 120 km/h	20 km/h to 120 km/h
Maximum data size*1	715 bytes (465+250)	715 bytes (465+250)	715 bytes (465+250)
Cyclic or acyclic	Cyclic	Cyclic	Cyclic
Transmission cycle*2	Minimum 7.65 sec.	Minimum 7.65 sec.	Minimum 7.65 sec.
PAR per packet*3	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)
Allowable delay of radio communication section	Not specified	Not specified	Not specified

Table 2.1.1-3 Communication requirements of use cases using wide-area communication (3/4)

Classification by function	e. Lookahead information: Emergency vehicle notification	f. Information collection / distribution by infrastructure	
Use case	Driving assistance based on emergency vehicle information	Request for rescue (e-Call)	Collection of information to optimize the traffic flow
No.	e-1.	f-1.	f-2.
Message name	-	-	-
Communication format	V2N	V2N	V2N
Communication counterpart	Non-specified vehicles present in areas where emergency vehicle information can be effectively used	Non-specified vehicles	Non-specified vehicles
Target area (minimum range)	General road: Semicircle with radius of 700 m Expressway: Semicircle with radius of 1000 m	Communication area of public network by telecommunication carrier	Communication area of public network by telecommunication carrier
Number of transmitting vehicles per area	Uplink: Number of emergency vehicles (ordinarily 1 vehicle) Downlink: 285 (provisional, unicast assumed)	Not specified	Not specified
Required communication distance	General road: Semicircle with radius of 700 m Expressway: Semicircle with radius of 1000 m	-	-
Maximum relative speed	20 km/h to 120 km/h	20 km/h to 120 km/h	20 km/h to 120 km/h
Maximum data size*1	1035 bytes (785+250)	Uplink：675 bytes (425+250) Downlink: Not specified *Voice always communicated during communication for both Uplink and Downlink in addition to the above	Uplink：279 bytes (29+250) Downlink: Not specified
Cyclic or acyclic	Cyclic	Acyclic	Cyclic
Transmission cycle*2	Minimum 7.65 sec.	-	Minimum 1 minute
PAR per packet*3	PAR $\geq$ 99% (provisional)	-	-
Allowable delay of radio communication section	Not specified	Not specified	Not specified

Table 2.1.1-3 Communication requirements of use cases using wide-area communication (4/4)

Classification by function	f. Information collection / distribution by infrastructure		h. Remote control	
Use case	Update and automatic generation of maps	Distribution of dynamic map information	Operation and management of mobility service cars (Instructions for remote control outside ODD conditions)	Operation and management of mobility service cars (Instructions for travel route under ODD conditions)
No.	f-3.	f-4.	h-1a.	h-1b.
Message name	-	-	-	-
Communication format	V2N	V2N	V2N	V2N
Communication counterpart	Non-specified vehicles	Non-specified vehicles	Non-specified vehicles	Non-specified vehicles
Target area (minimum range)	Communication area of public network by telecommunication carrier	Communication area of public network by telecommunication carrier	Communication area of public network by telecommunication carrier	Communication area of public network by telecommunication carrier
Number of transmitting vehicles per area	Not specified	Not specified	Not specified	Not specified
Required communication distance	-	-	-	-
Maximum relative speed	20 km/h to 120 km/h	20 km/h to 120 km/h	T.B.D.	T.B.D.
Maximum data size*1	Uplink: 20.5M bytes (including image data (up to 5 images)) Downlink: Not specified	Uplink: Not specified Downlink：67 Mbps (Maximum case)	Uplink: Video information around vehicle, remote control request Downlink: Remote control data (when remote control is implemented)	Uplink: Video information around vehicle, route instruction request Downlink: Travel route (when travel route instruction implemented)
Cyclic or acyclic	Acyclic	Acyclic	Acyclic	Acyclic
Transmission cycle*2	-	-	-	-
PAR per packet*3	-	-	T.B.D.	T.B.D.
Allowable delay of radio communication section	Not specified	Not specified	T.B.D.	T.B.D.

*1 Indicates data size at application layer.
*2 Indicates transmission cycle at application layer.
*3 Indicates PAR at radio layer.

From the technical requirements described in Table 2.1.1-2 and the communication requirements described in Table 2.1.1-3, the extracted points to consider for communication in realizing use cases using wide-area communication are shown in Table 2.1.1-4. In addition, points to consider organized as they apply to each use case are shown in Table 2.1.1-5.

Table 2.1.1-4 Points to consider in realizing use cases using wide-area communication

No.	Item	Points to consider
1	Communication traffic	When used for information such as non-line of site lookahead information, the communication traffic is small. However, dynamic map information collection/distribution and remote control require high communication traffic due to the need to transmit video images in the quality necessary for judgment and operation.
2	Communication area	Area of telecommunications carrier's communication network assumed.
3	Communication delay	In providing lookahead information and collecting/distributing information, immediate response is not assumed to be required. Remote control requires immediate response according to required functions and performance.
4	Number of signaling devices	The required communication frequency (fixed cycle) and signaling devices according to the event occurrence are required for vehicles within the area of one base station. (Consideration by unicast and broadcast necessary)
5	Frequency of communication	The required communication frequency (fixed cycle) and communication frequency according to the event occurrence are required for vehicles within the area of one base station. (Consideration by unicast and broadcast necessary)

Table 2.1.1-5 Points to consider in communication requirements of each use case

Classification by function	Use case	Individual item	Common item
b. Traffic signal information	b-1-2. Driving assistance by using traffic signal information (V2N)	• None	• Communication delay Determination of measures to respond to requirements on communication delay for each use case • Communication quality Determination of measures to respond to requirements on communication quality for each use case • Communication technology Selection of broadcast, multicast, or unicast
d. Lookahead information: Trajectory change signal information	d-1. Driving assistance by notification of abnormal vehicles	• Frequency of communicating vehicle location information between vehicle and center in order to determine vehicles transmitting information corresponding to communication technologies	
	d-2. Driving assistance by notification of wrong-way vehicles		
	d-2. Driving assistance by notification of wrong-way vehicles		
	d-3. Driving assistance based on traffic congestion information		
	d-4. Traffic congestion assistance at branches and exits		
	d-5. Driving assistance based on hazard information		
e. Lookahead information: Emergency vehicle notification	e-1. Driving assistance based on emergency vehicle information		
f. Information collection / distribution by infrastructure	f-1. Request for rescue (e-Call)	• None	
	f-2. Collection of information to optimize the traffic flow	• None	
	f-3. Update and generation of maps	• None	
	f-4. Distribution of dynamic map information	• None	
h. Remote control	h-1. Operation and management of mobility service cars	• Communication traffic between the vehicle and the center during remote control (video, etc.) • Communication delay between the vehicle and the center during remote control (maneuver)	

2.1.2 Organization of compatibility of target use cases

The following describes the perspective for evaluating the selection of use cases using wide-area communication to be considered when examining problems and countermeasures for wide-area communication, and the results of the selection of use cases to be considered.

(1) Perspective for evaluating selection of use cases

Based on section 2.1.1, the following evaluation perspectives are important for cooperative driving automation use cases using wide-area communication.

- Communication traffic

In remote control (maneuver) (h-1.), important information to be sent from the vehicle to the operation manager includes image information of the vehicle's surroundings, and that is expected to be large-volume communication. Large-volume communication will be needed in dynamic map distribution (f-4.) as well.

- Communication delay

In remote control (maneuver) (h-1.), immediacy necessary for safe operation will be needed from the operations manager to the vehicle based on information obtained from the vehicle. It is also necessary to recognize the vehicle's location information, etc., that should provide the necessary information.

- Number of signaling devices / Frequency of communication

The vehicle needs to send location information and vehicle information to the management server at regular intervals. However, if this interval is long, vehicle location error will increase; and if it is short, the accuracy will improve but the network load may increase. It is necessary to consider how many vehicles are present in the information distribution area required for the use case.

In light of the above, desktop evaluation was conducted on problems and countermeasures in terms of "communication traffic," "communication delay," and "number of signaling devices / frequency of communication". For desktop evaluation results, see case 3.1.

(2) Selection of use cases

The "communication traffic," "communication delay," and "number of signaling devices / frequency of communication" are shown in Table 2.1.1-3 as communication for realizing cooperative driving automation use cases using wide-area communication. And for the points to consider shown in Table 2.1.1-4, the following supplements are provided for "communication traffic," "communication delay," and "number of signaling devices / frequency of communication."

- Communication traffic

In remote control (h-1.), information such image information around the vehicle needed for remote control must be sent from the vehicle to the operation manager. In addition, a large volume of communication must take place in the vehicle-to-base station direction (Uplink).

And in dynamic map distribution (f-4.), large volumes of map information will be continuously distributed from base station to vehicle (Downlink).

- Communication delay

In remote control (maneuver) (h-1.), immediacy required for safe operation will be needed from the operations manager to the vehicle based on information obtained from the vehicle, but processing delay at each device in the wide-area network and communication delay at the communication paths connecting each device will each accumulate. Low delay is required for remote control that requires immediacy.

- Number of signaling devices / Frequency of communication

For example, with look-ahead information, the distribution area is selected by considering how long the information is needed before the vehicle arrives at the location where the alert occurs (how many seconds before arriving at the site where the alert occurs so that the trajectory can be safely changed), and the number of target vehicles is determined by considering how many vehicles may be present in that area. The frequency of communication was derived by examining the degree of accuracy required for vehicle location.

These issues mean that in order to achieve remote control using wide-area communication, a large volume of communication must be realized using Uplink with communication delay that does not interfere with operation. Although the distribution of map information is expected to be of large volume, the communication traffic is currently undetermined and some communication delay is acceptable, so the study was given a lower priority.

In addition, wide-area communication requires the accuracy necessary to realize the use cases of the location information of the vehicles to be managed. Shorter intervals between vehicle location information being provided increases accuracy, but as the number of vehicles increases, the communication traffic increases, which increases the load on the communication network and raises the concern of communication congestion. To prevent this from happening, it is necessary to establish an appropriate frequency of communication that takes into account the communication area and the number of target vehicles.

Based on the results of section 2.1.1 and this section, the following use cases were selected for desk review of problems and countermeasures.

1) h. Remote control

Use cases where communication delay between vehicles and the center at remote control (maneuver) greatly impact system performance

- h-1. Operation and management of mobility service cars

2) d. Lookahead information: Trajectory change signal information

Typical use cases of providing lookahead information to the vehicle in question based on notification from the vehicle

- d-1. Driving assistance by notification of abnormal vehicles

Results of countermeasures against the selected used cases are shown in section 3.1.

2.2 Evaluation of compatibility in narrow-area communication

In considering compatibility of cooperative driving automation use cases using narrow-area communication, this section describes as understanding of the use cases the technical requirements necessary to realize use cases using narrow-area communication and the communication scenario and communication requirements. Note that narrow-area communication includes vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I), so organization and consideration of both was conducted.

2.2.1 Understanding of use cases

Of the 25 use cases of cooperative driving automation shown in Table 2-1 to Table 2-3, those classified as "realized using narrow-area communication" are as follows.

1) a. Merging / lane change assistance
- a-1-1. Merging assistance by preliminary acceleration and deceleration
- a-1-2. Merging assistance by targeting the gap on the mainline
- a-1-3. Cooperative merging assistance with vehicles on the mainline by roadside control
- a-1-4. Merging assistance based on negotiations between vehicles
- a-2. Lane change assistance when the traffic is heavy
- a-3. Entry assistance from non-priority roads to priority roads during traffic congestion

2) b. Traffic signal information
- b-1-1. Driving assistance by using traffic signal information (V2I)

3) c. Lookahead information: Collision avoidance
- c-1. Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly
- c-2-1. Driving assistance based on intersection information (V2V)
- c-2-2. Driving assistance based on intersection information (V2I)
- c-3. Collision avoidance assistance by using hazard information

4) d. Lookahead information: Trajectory change signal information
- d-1. Driving assistance by notification of abnormal vehicles
- d-2. Driving assistance by notification of wrong-way vehicles
- d-3. Driving assistance based on traffic congestion information
- d-4. Traffic congestion assistance at branches and exits
- d-5. Driving assistance based on hazard information

5) e. Lookahead information: Emergency vehicle notification
- e-1. Driving assistance based on emergency vehicle information

6) f. Information collection / distribution by infrastructure
- f-2. Collection of information to optimize the traffic flow

7) g. Platooning / adaptive cruise control
- g-1. Unmanned platooning of following vehicles by electronic towbar
- g-2. Adaptive cruise control and manned platooning of following vehicles using adaptive cruise control

Points to consider (communication requirements, etc.) noted by the TF regarding these use cases are described in Table 2.2.1-1.

Table 2.2.1-1 Points to consider on use cases using narrow-area communication (communication requirements, etc.) (1/6)

Classification by function		a. Merging / lane change assistance		
Use case		a-1-1. Merging assistance by preliminary acceleration and deceleration	a-1-2. Merging assistance by targeting the gap on the mainline	a-1-3. Cooperative merging assistance with vehicles on the mainline by roadside control
Communication		V2I	V2I	V2I
Connection type		One-to-many	One-to-many	One-to-many
Control use		Preliminary acceleration/deceleration	Speed adjustment	Speed adjustment, interval adjustment
Immediate response		Necessary	Necessary	Necessary
Data section / information content	Message	Estimated time of arrival at merge point (mainline vehicle)	Estimated time of arrival at merge point (mainline vehicle)	Time of arrival at merge point (mainline vehicle), interval adjustment request
	Sensor data	Speed (mainline spot measurement), vehicle length	Speed, location (mainline spot measurement), vehicle length	Speed, location
	Rich content	-	-	-
Data volume		Small	Small	Small

Table 2.2.1-1 Points to consider on use cases using narrow-area communication (communication requirements, etc.) (2/6)

Classification by function		a. Merging / lane change assistance		
Use case		a-1-4. Merging assistance based on negotiations between vehicles	a-2. Lane change assistance when the traffic is heavy	a-3. Entry assistance from non-priority roads to priority roads during traffic congestion
Communication		V2V	V2V	V2V
Connection type		One-to-many -> One-to-one	One-to-many -> One-to-one	One-to-many -> One-to-one
Control use		Speed adjustment, interval adjustment	Interval adjustment, lane change	Right/left turn, interval adjustment
Immediate response		Necessary	Necessary	Necessary
Data section / information content	Message	Interval adjustment request, acceptance permission	Interval adjustment request, acceptance permission	Entry request, acceptance permission
	Sensor data	Speed, location	Speed, location	Speed, location
	Rich content	-	-	-
Data volume		Small	Small	Small

Table 2.2.1-1 Points to consider on use cases using narrow-area communication (communication requirements, etc.) (3/6)

Classification by function		b. Traffic signal information	c. Lookahead information: Collision avoidance	
Use case		b-1-1. Driving assistance by using traffic signal information (V2I)	c-1. Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly	c-2-1. Driving assistance based on intersection information (V2V)
Communication		V2I	V2V	V2V
Connection type		One-to-many	One-to-many	One-to-many
Control use		Speed adjustment, stop	Speed adjustment, stop	Transmission ability judgement, speed adjustment, stop
Immediate response		Necessary	Necessary	Necessary
Data section / information content	Message	Current traffic signal color, traffic signal phase and timing information	Sudden braking information	-
	Sensor data	-	Location, speed	Location, speed
	Rich content	-	-	-
Data volume		Small	Small	Small

Table 2.2.1-1 Points to consider on use cases using narrow-area communication (communication requirements, etc.) (4/6)

Classification by function		c. Lookahead information: Collision avoidance		d. Lookahead information: Trajectory change
Use case		c-2-2. Driving assistance based on intersection information (V2I)	c-3. Collision avoidance assistance by using hazard information	d-1. to d-5.
Communication		V2I	V2V	See Table 2.1.1-1
Connection type		One-to-many	One-to-many	
Control use		Transmission ability judgement, speed adjustment, stop	Trajectory change, lane changes, automated driving control support level change	
Immediate response		Necessary	Necessary	
Data section / information content	Message	-	Obstacle information, emergency control, steering	
	Sensor data	Location, speed	Location	
	Rich content	-	-	
Data volume		Small	Small	

Table 2.2.1-1 Points to consider on use cases using narrow-area communication (communication requirements, etc.) (5/6)

Classification by function		e. Lookahead information: Emergency vehicle notification	f. Information collection / distribution by infrastructure
Use case		e-1. Driving assistance based on emergency vehicle information	f-2. Collection of information to optimize the traffic flow
Communication		See Table 2.1.1-1	See Table 2.1.1-1
Connection type			
Control use			
Immediate response			
Data section / information content	Message		
	Sensor data		
	Rich content		
Data volume			

Table 2.2.1-1 Points to consider on use cases using narrow-area communication (communication requirements, etc.) (6/6)

Classification by function		g. Platooning / adaptive cruise control	
Use case		g-1. Unmanned platooning of following vehicles by electronic towbar	g-2. Adaptive cruise control and manned platooning of following vehicles using adaptive cruise control
Communication		V2V	V2V
Connection type		One-to-many	One-to-one or one-to-many
Control use		Interval adjustment, maintaining platooning	Maintaining interval
Immediate response		Necessary	Necessary
Data section / information content	Message	Acceleration, braking, steering operation, following vehicle information	Acceleration, braking operation
	Sensor data	Location, speed, intervehicle distance, acceleration/deceleration	Location, speed, intervehicle distance, acceleration/deceleration
	Rich content	Video transmission from vehicle 2 to the lead vehicle using electronic mirrors	-
Data volume		Large	Small

Also, images of realizing each use case are described.

1) a. Merging / lane change assistance

- a-1-1. Merging assistance by preliminary acceleration and deceleration

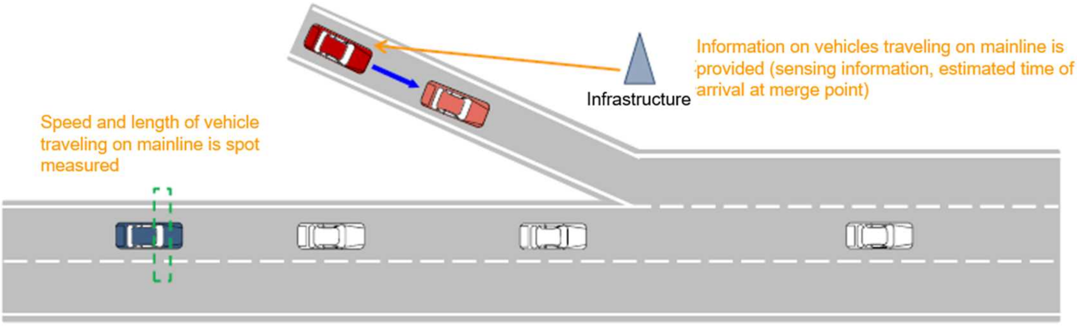

Fig. 2.2.1-1 a-1-1. Merging assistance by preliminary acceleration and deceleration

- a-1-2. Merging assistance by targeting the gap on the mainline

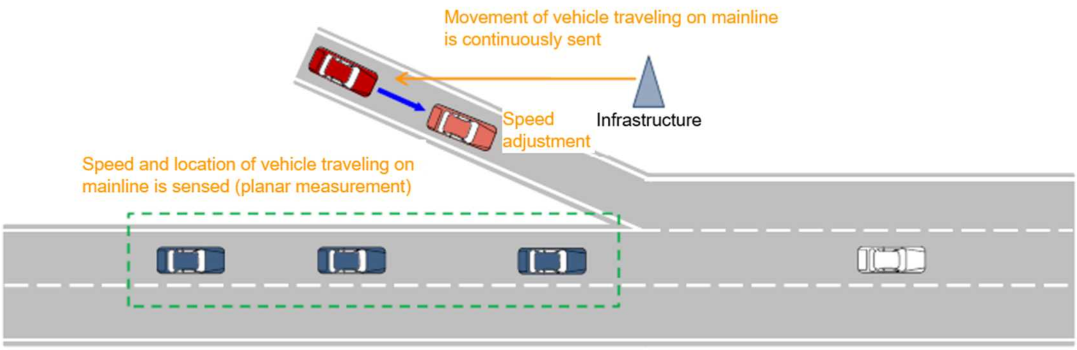

Fig. 2.2.1-2 a-1-2. Merging assistance by targeting the gap on the mainline

- a-1-3. Cooperative merging assistance with vehicles on the mainline by roadside control

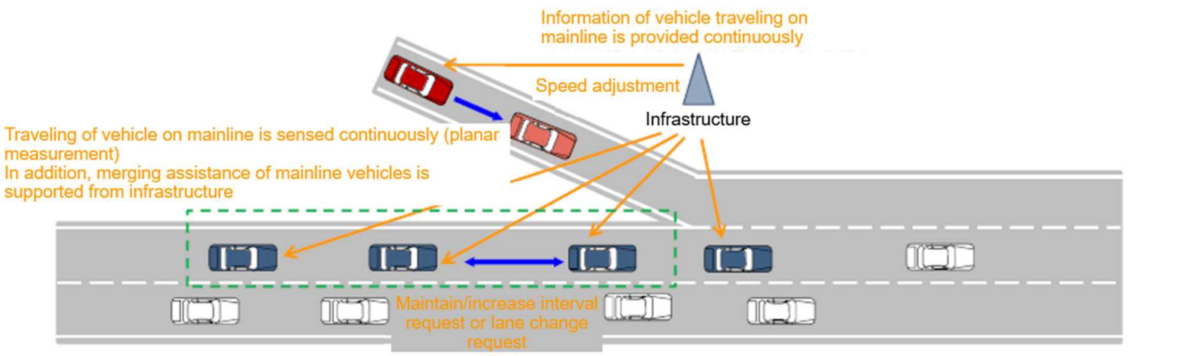

Fig. 2.2.1-3 a-1-3. Cooperative merging assistance with vehicles on the mainline by roadside control

- a-1-4. Merging assistance based on negotiations between vehicles

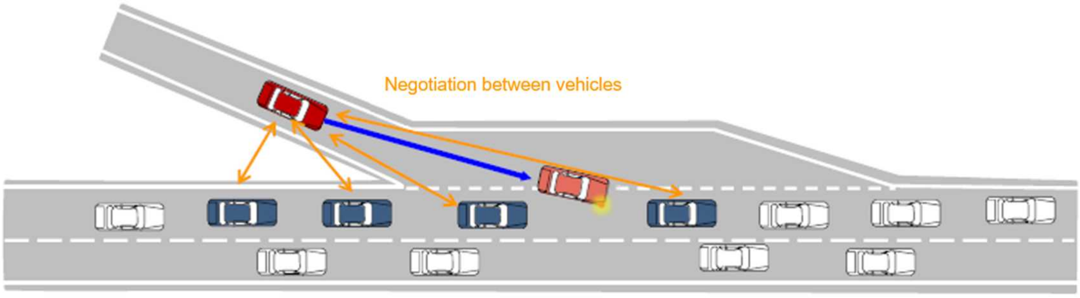

Fig. 2.2.1-4 a-1-4. Merging assistance based on negotiations between vehicles

- a-2. Lane change assistance when the traffic is heavy

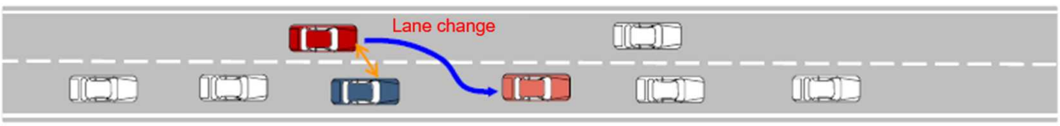

Fig. 2.2.1-5 a-2. Lane change assistance when the traffic is heavy

- a-3. Entry assistance from non-priority roads to priority roads during traffic congestion

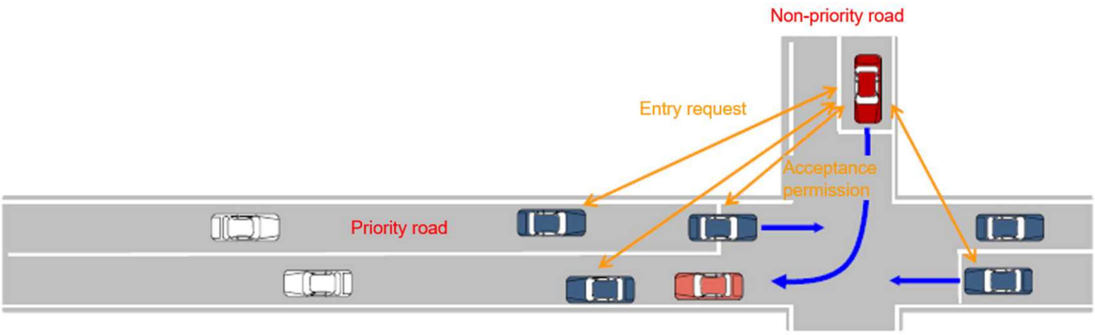

Fig. 2.2.1-6 a-3. Entry assistance from non-priority roads to priority roads during traffic congestion

2) b. Traffic signal information

- b-1-1. Driving assistance by using traffic signal information (V2I)

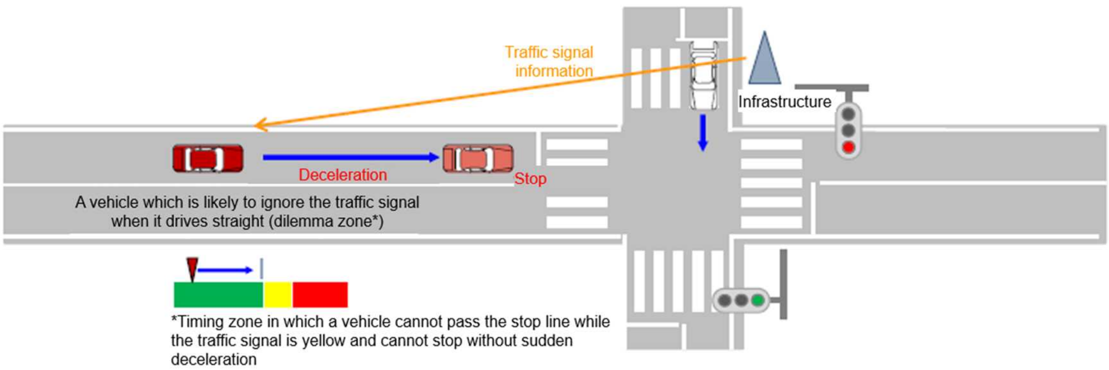

Fig. 2.2.1-7 b-1-1. Driving assistance by using traffic signal information (V2I)

3) c. Lookahead information: Collision avoidance

- c-1. Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly

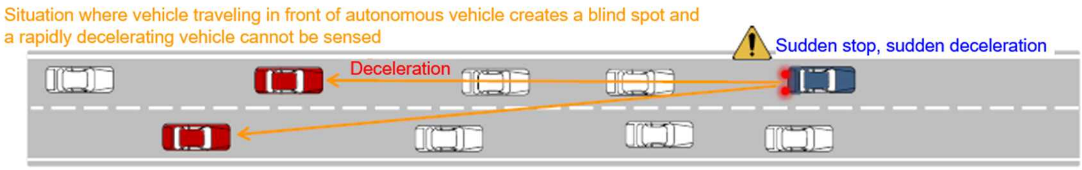

Fig. 2.2.1-8 c-1. Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly

- c-2-1. Driving assistance based on intersection information (V2V)

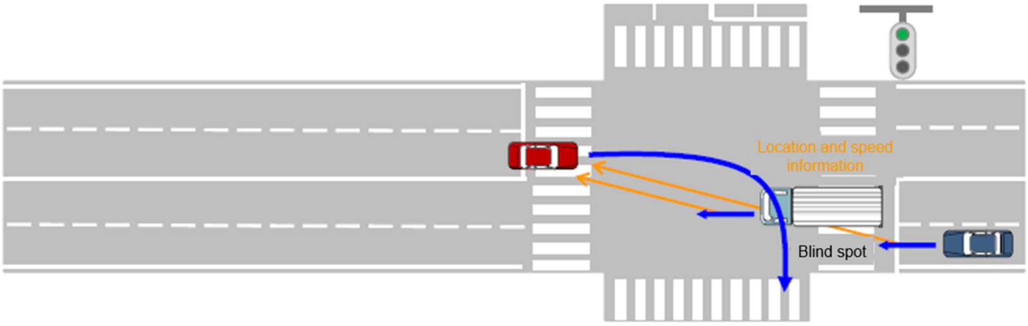

Fig. 2.2.1-9 c-2-1. Driving assistance based on intersection information (V2V)

- c-2-2. Driving assistance based on intersection information (V2I)

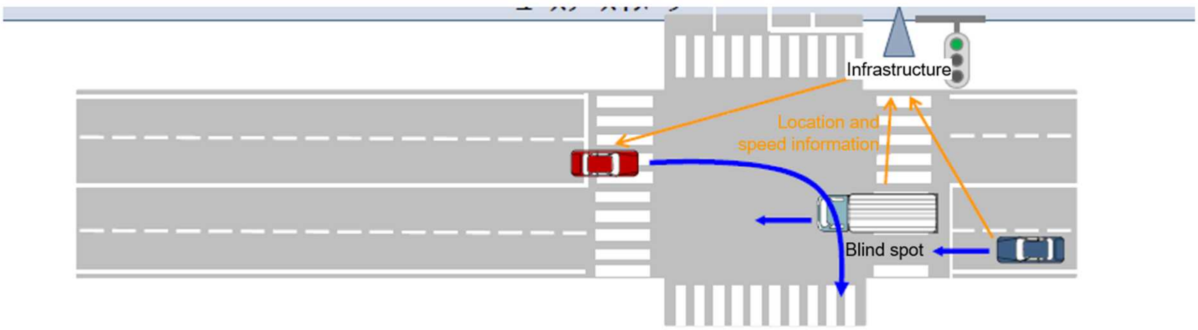

Fig. 2.2.1-10 c-2-2. Driving assistance based on intersection information (V2I)

- c-3. Collision avoidance assistance by using hazard information

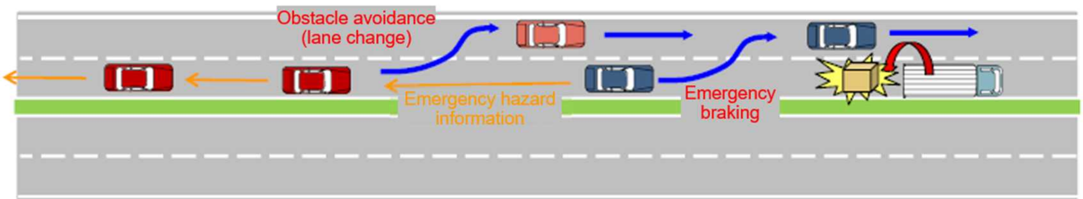

Fig. 2.2.1-11 c-3. Collision avoidance assistance by using hazard information

4) d. Lookahead information: Trajectory change signal information

- d-1. Driving assistance by notification of abnormal vehicles
- d-2. Driving assistance by notification of wrong-way vehicles
- d-3. Driving assistance based on traffic congestion information
- d-4. Traffic congestion assistance at branches and exits
- d-5. Driving assistance based on hazard information

  See section 2.1.1

5) e. Lookahead information: Emergency vehicle notification

- e-1. Driving assistance based on emergency vehicle information

  See section 2.1.1

6) f. Information collection / distribution by infrastructure

- f-2. Collection of information to optimize the traffic flow

  See section 2.1.1

7) g. Platooning / adaptive cruise control

- g-1. Unmanned platooning of following vehicles by electronic towbar

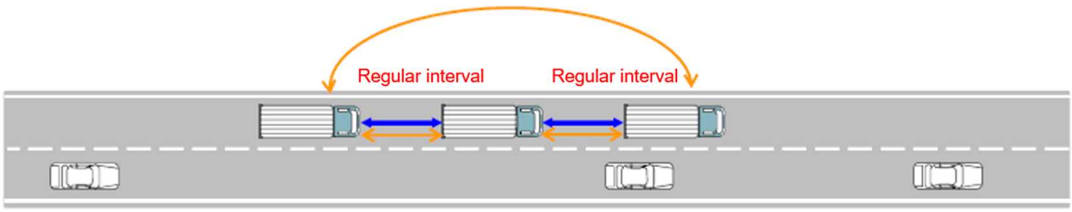

Fig. 2.2.1-12 g-1. Unmanned platooning of following vehicles by electronic towbar

- g-2. Adaptive cruise control and manned platooning of following vehicles using adaptive cruise control

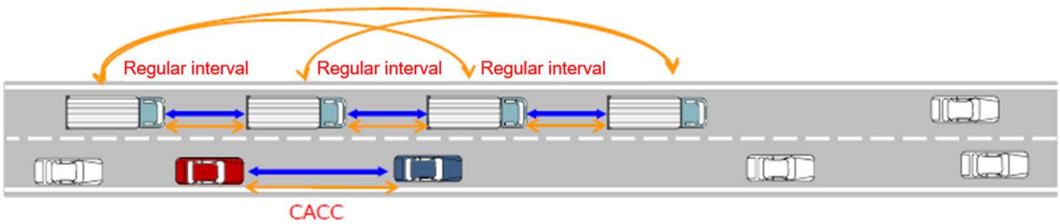

Fig. 2.2.1-13 g-2. Adaptive cruise control and manned platooning of following vehicles using adaptive cruise control

(1) Technical requirements

In the cooperative driving automation use cases formulated by the TF, the technical requirements for realizing the narrow-area communications use cases are described in Table 2.2.1-2.

Table 2.2.1-2 Technical requirements of use cases using narrow-area communication (1/4)

Use case	Technical requirements
a-1-1. Merging assistance by preliminary acceleration and deceleration	Information such as the speed of vehicles traveling on the mainline and the estimated time of arrival at the merge point is measured and provided from the roadside infrastructure to merging vehicles to support preliminary acceleration and deceleration.
a-1-2. Merging assistance by targeting the gap on the mainline	Continuously measured information on the location and speed of vehicles traveling on the mainline is continuously provided from the roadside infrastructure to merging vehicles to assist in merging by targeting gaps between vehicles traveling on the mainline.
a-1-3. Cooperative merging assistance with vehicles on the mainline by roadside control	Information on the location and speed of vehicles traveling on the mainline measured in a planar manner is provided from the roadside infrastructure to merging vehicles and control is requested from the roadside infrastructure for cooperative driving vehicles traveling on the mainline and connecting route.
a-1-4. Merging assistance based on negotiations between vehicles	When merging onto a congested mainline, the vehicle requesting to merge makes an agreement request to the receiving/responding vehicle, and the receiving/responding vehicle returns an agreement response. The system negotiates update requests and update responses as necessary based on the information responded and own-vehicle information to support merging.
a-2. Lane change assistance when the traffic is heavy	When lane changing to a congested lane, the vehicle requesting to change lanes makes an agreement request to the receiving/responding vehicle, and the receiving/responding vehicle returns an agreement response. The system negotiates update requests and update responses as necessary based on the information responded and own-vehicle information to support lane changing.
a-3. Entry assistance from non-priority roads to priority roads during traffic congestion	At an intersection without a traffic signal, the vehicle requesting to enter makes an agreement request to the receiving/responding vehicle, and the receiving/responding vehicle returns an agreement response. The system negotiates update requests and update responses as necessary based on the information responded and own-vehicle information to entry from non-priority roads to priority roads.

Table 2.2.1-2 Technical requirements of use cases using narrow-area communication (2/4)

Use case	Technical requirements
b-1-1. Driving assistance by using traffic signal information (V2I)	Current traffic signal color and traffic signal phase and timing information (the next traffic signal color and the time until change), etc., at intersections are provided periodically by the roadside infrastructure to vehicles that enter intersections to assist deceleration and stopping, and thereby avoid a dilemma.
c-1. Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly	Sudden braking information as well as location and speed information are provided by the suddenly decelerating vehicle to following vehicles to encourage them to stop or slow down in advance, thereby preventing pileups.
c-2-1. Driving assistance based on intersection information (V2V)	Location and speed information of vehicles that approach intersections is provided by approaching vehicles to other vehicles that approach or pass through intersections to assist them to pass through or make a right turn at intersections with many blind spots.
c-2-2. Driving assistance based on intersection information (V2I)	Location and speed information of vehicles that approach intersections, which is obtained from roadside sensors or vehicles, is provided by the roadside infrastructure to other vehicles that approach or pass through intersections to assist them to pass through or make a right turn at intersections with many blind spots.
c-3. Collision avoidance assistance by using hazard information	In the event of sudden deceleration or emergency lane change by a vehicle traveling ahead, emergency hazard information is provided to following vehicles to support smooth avoidance control.

Table 2.2.1-2 Technical requirements of use cases using narrow-area communication (3/4)

Use case	Technical requirements
d-1. Driving assistance by notification of abnormal vehicles	Event information (broken-down vehicle, accident vehicle, etc.) and location information (section located, lane) of abnormal vehicles stopped on the road are sent from the abnormal vehicle via the roadside infrastructure to the management server. The management server provides information on abnormal vehicles to surrounding vehicles via the roadside infrastructure to assist them in making lane changes and trajectory changes earlier.
d-2. Driving assistance by notification of wrong-way vehicles	The location and speed of the wrong-way vehicles and information on the presence of the wrong-way vehicles are sent from the wrong-way vehicle via the roadside infrastructure to the management server. Information on wrong-way vehicles is provided from the management server to surrounding vehicles via the roadside infrastructure to encourage them to change lanes, etc., in advance to assist in collision avoidance.
d-3. Driving assistance based on traffic congestion information	Information on congestion status is sent from vehicles in congestion via the roadside infrastructure to the management server. Information on congestion status is provided from the management server to surrounding vehicles via the roadside infrastructure to assist driving.
d-4. Traffic congestion assistance at branches and exits	Information on shoulder congestion status (location and speed) is sent from vehicles in congestion via the roadside infrastructure to the management server. Information on congestion status is provided from the management server to surrounding vehicles via the roadside infrastructure to assist them in entering branches.
d-5. Driving assistance based on hazard information	Obstacle, construction, congestions, and other information is provided from the management server via the roadside infrastructure to surrounding vehicles to assist driving.

Table 2.2.1-2 Technical requirements of use cases using narrow-area communication (4/4)

Use case	Technical requirements
e-1. Driving assistance based on emergency vehicle information	Information on the direction of movement and speed of emergency vehicles and their planned route (planned travel lane) is provided periodically from emergency vehicles to surrounding vehicles to encourage surrounding vehicles to slow down or stop, etc., to support smooth passage of the emergency vehicle.
f-2. Collection of information to optimize the traffic flow	Information on the location and speed of the traveling vehicles is collected via the roadside infrastructure for traffic volume analysis and optimization.
g-1. Unmanned platooning of following vehicles by electronic towbar	Operational information and other information on platooning vehicles is periodically provided between the trucks forming the column to support platooning.
g-2. Adaptive cruise control and manned platooning of following vehicles using adaptive cruise control	Location, speed, driving operation information of the vehicle ahead, etc., are periodically communicated to the vehicle behind to support adaptive cruise control.

(2) Communication requirements

Communication requirements based on communication scenarios are shown in Table 2.2.1-3.

Table 2.2.1-3 Communication requirements of use cases using narrow-area communication (1/7)

Classification by function	a. Merging / lane change assistance					
Use case	Merging assistance by preliminary acceleration and deceleration	Mainline gap aiming merging support	Mainline vehicle cooperative merging support by roadside control			
No.	a-1-1	a-1-2	a-1-3			
Message name	Location information	Location information	Location information	Control request	Agreement request update request	Agreement response update response
Communication format	V2I (I -> V)	V2I (I -> V)	V2I (I -> V)	V2I (V -> I)	V2I (I -> V)	V2I (V -> I)
Communication counterpart	Non-specified vehicles	Non-specified vehicles	Non-specified vehicles	Road infrastructure	Specified vehicles	Specified vehicles
Target area (minimum range)	From 6 seconds before merging starting point to the center between 6 seconds before merging starting point and merging starting point	From 6 seconds before merging starting point to merging starting point	From 6 seconds before merging starting point to merging starting point	Within control request range	Within control request range	Within control request range
Number of transmitting vehicles per area	1 vehicle	1 vehicle	1 vehicle	1 vehicle	1 vehicle (× control number)	48 vehicles *5 (control number, when traffic is heavy)
Required communication distance*1	33.9 to 59.3 m (NILIM standard: 95 m)	67.8 to 118.6 m	Connecting route: 67.8 to 118.6 m Mainline: 112.5 to 270 m	67.8 to 118.6 m	Connecting route: 67.8 to 118.6 m Mainline: 112.5 to 270.0 m	Connecting route: 67.8 to 118.6 m Mainline: 112.5 to 270.0 m
Maximum relative speed	Connecting route 20 to 70 km/h	Connecting route 20 to 70 km/h	Connecting route 20 to 70 km/h Mainline: 20 to 120 km/h	Connecting route 20 to 70 km/h Mainline: 20 to 120 km/h	Connecting route 20 to 70 km/h Mainline: 20 to 120 km/h	Connecting route 20 to 70 km/h Mainline: 20 to 120 km/h
Maximum data size	1510 bytes (1260+250) Anticipated vehicles: 46	2752 bytes (2502+250) Anticipated vehicles: 92 *2	5236 bytes (4986+250) Anticipated vehicles: 184 *3	287 bytes (37+250)	369 bytes (119+250) *4	287 bytes (37+250)
Cyclic or acyclic	Cyclic	Cyclic	Cyclic	Acyclic	Acyclic	Acyclic
Transmission cycle	100 ms	100 ms	100 ms	Not specified		
PAR per packet	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)
Allowable delay of radio communication section	Not specified	Not specified	Not specified	Assume 100 ms as allowable delay of radio communication section	Assume 100 ms as allowable delay of radio communication section	Assume 100 ms as allowable delay of radio communication section

*1 Roadside infrastructure is installed at the merging starting point, and the difference in elevation is ignored. It is expected that roadside infrastructure antennas will be installed at some distance from the merging starting point, but this has not been taken into account. In practice, it is necessary to calculate the required communication distance, including the location of the roadside infrastructure antenna and the difference in elevation.

*2 Cases where information is provided for two lanes (mainline). If mainline is three lanes (anticipated vehicles: 138), 3744+250=3994 bytes.
If mainline is six lanes (anticipated vehicles: 276), 7470+250=7720 bytes.

*3 Cases where information is provided for three lanes (mainline) and one lane (connecting route). If connecting route is two lanes and mainline is six lanes (anticipated vehicles: 368), 9954+250=10204 bytes.

*4 In the control response message, the information element of the scheduled time to start action (2 bytes) is added, for 121+250=371 bytes.

*5 Cases where vehicle density is estimated at 12 vehicles/lane for three lanes (mainline) and one lane (connecting route). With six lanes (mainline) and two lanes (connecting route), the number of transmitting vehicles is 96 vehicles.

Table 2.2.1-3 Communication requirements of use cases using narrow-area communication (2/7)

Classification by function	a. Merging / lane change assistance					
Use case	Merging assistance based on negotiations between vehicles		Lane change assistance when the traffic is heavy		Entry assistance from non-priority roads to priority roads during traffic congestion	
No.	a-1-4		a-2		a-3	
Message name	Agreement request Update request	Agreement response Update response	Agreement request Update request	Agreement response Update response	Agreement request Update request	Agreement response Update response
Communication format	V2V	V2V	V2V	V2V	V2V	V2V
Communication counterpart	Non-specified vehicles (agreement request) Specified vehicles (update request)	Specified vehicles (requesting vehicle)	Non-specified vehicles (agreement request) Specified vehicles (update request)	Specified vehicles (requesting vehicle)	Non-specified vehicles (agreement request) Specified vehicles (update request)	Specified vehicles (requesting vehicle)
Target area (minimum range)	Within agreement request range	Within agreement request range	Within lane change request range	Within lane change request range	Within intersection request range	Within intersection request range
Number of transmitting vehicles per area	When temporarily stopping: 1 vehicle *6 When starting to merge: 1 vehicle *6	When temporarily stopping: 27 vehicles *6 When starting to merge: 36 vehicles *6	73 vehicles	48 vehicles	2 vehicles	68 vehicles
Required communication distance	255 m	255 m	Agreement request: 255 m Update request: 38.9 m	Agreement response: 255 m Update response: 38.9 m	111.1 m	111.1 m
Maximum relative speed	20 to 70 km/h	20 to 70 km/h	Agreement request: 0 to 120 km/h Update request: 0 to 20 km/h	Agreement response: 0 to 120 km/h Update response: 0 to 20 km/h	0 to 60 km/h	0 to 60 km/h
Maximum data size	291 bytes (41+250)	287 bytes (37+250)	291 bytes (41+250)	287 bytes (37+250)	291 bytes (41+250) *7	287 bytes (37+250)
Cyclic or acyclic	Acyclic	Acyclic	Acyclic	Acyclic	Acyclic	Acyclic
Transmission cycle	Not specified		Not specified		Not specified	
PAR per packet	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)
Allowable delay of radio communication section	Assume 100 ms as allowable delay of radio communication section	Assume 100 ms as allowable delay of radio communication section	Assume 100 ms as allowable delay of radio communication section	Assume 100 ms as allowable delay of radio communication section	Assume 100 ms as allowable delay of radio communication section	Assume 100 ms as allowable delay of radio communication section

*6 Number of vehicles assuming temporary stop scenario of merging lane length 190 m @ 70 km/h and merging start time scenario of merging lane length 255 m @ 100 km/h

*7 If intersection information is not available from the dynamic map, 10 bytes should be added.

Table 2.2.1-3 Communication requirements of use cases using narrow-area communication (3/7)

Classification by function	b. Traffic signal information	c. Lookahead information: Collision avoidance	
Use case	Driving assistance by using traffic signal information (V2I)	Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly	Driving assistance based on intersection information
No.	b-1-1.	c-1.	c-2-1.
Message name	-	Merged with c-3.	-
Communication format	V2I	Merged with c-3.	V2V
Communication counterpart	Non-specified vehicles	Merged with c-3.	Non-specified vehicles
Target area (minimum range)	Passenger vehicles: Approx. 138.5 m (provisional) Large vehicles: Approx. 206.3 m (provisional) (yellow 4 sec. 60 km/h)	Merged with c-3.	(Communication area in which right-turning vehicle needs distributed information) • Upstream side: upstream from location right-turning vehicle turns on turn signal (point 30 m upstream stop line) • Downstream side: last stopping point at right turn destination (oncoming vehicle range in which right-turning vehicle needs information) *Target lanes are all straight ahead lanes • Upstream side: Oncoming vehicle in a location to initiate a right turn at safe acceleration from the right-turn waiting point within the intersection and finish crossing the oncoming lane in a situation where waiting to turn right at the right-turn waiting point within the intersection, with the intersection center or right-turn waiting point as the base point If the right-turn waiting point exceeds the center of the intersection, the right-turn waiting point shall be the base point, and if there are multiple right-turn waiting points, the point closer to the oncoming lane shall be used.) • Downstream side: The location not within line of sight (i.e., there is a blind spot) when looking from right-turning vehicle to oncoming vehicles moving straight through the intersection. If this position is upstream from the stop line of the lane in which the oncoming vehicles moving straight is traveling, it shall be the stop line position.
Number of transmitting vehicles per area	RSU installation model (See https://www.soumu.go.jp/main_content/000455914.pdf Part 4.2)	Merged with c-3.	(Number of lanes in one direction: 6; oncoming vehicle speed: 70 km/h) 348 vehicles (Number of lanes in one direction: 3; oncoming vehicle speed: 70 km/h) 125 vehicles
Required communication distance	Passenger vehicles: Approx. 138.5 m (provisional) Large vehicles: Approx. 206.3 m (provisional) (yellow 4 sec. 60 km/h) Note, 700 MHz band system request value is 240 m	Merged with c-3.	(Number of lanes in one direction: 6; oncoming vehicle speed: 70 km/h) 190 vehicles (Number of lanes in one direction: 3; oncoming vehicle speed: 70 km/h) 135 m

Maximum relative speed	70 km/h	Merged with c-3.	Up to 70 km/h
Maximum data size	About 1K byte / intersection	Merged with c-3.	282 bytes
Cyclic or acyclic	Cyclic	Merged with c-3.	Cyclic
Transmission cycle	100 ms	Merged with c-3.	100 ms
PAR per packet	At least 99% in 5 m evaluation section*8 (Same as 700 MHz band system)	Merged with c-3.	PAR ≥ 99%
Allowable delay of radio communication section	Delay not specified. Fluctuation within ±300 ms See (https://www.sip-adus.go.jp/rd/rddata/rd03/205.pdf)	Merged with c-3.	Assume 100 [ms] as allowable delay of radio communication section

*8 70 km/h is approx. 20 m/s. 250 ms required in 5 m evaluation section. Two 100 ms cycle transmissions occur within 250 ms.
Cumulative packet arrival rate 99% should be satisfied at least 90% packet arrival per packet, derived from 1-(0.1*0.1) = 0.99. Thus, 90% packet arrival rate at 100 ms allowable delay of radio communication section.

Table 2.2.1-3 Communication requirements of use cases using narrow-area communication (4/7)

Classification by function	c. Lookahead information: Collision avoidance		
Use case	Driving assistance based on intersection information		Collision avoidance assistance by using hazard information / Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly
No.	c-2-2.		c-3.
Message name	Not considered	-	-
Communication format	V2I (V=>I)	V2I (I => V)	V2V
Communication counterpart	Not considered	Non-specified vehicles	Non-specified vehicles
Target area (minimum range)	Not considered	(Communication area in which right-turning vehicle needs distributed information) Same as c-2-1.	• Direct V2V communication: 250 m upstream from point where event occurs • If relay: 1 km upstream from point where event occurs
Number of transmitting vehicles per area	Not considered	N/A	(Vehicle speed: 120 km/h; intervehicle distance: 2 s) 79 vehicles (Vehicle speed: 60 km/h; intervehicle distance: 1 s) 277 vehicles (Total vehicles for 6 lanes in 1 km section from point where emergency action occurs
Required communication distance	Not considered	Dependent on road infrastructure antenna location. The following if roadside infrastructure antenna installed at side of intersection and antenna height 6 m: (No. of lanes on one side: 6) 75.2 m (No. of lanes on one side: 3) 52.4 m	• Direct V2V communication: 250 m upstream from point where event occurs • If relay: 1 km upstream from point where event occurs
Maximum relative speed	Not considered	Up to 70 km/h	Up to 120 km/h
Maximum data size	Not considered	(No. of lanes on one side: 6) 15341400 bytes (No. of lanes on one side: 3) 1150896 bytes [*9]	312 bytes
Cyclic or acyclic	Not considered	Cyclic	Cyclic
Transmission cycle	Not considered	100 ms	100 ms
PAR per packet	Not considered	PAR ≥ 99%	PAR ≥ 99% in direct V2V communication
Allowable delay of radio communication section	Not considered	Assume 100 [ms] as allowable delay of radio communication section	• Up to 255 m upstream from place where emergency avoidance action occurs: within 100 [ms]

			• Points upstream from the above: up to 1 km upstream, relax to as much as 30 s based on distance

*9 Message size when traffic signal information, intersection identification information, and vehicle detection information are sent together in a single message.
If each piece of information is sent in a separate message, the security overhead is taken into account for each piece of information.

Table 2.2.1-3 Communication requirements of use cases using narrow-area communication (5/7)

Classification by function	d. Lookahead information: Trajectory change				
Use case	Driving assistance by notification of abnormal vehicles	Driving assistance by notification of wrong-way vehicles	Driving assistance based on traffic congestion information	Traffic congestion assistance at branches and exits	Driving assistance based on hazard information
No.	d-1	d-2	d-3	d-4	d-5
Message name	-	-	-	-	-
Communication format	V2I	V2I	V2I	V2I	V2I
Communication counterpart	Non-specified vehicles present in areas where hazard information can be effectively used	Non-specified vehicles present in areas where hazard information can be effectively used	Non-specified vehicles present in areas where hazard information can be effectively used	Non-specified vehicles present in areas where hazard information can be effectively used	Non-specified vehicles present in areas where hazard information can be effectively used
Target area (minimum range)	Minimum 66.6 m and up	Minimum 66.6 m and up	Minimum 66.6 m and up	Minimum 66.6 m and up	Minimum 66.6 m and up
Number of transmitting vehicles per area	Uplink: Number of abnormal vehicles (ordinarily 1 vehicle) Downlink: Broadcast	Uplink: Number of abnormal vehicles (ordinarily 1 vehicle) Downlink: Broadcast	Uplink: Number of abnormal vehicles (ordinarily 1 vehicle) Downlink: Broadcast	Uplink: Number of abnormal vehicles (ordinarily 1 vehicle) Downlink: Broadcast	Downlink: Broadcast
Required communication distance	Minimum 66.6 m and up	Minimum 66.6 m and up	Minimum 66.6 m and up	Minimum 66.6 m and up	Minimum 66.6 m and up
Maximum relative speed	20 km/h to 120 km/h	20 km/h to 120 km/h	20 km/h to 120 km/h	20 km/h to 120 km/h	20 km/h to 120 km/h
Maximum data size	715 bytes (465+250)	715 bytes (465+250)	715 bytes (465+250)	715 bytes (465+250)	715 bytes (465+250)
Cyclic or acyclic	Cyclic	Cyclic	Cyclic	Cyclic	Cyclic
Transmission cycle	Minimum 1 second	Minimum 1 second	Minimum 1 second	Minimum 1 second	Minimum 1 second
PAR per packet	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)
Allowable delay of radio communication section	Not specified	Not specified	Not specified	Not specified	Not specified

Table 2.2.1-3 Communication requirements of use cases using narrow-area communication (6/7)

Classification by function	e. Lookahead information: Emergency vehicle notification	f. Information collection / distribution by infrastructure
Use case	Driving assistance based on emergency vehicle information	Collection of information to optimize the traffic flow
No.	e-1	f-2
Message name	-	-
Communication format	V2V	V2I
Communication counterpart	Non-specified vehicles present in areas where emergency vehicle information can be effectively used	Non-specified vehicles
Target area (minimum range)	150 m semicircle	Circle of radius 171.8 m*10
Number of transmitting vehicles per area	Downlink: Broadcast	389 vehicles (maximum case)*10
Required communication distance	Minimum 150 m	Minimum 33.3 m * Travel distance in 1 second when driving at 120 km/h
Maximum relative speed	20 km/h to 120 km/h	20 km/h to 120 km/h
Maximum data size	302 bytes (52+250)	Uplink：279 bytes (29+250) Downlink: Not specified
Cyclic or acyclic	Cyclic	Cyclic
Transmission cycle	100 ms	Minimum 1 second
PAR per packet	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)
Allowable delay of radio communication section	V2V: 100 ms or less	Not specified

*10 Assumes communication area: 171.8 m (360°), maximum three lanes in one direction, two-way intersection, vehicle speed 20 km/h, vehicle interval 1 s, average vehicle length 5 m. Transmitting vehicles per area: 171.8×3×2×4÷(5.6×1+5)＝389 vehicles)

Table 2.2.1-3 Communication requirements of use cases using narrow-area communication (7/7)

Classification by function	g. Platooning / adaptive cruise control		
Use case	Unmanned platooning of following vehicles by electronic towbar (Non-rich content)	Unmanned platooning of following vehicles by electronic towbar (Rich content)	Adaptive cruise control and manned platooning of following vehicles using adaptive cruise control
No.	g-1.	g-1.	g-2.
Message name	-	-	-
Communication format	V2V	V2V	V2V
Communication counterpart	Specified vehicles (use one-to-N to achieve one-to-one)	Specified vehicles (use one-to-N to achieve one-to-one)	Non-specified vehicles
Target area (minimum range)	Relative distance about 60 m	Relative distance about 60 m	141 m
Number of transmitting vehicles per area	3 vehicles	3 vehicles	Calculated with 4 vehicles
Required communication distance	Relative distance about 60 m	Relative distance about 60 m	141 m
Maximum relative speed	Large vehicles 80 km/h	Large vehicles 80 km/h	Passenger vehicles 100 km/h; large vehicles 80 km/h
Maximum data size	Up to same as 700 MHz band system	*11	Up to same as 700 MHz band system
Cyclic or acyclic	Cyclic	*11	Cyclic
Transmission cycle	100 ms, in emergencies 20 ms	*11	100 ms
PAR per packet	98% per 100 ms in normal, 99.99% per 100 ms in emergency	*11	95% packet accumulation rate in 10 m of travel (same as 700 MHz band system)
Allowable delay of radio communication section	100 ms (intervehicle distance 10 m; speed 80 km/h)	*11	100 ms or less

*11 Full high-definition real-time communication is needed, and United Nations Economic Commission for Europe Regulation 46 electronic mirror regulations can be used as a reference for delay and communication quality in the camera-to-display section. However, the delay for encoding and decoding images will differ depending on what image encoding method is used, resulting in different transmission bandwidth and communication delay required for the radio section. It is necessary to specify the communication delay in the radio section, taking into account implementation of the delay in the camera and display as well. From these, specific content and size cannot be specified in this document.

From the technical requirements described in Table 2.2.1-2 and the communication requirements described in Table 2.2.1-3, the extracted points to consider for communication in realizing use cases using narrow-area communication are shown in Table 2.2.1-4. In addition, points to consider organized as they apply to each use case are shown in Table2.2.1-5.

Table 2.2.1-4 Points to consider in realizing use cases using narrow-area communication

No.	Item	Points to consider
1	Communication traffic	Communication traffic is assumed to be small, except in the following use cases. Image transfer in g-1. Unmanned platooning of following vehicles by electronic towbar
2	Communication area	Communication area required to realize each use case
3	Communication delay	Collision avoidance (use case c-x.) in particular requires immediacy
4	Number of signaling devices	The required communication frequency (fixed cycle) and signaling devices according to the event occurrence are required for vehicles within the communication area of assumed use cases. (Consideration should be given to differences due to traffic volume in the communication area, such as off-peak hours, regular hours, congestion, etc.)
5	Frequency of communication	The required communication frequency (fixed cycle) and communication frequency according to the event occurrence are required for vehicles within communication area.

Table2.2.1-5 Points to consider in communication requirements of each use case

Classification by function	Use case	Individual item	Common item
a. Merging / lane change assistance	a-1-1. Merging assistance by preliminary acceleration and deceleration	• None	• Communication delay Determination of measures to respond to requirements on communication delay for each use case
	a-1-2. Merging assistance by targeting the gap on the mainline	• None	
	a-1-3. Cooperative merging assistance with vehicles on the mainline by roadside control	• Communication load due to multi-vehicle, bi-directional communication • Communication load due to simultaneous implementation of use cases around the merge point	
	a-1-4. Merging assistance based on negotiations between vehicles	• Communication load due to multi-vehicle, bi-directional communication • Communication load due to simultaneous implementation of use cases around the merge point	
	a-2. Lane change assistance when the traffic is heavy	• Communication load due to multi-vehicle, bi-directional communication • Communication load due to simultaneous implementation of use cases around the merge point	
	a-3. Entry assistance from non-priority roads to priority roads during traffic congestion	• Communication load due to multi-vehicle, bi-directional communication • Communication load due to simultaneous implementation of use cases around the merge point	

Classification by function	Use case	Individual item	Common item
b. Traffic signal information	b-1-1. Driving assistance by using traffic signal information (V2I)	• Communication load due to simultaneous implementation of use cases around the intersection	• Communication quality Determination of measures to respond to requirements on communication quality for each use case
c. Lookahead information: Collision avoidance	c-1. Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly	• Communication load due to simultaneous implementation of use cases around the intersection	
	c-2-1. Driving assistance based on intersection information (V2V)	• Communication load due to simultaneous implementation of use cases around the intersection	
	c-2-2. Driving assistance based on intersection information (V2I)	• Communication load due to simultaneous implementation of use cases around the intersection	
	c-3. Collision avoidance assistance by using hazard information	• Communication load due to simultaneous implementation of use cases around the intersection	
d. Lookahead information: Trajectory change signal information	d-1. Driving assistance by notification of abnormal vehicles	• None	
	d-2. Driving assistance by notification of wrong-way vehicles	• None	
	d-2. Driving assistance by notification of wrong-way vehicles	• None	
	d-3. Driving assistance based on traffic congestion information	• None	
	d-4. Traffic congestion assistance at branches and exits	• None	
	d-5. Driving assistance based on hazard information	• None	
e. Lookahead information: Emergency vehicle notification	e-1. Driving assistance based on emergency vehicle information	• Communication load due to simultaneous implementation of use cases around the intersection	
f. Information collection / distribution by infrastructure	f-2. Collection of information to optimize the traffic flow	• Communication load due to simultaneous implementation of use cases around the intersection	
g. Platooning / adaptive cruise control	g-1. Unmanned platooning of following vehicles by electronic towbar	• None	
	g-2. Adaptive cruise control and manned platooning of following vehicles using adaptive cruise control	• None	

2.2.2Organization of compatibility of target use cases

The following describes the perspective for evaluating the selection of use cases using narrow-area communication to be considered when examining problems and countermeasures for narrow-area communication, and the results of the selection of use cases to be considered.

(1) Perspective for evaluating selection of use cases

Based on section 2.2.1, the following evaluation perspectives are important for cooperative driving automation use cases using narrow-area communication.

- Communication traffic

In b-1-1. Driving assistance by using traffic signal information (V2I), c. Lookahead information: Collision avoidance, and e. Lookahead information: Emergency vehicle notification, it is necessary to secure large capacity communication bandwidth since simultaneous occurrence of use cases is expected around intersections.

- Communication delay

In a. Merging / lane change assistance, b-1-1. Driving assistance by using traffic signal information (V2I), c. Lookahead information: Collision avoidance, and g. Platooning / adaptive cruise control, the system must have low delay in order to perform immediate driving operations based on information collected from surrounding vehicles.

- Number of signaling devices / Frequency of communication

When performing driving support in a. Merging / lane change assistance, multi-vehicle and bi-directional communication is performed, so the number of signaling devices and frequency of communication need to be studied in advance.

In light of the above, use cases to be studied were selected and simulation of narrow-area communication performance was verified and evaluated in simulations in terms of “communication traffic,” “communication delay,” and “number of signaling devices / frequency of communication”. Also, demonstration and evaluation were performed to confirm communication performance in a real environment. For evaluation results, see section 3.3 and case 3.4.

(2) Selection of use cases

Major use cases that greatly affect “communication traffic,” “communication delay,” and “number of signaling devices / frequency of communication” that have frequent bidirectional communication between multiple communication terminals and where communication congested is expected are shown in Table 2.2.2-1.

Table 2.2.2-1 Use cases where frequent two-way communication is expected

Communication requirement item	a-1-3. (Merging assistance: V2I)	a-1-4. (Merging assistance: V2V)	a-2. (Lane change: V2V)	a-3. (Entry assistance: V2V)
Number of communication terminals	• RSU: 1 unit • Merging vehicles: 1 • Mainline vehicles: Up to 6	• Merging vehicles: 1 • Mainline vehicles: Up to 36 *Number of simultaneous vehicles is several vehicles around merging vehicle	• Changing vehicles: 73 • Accepting vehicles: Up to 48 *Number of simultaneous vehicles is several vehicles around changing vehicle	• Entering vehicles: 2 • Accepting vehicles: Up to 68 *Number of simultaneous vehicles is several vehicles around entering vehicle
Communication path	• RSU -> Merging vehicle (Location information) • RSU -> Merging vehicle (Request/reply) • RSU -> Mainline vehicle • Merging vehicle -> RSU Mainline vehicle -> RSU	• Merging vehicle -> Mainline vehicle • Mainline vehicle -> Merging vehicle	• Changing vehicle -> Accepting vehicle • Accepting vehicle -> Changing vehicle	• Entering vehicle -> Accepting vehicle • Accepting vehicle -> Entering vehicle
Maximum data size	5,236 bytes (location information) 369 bytes (request/reply)	291 bytes (request/reply)	291 bytes (request/reply)	291 bytes (request/reply)
Frequency of communication	100 ms at event occurrence	100 ms at event occurrence	100 ms at event occurrence	100 ms at event occurrence
Allowable delay of radio communication section	100 ms	100 ms	100 ms	100 ms

Major use cases where multiple use cases occur in the same communication area and where various communication congestion between multiple communication terminals is expected as a result are shown in Table 2.2.2-2.

Table 2.2.2-2 Use cases where communication congestions is expected due to simultaneous occurrence of use cases (1/2)

Location of appearance	a-1-3. (Merging assistance: V2I)	a-1-4. (Merging assistance: V2V)	a-2. (Lane change: V2V)	b-1-1. (Traffic signal information: V2I)
Around merge point	Good	Poor	Good	-
Around intersection	-	-	Good	Good
Communication path	• RSU -> Merging vehicle (location information) • RSU -> Merging vehicle (request/reply) • RSU -> Mainline vehicle • Merging vehicle -> RSU • Mainline vehicle -> RSU	• Merging vehicle -> Mainline vehicle • Mainline vehicle -> Merging vehicle	• Changing vehicle -> Accepting vehicle • Accepting vehicle -> Changing vehicle	• RSU -> Surrounding vehicle

Legend Good: Frequency of appearance high; Poor: Frequency of appearance medium; -: Not present

Table 2.2.2-2 Use cases where communication congestions is expected due to simultaneous occurrence of use cases (2/2)

Location of appearance	c-1. (Collision avoidance: V2V)	c-2-1. (Intersection Information : V2V)	c-2-2. (Intersection Information : V2I)	c-3. (Hazard information: V2V)	e-1. (Emergency vehicle: V2I, V2V)	f-2. (Information collection/distribution: V2I)
Around merge point	Good	-	-	Good	-	-
Around intersection	Good	Poor	Good	Good	Good	Poor
Communication path	• Detected vehicle -> Surrounding vehicle	• Oncoming vehicle -> Right-turning vehicle	• Oncoming vehicle -> RSU • RSU -> Right-turning vehicle	• Detected vehicle -> Surrounding vehicle	• Emergency vehicle -> Surrounding vehicle • Emergency vehicle -> RSU -> Surrounding vehicle	• Surrounding vehicle -> RSU

Legend Good: Frequency of appearance high; Poor: Frequency of appearance medium; -: Not present

Table 2.2.2-1 shows that because merging agreement is performed by merging vehicles and mainline vehicles via roadside units, bidirectional communication between occurs frequently in “a. Merging / lane change assistance” and “a-1-3. Cooperative merging assistance with vehicles on the mainline by roadside control.” Also, the data size used in communication is also the largest, indicating that this is the most severe communication condition in terms of communication traffic as well.

And Table 2.2.2-2 shows that many use cases can occur simultaneously around intersections.

Based on the results of section 2.2.1 and this section, the following use cases were selected for review of problems and countermeasures.

1) Communication congestion due to frequent bidirectional communication

Use case where communication between vehicles and RSU is used, and communication congestion is expected to occur due to multiple vehicles performing bidirectional communication with RSU.

- a-1-3. Cooperative merging assistance with vehicles on the mainline by roadside control

2) Communication congestion due to conflicting multiple use cases

Cases where multiple use cases are expected to occur simultaneously around intersections

- b-1-1. Driving assistance by using traffic signal information (V2I)
- c-1. Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly
- c-2-2. Driving assistance based on intersection information (V2I)

Results of countermeasures against the selected used cases are shown in section 3.2.

3. Verification of validity through drafting countermeasures to solve problems and evaluation through demonstration experiments

This part summarizes problems related to wide-area communication and describes the results of desk study of countermeasures. It also summarizes problems related to narrow-area communication and covers the results of study by verification using a simulator and demonstration testing on a test course.

3.1 Examination of problems and countermeasures for wide-area communication

Use cases used in wide-area communication are shown in Table 3.1-1 based on 25 use cases of cooperative driving automation shown in cooperative driving automation use cases[4].

Table 3.1-1 Use cases using wide-area communication

Classification by function	Use case	Overview
b. Traffic signal information	• b-1-2. Driving assistance by using traffic signal information (V2N)	Traffic signal phase and timing information (the next traffic signal color and the time until change), etc., of traffic signals at intersections is provided via a network to vehicles that enter intersections to assist deceleration and stopping, and thereby avoid a dilemma.
d. Lookahead information: Trajectory change	• d-1. Driving assistance by notification of abnormal vehicles	Event information (broken down vehicle, accident vehicle, etc.) and location information (section located, lane) of abnormal vehicles stopped on the road is provided from the infrastructure to surrounding vehicles or from abnormal vehicles to surrounding vehicles to support early lane change and trajectory change.
	• d-2. Driving assistance by notification of wrong-way vehicles	Information on the location and speed of wrong-way vehicles and the presence of the wrong-way vehicles is provided from the infrastructure to surrounding vehicles to encourage them to change lanes, etc., in advance to assist in collision avoidance.
	• d-3. Driving assistance based on traffic congestion information	Traffic congestion information obtained from vehicles in congestion is provided from the infrastructure to surrounding vehicles to assist driving.
	• d-4. Traffic congestion assistance at branches and exits	Information (location and speed) on shoulder congestion is provided from the infrastructure to mainline vehicles to assist them in entering branches.
	• d-5. Driving assistance based on hazard information	Obstacle, construction, congestion, and other information is provided from the infrastructure to surrounding vehicles to assist driving.
e. Lookahead information: Emergency vehicle notification	• e-1. Driving assistance based on emergency vehicle information	Information on the direction of movement and speed of emergency vehicles and their planned route (planned travel lane) is provided from emergency vehicles to surrounding vehicles to encourage surrounding vehicles to slow down or stop, etc., to support smooth passage of the emergency vehicle.
f. Information collection / distribution by infrastructure	• f-1. Request for rescue (e-Call)	Rescue information is sent from vehicles involved in accident or other abnormal vehicles to the infrastructure to request rescue.
	• f-2. Collection of information to optimize the traffic flow	Information on the location and speed of the traveling vehicles is collected via the infrastructure for traffic volume analysis and optimization.
	• f-3. Update and automatic generation of maps	Information collected by vehicles is collected by the infrastructure to update and automatically generate map data.
	• f-4. Distribution of dynamic map information	Dynamic map information is provided from the infrastructure to vehicles.
h. Remote control	• h-1. Operation and management of mobility service cars	In traffic environments where avoidance is difficult with an autonomous driving system, video information, etc., from the mobility service cars and remote control instructions from the operation manager are communicated between the operation manager and the mobility service car to operate and manage the vehicle from a remote location.

This section, summarizes issues based on points to consider extracted in study of communication shown in 2.1.1 for the use cases shown in Table 3.1-1 and covers the countermeasures against them.

[4]Source: SIP Cooperative Driving Automation Use Cases - 2019 Task Force on V2X Communication for Cooperative Driving Automation Activity Report-

3.1.1 Anticipated system image

An image of the system anticipated in realizing use cases using wide-area communication is shown in Fig. 3.1.1-1.

In wide-area communications, it is assumed that an MNO network will be utilized. There may also be management servers that play the following roles on the network (assumed to be on a base station or on a network wired to a base station), and that these management servers will be located such as in each area to distribute the load.

- Manage information sent periodically from the vehicle
- Analyze and determine events based on information obtained from the vehicle
- Determine the information that needs to be distributed to vehicles based on the determined events and identify the areas where it should be distributed
  (Including management of area information and vehicle location information to distribute information)

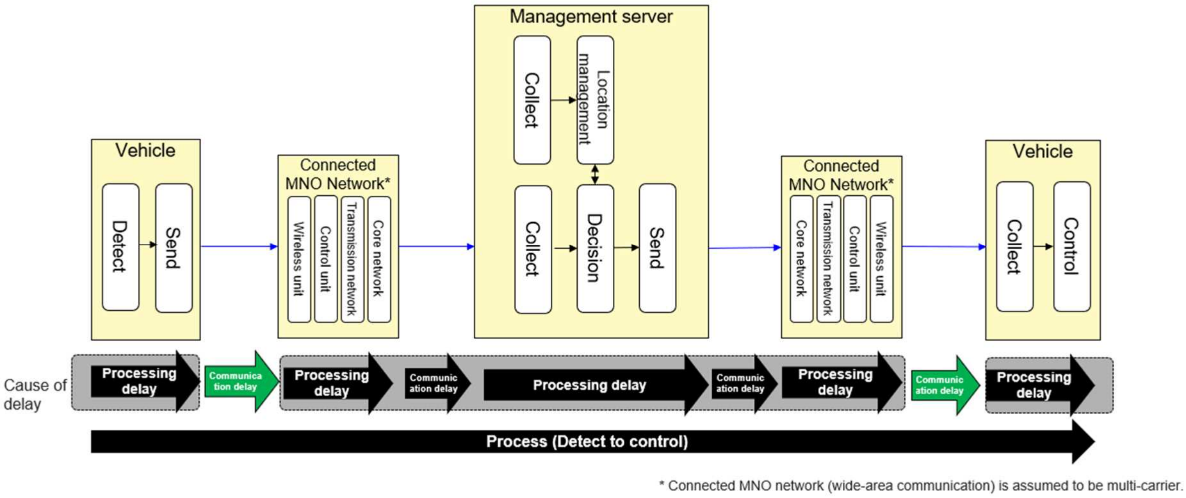

Fig. 3.1.1-1 System image (anticipated)

One of the concerns in distributing information via devices such as vehicles and management servers and networks is the occurrence of delays in information transmission. However, in this research, processing delays in devices such as vehicles and management servers (including application processing) are not included in the study due to system requirements in individual use cases not being finalized, and problems related to communication delays on the wireless network are summarized.

3.1.2Considerations on problems

Based on section 2.1, communication requirements in terms of communication traffic, communication area, communication delay, number of signaling devices, and frequency of communication were examined as they relate to communication on the wireless network in each use case.

- Communication traffic

f-4 and h-1 are use cases where large volumes of data are expected to be handled between vehicles and management servers. In the distribution of dynamic map information in f-4, it is assumed that map data will be continuously distributed in Downlink (hereinafter, "DL"). In distribution of video information, etc., at remote control in h-1, video information around the vehicle is assumed to be handled by Uplink (hereinafter, "UL"), and although the data size specification has not yet been finalized, it will be larger than the data size handled by f-4. Other use cases are those that do not handle large amounts of data, such as the transmission of event or location information from vehicle to management server or from management server to vehicle, all of which are less than 1 KB in data size.

- Communication area

When wide-area communication is used, it is assumed that the communication area of a public network at a telecommunications carrier is used. Depending on the use case, however, V2I is assumed to be used as well in areas where dense communication is required.

- Communication delay

h-1 is a use case where immediacy of information transfer is high. Remote control in h-1 requires a low-delay environment for smooth control. Other use cases are those where immediacy of transfer of information such as lookahead information is low.

- Number of signaling devices, frequency of communication

As a result of estimating from areas where vehicle speed and the target area require information transmission for each use case, the maximum number of signaling devices is assumed to be approx. 600, and the minimum frequency of communication is assumed to be at least one-second cycle.

A list of issues to consider regarding communication requirements is shown in Table 3.1.2-1.

Table 3.1.2-1 Issues to consider

Item	Communications requirements (summary)	Issues to consider
Communication traffic	• Up to approx. 1 KB (Except for the following) f-4: Communication traffic between the vehicle and the center during distribution of dynamic map information h-1: Communication traffic between the vehicle and the center during remote control (video, etc.)	• f-4 is realization of communication traffic for required functions and performance • h-1 is realization of communication traffic for required functions and performance
Communication area	• Communication areas in public networks assumed • Use V2I in combination in areas where overcrowded communication is conceivable d-1,5: (Unexpected) d-2: Around approach d-3: Congestion hot spot d-4: Around branches and exits e-1, f-1, f-2: Around intersections	None
Communication delay	• Unexpected (Except for the following) h-1: Communication delay between the vehicle and the center during remote control	• h-1 is realization of communication delay for required functions and performance
Number of signaling devices	• Up to approx. 600	• The feasibility of communication technologies required for achieving the use cases • Feasibility of the number of vehicles that can be accommodated and of the frequency of communication according to the communication technology (However, it is necessary to consider implementation constraints by the public network for the communication technologies.)
Frequency of communication	• Minimum 1 second	

In terms of communication traffic, h-1 will be studied as a typical example as it is assumed to handle a larger volume of data than f-4 because it handles video and other data during remote monitoring and operation.

In terms of communication delay, h-1 will be studied as a typical example as it requires lower delay communication during remote control than other use cases (less urgent and less delay sensitive, such as look-ahead information).

In terms of number of signaling devices / frequency of communication, frequency of communication of location information for information transmission vehicle judgment will be studied as an issue because vehicle location information needs to be managed by a management server in each use case. And in information distribution from the management server to vehicles, number of signaling devices and frequency of communication affect the communication traffic, so the feasibility of the communication technology according to the use case and the feasibility of the number of vehicles that can be accommodated and of the communication frequency according to the communication technology will be examined as issues.

In light of the above, those are mapped in the system image as issues (1) to (4) as shown in Fig. 3.1.2-1.

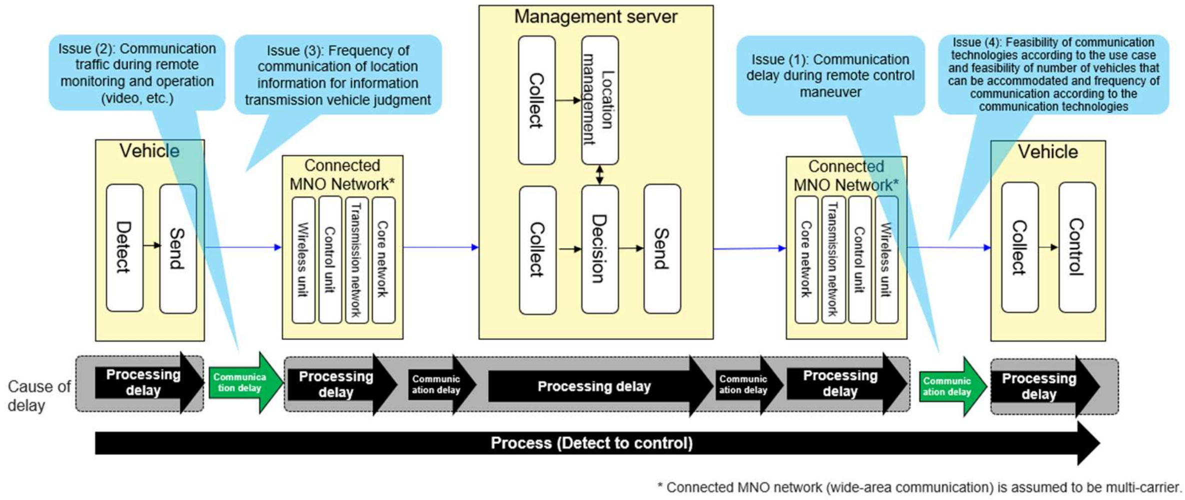

Fig. 3.1.2-1 Summary of issues

Considerations for countermeasures against issues (1) to (4) are as follows.

(1) Communication delay during remote control [Issue (1)]

Transmission and reception of control information for remote control (maneuver) between vehicles and the center is assumed at remote control (maneuver). Reducing communication delay in each direction between the vehicle and the management server and between the management server and the vehicle are considerations in order to perform smooth remote control, since control information must be transmitted with as little delay as possible.

(2) Communication traffic during remote monitoring and operation (video, etc.) [Issue (2)]

Large volumes of communication between vehicles and management server, such as video, is anticipated at remote monitoring and operation. Reducing communication delay between the vehicle and the management server is a consideration in order to perform smooth remote control, since video information must be transmitted with as little delay as possible. And since reducing the communication traffic itself is expected to have the effect of deterring communication delays, reducing the communication traffic between the vehicle and the management server is a matter for consideration.

(3) Frequency of communication of location information for information transmission vehicle judgment [Issue (3)]

In the use cases where wide-area communication is utilized, it is assumed that the management server manages the location information of surrounding vehicles by having the surrounding vehicles send their own-vehicle information to the management server in order to distribute the information to the surrounding vehicles via the management server. As the vehicle moves, location information is periodically sent from the vehicle to the management server to update the location data managed by the management server. However, there is concern that frequent location information transmission by a large number of surrounding vehicles may cause communication congestion, so reducing the frequency of communication between vehicles and management server is a matter for consideration.

(4) Feasibility of communication technologies according to the use case and feasibility of number of vehicles that can be accommodated and frequency of communication according to the communication technologies [Issue (4)]

In the use cases where wide-area communication is utilized, information is distributed to surrounding vehicles via the management server. Since it is assumed that information is distributed from the management server to a large number of vehicles, there is concern that this may cause communication congestion depending on the number of vehicles that can be accommodated in the area to which the information is distributed and the frequency of communication. Since the frequency in which surrounding vehicles require information from the management server varies depending on the use case, reducing the communication traffic between the management server and vehicles by selecting an appropriate communication technology, etc., according to the use case is a matter for consideration.

3.1.3 Consideration of countermeasures

Countermeasures were considered based on the considerations for issues (1) to (4) in section 3.1.2. Countermeasures are as follows, and details are shown in section 3.1.3(1).

- Priority control of wireless communications
- Securing dedicated frequency bands
- Securing dedicated bandwidth end-to-end
- Appropriate placement of edge processing (reference)
- Securing uplink (V->N) communication capacity
- Optimization of communication traffic (reference)
- Consideration of feasibility of each communication technology

Countermeasures will be considered for issues (1) and (2) with h-1 as a typical example as it requires lower delay communication during remote control than other use cases (less urgent and less delay sensitive, such as look-ahead information).

For issues (3) and (4), the target use cases are not defined, and the characteristics of each communication technology are summarized and considerations for applying each communication technology to each use case are described.

Moreover, the countermeasures considered do not necessarily correspond one-to-one to issues (1) through (4), and there are some that could be countermeasures to address multiple issues. For that reason, section 3.1.3(1) presents the proposed countermeasures considered, and section 3.1.3(2) then shows the relationship between the proposed countermeasures and issues (1) through (4).

(1) Proposed countermeasures

(a) Priority control of wireless communications

Quality of Service (QoS) is a technology for ensuring service quality in a network. QoS is concerned with the degree to which data communication speed and response time are guaranteed. In LTE networks, a device called PCRF (Policy and Charging Rules Function), which is a device related to network policy and charging, is connected to the P-GW in the middle of the route over which the data sent and received by users flows. The P-GW, S-GW, and base stations control the user packet data transmitted and received in LTE communication on a packet-by-packet basis according to the commands from the PCRF. The QCI (QoS Class Identifier) is an identifier that indicates which data has what priority then. QCI is regulated in 3GPP document TS 23.203.

In 5G as well, a 5QI (5G QoS Identifier) is also set as an identifier for QoS control. 5QI is regulated in 3GPP document TS23.501.

Table 3.1.3-1 QCI regulation in 3GPP (TS 23.203 V17.2.0(2021-12)) (excerpt)

QCI	Resource Type	Priority Level	Packet Delay Budget	Packet Error Loss Rate	Example Services
1	GBR	2	100 ms	10^{-2}	Conversational Voice
2		4	150 ms	10^{-3}	Conversational Video (Live Streaming)
3		3	50 ms	10^{-3}	Real Time Gaming, V2X messages
4		5	300 ms	10^{-6}	Electricity distribution - medium voltage (e.g., clause7.2.2 of TS22.261 [51])
65		0.7	75 ms	10^{-2}	Process automation - monitoring (e.g., clause7.2.2 of TS22.261 [51])
66		2	100 ms	10^{-2}	Non-Conversational Video (Buffered Streaming)
67		1.5	100 ms	10^{-3}	Mission Critical user plane Push To Talk voice (e.g., MCPTT)
75		2.5	50 ms	10^{-2}	Non-Mission-Critical user plane Push To Talk voice
71		5.6	150 ms	10^{-6}	Mission Critical Video user plane
72		5.6	300 ms	10^{-4}	V2X messages
73		5.6	300 ms	10^{-8}	"Live" Uplink Streaming (e.g., TS26.238 [53])

Table 3.1.3-2 5QI regulation in 3GPP (TS 23.501 V17.3.0(2021-12)) (excerpt)

5QI Value	Resource Type	Default Priority Level	Packet Delay Budget	Packet Error Rate	Default Maximum Data Burst Volume	Default Averaging Window	Example Services
1	GBR	20	100 ms	10^{-2}	N/A	2000 ms	Conversational Voice
2		40	150 ms	10^{-3}	N/A	2000 ms	Conversational Video (Live Streaming)
3		30	50 ms	10^{-3}	N/A	2000 ms	Real Time Gaming, V2X messages (see TS 23.287 [121]). Electricity distribution – medium voltage, Process automation monitoring
4		50	300 ms	10^{-6}	N/A	2000 ms	Non-Conversational Video (Buffered Streaming)
65		7	75 ms	10^{-2}	N/A	2000 ms	Mission Critical user plane Push To Talk voice (e.g. MCPTT)
66		20	100 ms	10^{-2}	N/A	2000 ms	Non-Mission-Critical user plane Push To Talk voice
67		15	100 ms	10^{-3}	N/A	2000 ms	Mission Critical Video user plane
71		56	150 ms	10^{-6}	N/A	2000 ms	"Live" Uplink Streaming (e.g., TS 26.238 [76])
72		56	300 ms	10^{-4}	N/A	2000 ms	"Live" Uplink Streaming (e.g., TS 26.238 [76])

In use case h-1 (remote control), QoS control is expected to reduce delay factors by setting the appropriate priority level (Priority Level), allowable delay time (Packet Delay Budget), allowable data loss rate (Packet Error Rate), etc., for control information communication (DL) and communication such as for video information (UL).

As an issue for implementation, it is necessary to consider the details of function implementation in the public network so that priority control can be performed according to the priority level of services provided by each service provider. This is because which service is controlled with priority will affect other services provided by individual providers.

(b) Securing dedicated frequency bands

In order to ensure that the sending and receiving of control information and other information necessary for automated driving is not affected by other communication, one measure is to secure dedicated frequency bands for wide-area communications for the use case by utilizing local 5G[5] or SoftBank's private 5G service.

Unlike public 5G, which is used by the public, local 5G is an independent and dedicated network, so it is possible to build a stable communication environment. However, there are disadvantages in that it is necessary to obtain an operator's license to build local 5G and that it is time-consuming and costly to build and operate the network. Private 5G is a service SoftBank plans to offer that falls between public 5G and local 5G. The service is scheduled to be launched in FY 2022 as a service that provides a 5G network with the required bandwidth and capacity on the premises of companies and municipalities.

In use case h-1 (remote control), local 5G and private 5G services in a limited area of level 4 automated driving for example are expected to reduce delay factors in control information communication (DL) and communication such as for video information (UL).

As an issue for implementation, it is necessary to consider the possibility of providing services in limited areas as level 4 automated driving, or in cooperation with telecommunications carriers, such as with private 5G. This is because, as mentioned above, local 5G requires obtaining operator's license and large-scale construction work depending on the system to be built, including deploying base stations.

(c) Securing dedicated bandwidth end-to-end

With 5G, the number of terminal connections and applications is expected to be diverse, and networks tailored to the characteristics of the services will be needed to provide a variety of services. The method designed to maximize the characteristics of each service so that they do not interfere with each other is "network slicing."

In 3GPP, network slicing specifications are defined as follows.

- Technology designed to make maximum so that various services do not interfere with each other and that logically divides the configuration and resources per communication service characteristic.
- Slices are formed by S-NSSAI (Single-Network Slice Selection Assistance Information) identifiers (up to 8 slices per terminal).
- S-NSSAI can be carried in the terminal-RAN-core NW (End-to-End network slicing).

Network slicing is technology that divides and groups networks per service, enabling end-to-end isolation of other services. When operating multiple services with different service requirements (high speed, many connections, low delay, etc.), dividing the network for each service is expected to make maximum use of features so that individual services do not interfere with each other.

[5] Self-run 5G networks built by companies and municipalities for a limited range of use.

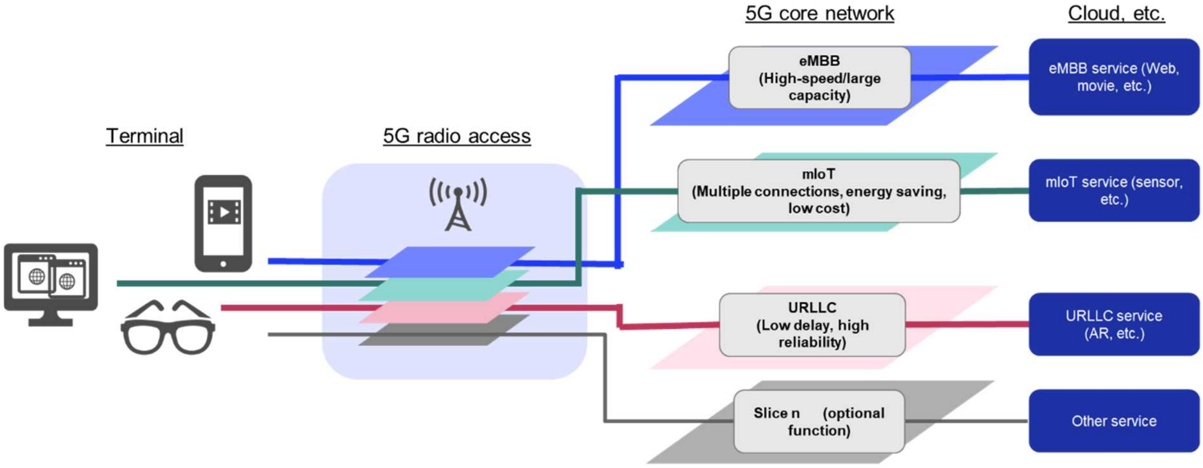

Fig. 3.1.3-1 Image of network slicing

In use case h-1 (remote control), a logical network optimized for service requirements of low delay communication (control information) and high-speed communication (video information) can be configured (network slicing), and that is expected to reduce delay factors in control information communication (DL) and video information and other communications (UL).

As an issue for implementation, it is necessary to consider the details of function implementation in a public network. The specification for slicing of the radio access part is still under development in 3GPP Release 17, and we will keep an eye on the possible timing of its implementation, and consideration taking into account the feasibility and timing of its implementation is needed.

(d) Appropriate placement of edge processing (reference)

MEC (Multi-access Edge Computing) is a network technology expected to play an active role in a future 5G era. MEC can reduce the amount of processing at the server at the end of the Internet by placing a server (edge) near the terminal and performing data processing at the edge server as much as possible. Moreover, if the physical distance between communication sections is shortened by building the system on a network using the MEC configuration, that is expected to reduce transmission delays and network load.

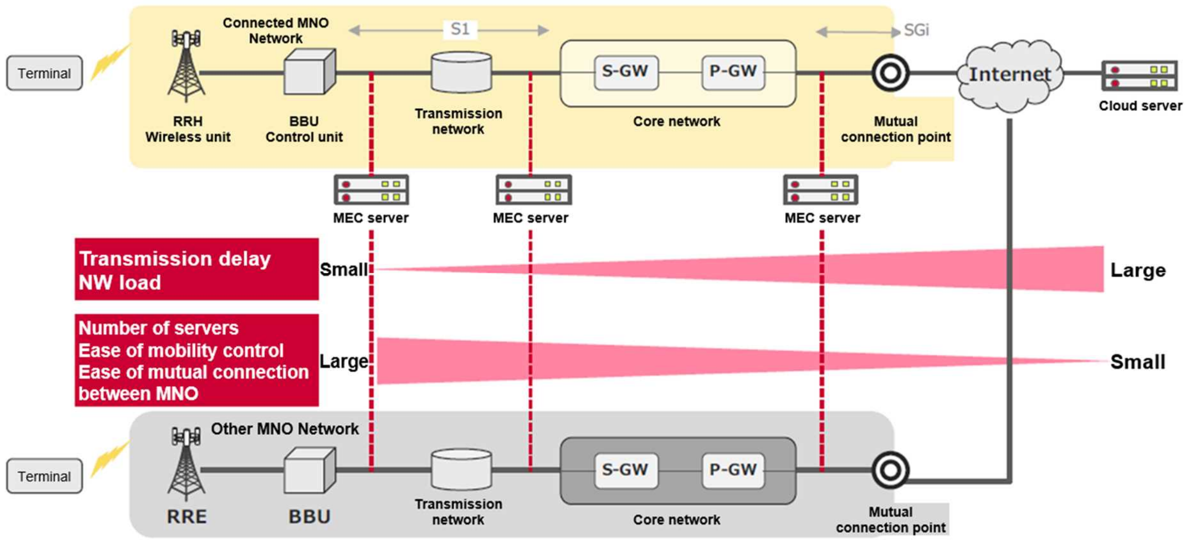

Fig. 3.1.3-2 Concept of placing edge processing[6]

In use case d (providing lookahead information), optimization of communication (reduction of communication delay and communication traffic) can be expected by performing the process of identifying target vehicles information is set to (recipient management) on the edge side, rather than on the host server side.

As an issue for implementation, it is necessary to consider, how to divide functions among vehicles, MEC, and host servers according to use cases, as well as how to coordinate among telecommunications carriers in the use of MEC (trends in studies on inter-carrier coordination[7]).

[6] Source: ITS Forum "Survey Report on Advanced ITS and Automated Driving Using Cellular Communications Technologies"

[7]Verification underway in EU 5G CARMEN Project (including in ITS field), etc., on MEC Platform, MEC Orchestration

(e) Securing uplink (V->N) communication capacity

In cases where video information is continuously sent to a server, such as remote monitoring, the communication traffic on the UL side is large, so a strategy to secure communication capacity by emphasizing the UL side is conceivable.

In Japan, the UL/DL bandwidth allocation in public networks is based on the TDD Config [8] agreed in 3GPP (5G/NR), with emphasis on DL as shown in Fig. 3.1.3-3, taking into account the amount of data traffic and future 5G service projections.

	Sub6 band	mmW band
How to utilize Massive MIMO	Utilized for MIMO multiplexing	Expansion of coverage by beamforming
Concept of coverage	Coverage similar to that of LTE 3.5 GHz band	High throughput provided utilizing wide-area network Spot deployment
Peak rate (3GPP standard value, including LTE)	Downlink 3.4 Gbit/s / Uplink 182 Mbit/s	Downlink 3.4 Gbit/s / Uplink 182 Mbit/s
Number of MIMO	Downlink 4×4 / Uplink SISO	Downlink/uplink 2×2 MIMO
Modulation method	Downlink 256QAM / Uplink 64QAM	Downlink/uplink 64QAM

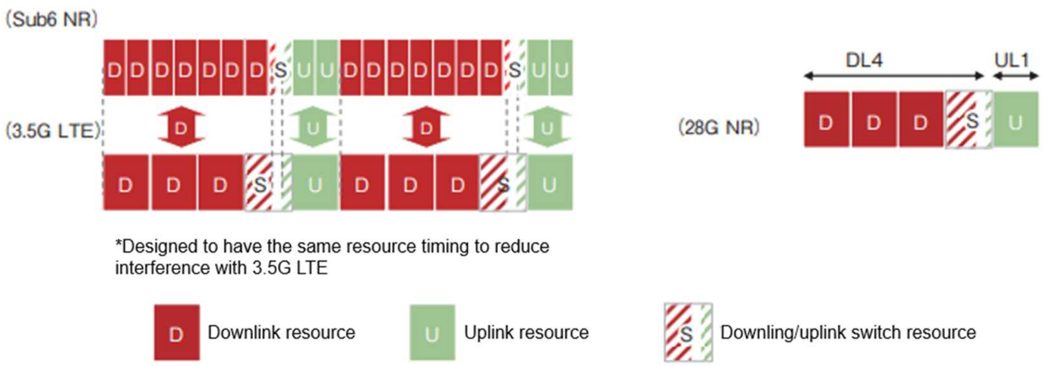

Fig. 3.1.3-3TDD Config used for frequencies in Japan[9]

In order to meet the requirements of various applications, the Ministry of Internal Affairs and Communications is currently studying the pattern of TDD when the ratio of local 5G UL and DL operations is variable.

In use case h-1 (remote control), utilizing local 5G in limited areas and using TDD patterns that take into account the volume of UL data as level 4 is expected to reduce the delay factor in communication such as for video information (UL).

As an issue for implementation, it is necessary to consider the possibility of using local 5G in limited areas at level 4, taking into account the status of the study of additional TDD patterns (local 5G).

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[8] Parameters that determine how the upper and lower slots of TDD (Time Division Duplex) are allocated
[9] Source: NTT Technical Journal 2020 vol. 32 No. 9

(f) Optimization of communication traffic (reference)

Although not directly related to the communication system, reducing communication traffic is expected to reduce the load on the network, leading to reductions in communication delays.

When transmitting large volume of data for video of the vehicle surroundings during remote monitoring and operation, use of AI (artificial intelligence) to optimize the communication traffic by making image quality higher for areas of interest and image quality lower in areas not of interest is conceivable.

As shown in Fig. 3.1.3-4 and Fig. 3.1.3-5, it was confirmed in a demonstration case (monitoring of images around vehicles) that communication traffic can be reduced by up to one-tenth by using the learning-based media transmission control technology developed by NEC (5 Mbps reduced to 0.5 Mbps).

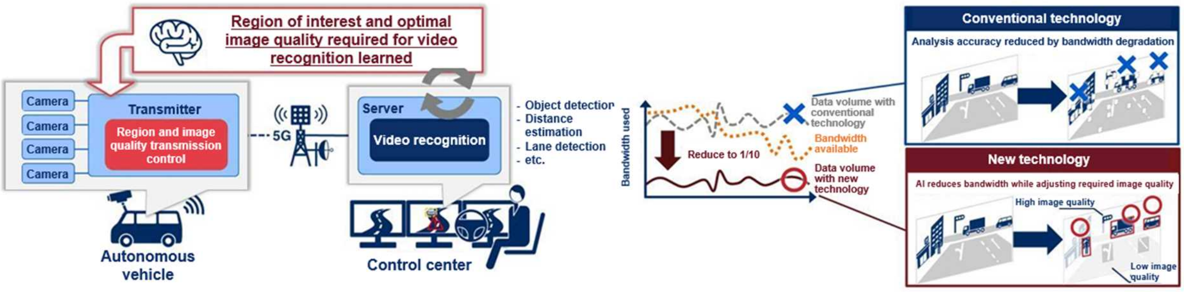

Fig. 3.1.3-4 Image of learning-based media transmission control technology

Fig. 3.1.3-5 Learning-based media transmission control technology demonstration example

In use case h-1 (remote control), limiting the area of interest in video monitoring of surroundings and optimizing the communication traffic on the vehicle side, is expected to reduce delay factors in communication such as for video information (UL).

As an issue for implementation, it is necessary to consider the implementation of video processing functions in vehicles (lightness of processing, real-time processing, etc.).

(g) Consideration of feasibility of each communication technology

Communication technologies assumed to be utilized in wide-area communications are the unicast and broadcast communication technologies covered in case 2.1. This section also describes the multicast technology and compares the characteristics of each communication technology.

One standard classified as multicast technology is “LTE-Broadcast” using eMBMS (evolved Multimedia Broadcast Multicast Service), which is standardized in 3GPP Release 9. In unicast used as a general data communication method, one bandwidth is allocated per terminal to send data from the server to the terminal, resulting in a load of one bandwidth per terminal even when the same data is sent. LTE-Broadcast, on the other hand, is characterized by its ability to transmit large volumes of data at once over the same bandwidth to all terminals in the area that wish to receive it.

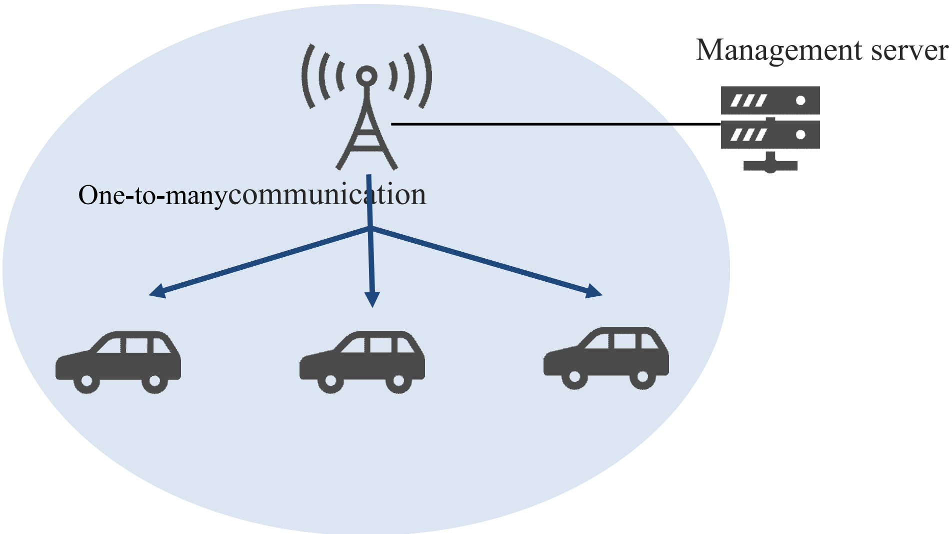

Fig. 3.1.3-6 Multicast

Results of organizing characteristics per communication technology are shown in Table 3.1.3-3.

Table 3.1.3-3 Comparison of communication technologies

	Unicast	Multicast	Broadcast
Identification of target vehicles to be sent information (Identification of target vehicle location information)	Required (Individual vehicle determination)	Required (Individual vehicle determination)	Unnecessary
Communication traffic	[Message + response] x No. of vehicles	Message	Message
Reliability as communication	High	Low	Low
Advantages	• Non-target vehicles do not receive • Arrival confirmation at communication level is possible	• Non-target vehicles do not receive • Communication network load is small	• Communication network load is small • Determination of target vehicle at server unnecessary
Disadvantages	• Communication network load is large (Session management methods in particular need to be studied) • Determination of target vehicle at server necessary	• Determination of target vehicle at server necessary • Receiving response from vehicle app is required, if necessary	• Sorting of information on vehicle app necessary • Receiving response from vehicle app is required, if necessary

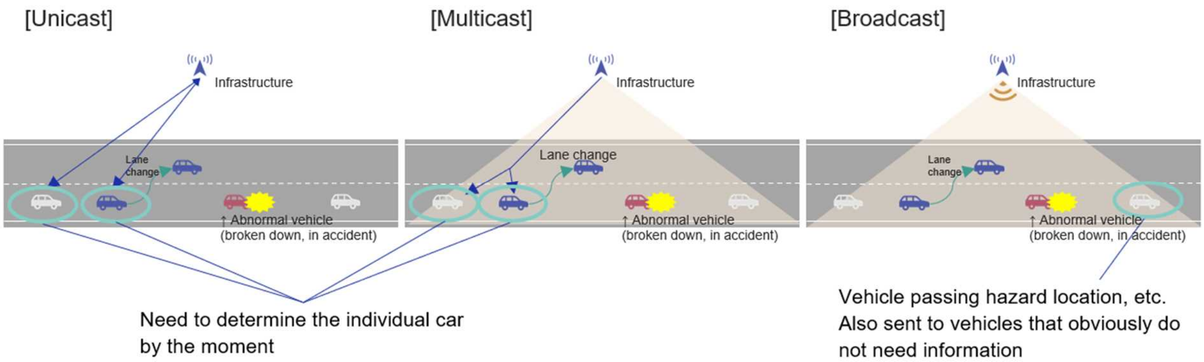

Fig. 3.1.3-7 Comparison of communication technologies

Considering the practicality of what type of communication technology is suitable by use case is expected to reduce the number of transmitting vehicles / frequency of communication. The items to be considered when applied to each use case are shown in Table 3.1.3-4.

Table 3.1.3-4 Application of communication technology to individual use cases

<table>
<tr><th></th><th>Unicast</th><th>Multicast</th><th>Broadcast</th></tr>
<tr><td>b-1-2.
Driving assistance by using traffic signal information</td><td>• Individual vehicle route information is necessary to provide more appropriate information (with push system).</td><td>• Individual vehicle route information is necessary to provide more appropriate information (with push system).</td><td rowspan="8">• Increased communication traffic and frequency of communication according to the broadcast range (increased load on vehicle apps)</td></tr>
<tr><td>d-1.
Driving assistance by notification of abnormal vehicles</td><td>-</td><td>-</td></tr>
<tr><td>d-2.
Driving assistance by notification of wrong-way vehicles</td><td>• Real-time individual vehicle determination according to wrong-way vehicle location is necessary to provide more appropriate information.</td><td>• Real-time area determination according to wrong-way vehicle location is necessary to provide more appropriate information.</td></tr>
<tr><td>d-3.
Driving assistance based on traffic congestion information</td><td rowspan="2">• Real-time individual vehicle determination according to end of congestion location is necessary to provide more appropriate information.</td><td rowspan="2">• Real-time area determination according to end of congestion location is necessary to provide more appropriate information.</td></tr>
<tr><td>d-4.
Traffic congestion assistance at branches and exits</td></tr>
<tr><td>d-5.
Driving assistance based on hazard information</td><td>-</td><td>-</td></tr>
<tr><td>e-1.
Driving assistance based on emergency vehicle information</td><td>• Real-time individual vehicle determination according to emergency vehicle location is necessary to provide more appropriate information.</td><td>• Real-time area determination according to emergency vehicle location is necessary to provide more appropriate information.</td></tr>
</table>

As an issue for implementation, it is necessary to consider selection of the optimal communication technology according to the characteristics of the use case, division of functions related to the identification process of target vehicles to be sent information (recipient management) among the components of the overall system, and the implementation details of related functions in the public network.

(2) Correspondence of issues and proposed countermeasures

Correspondence of issues covered in section 3.1.2 and proposed countermeasures shown in section 3.1.3(1)is shown in Table 3.1.3-5.

Table 3.1.3-5 Correspondence of issues and proposed countermeasures

Issue	Considerations	Proposed countermeasures
Issue (1) Communication delay during remote control	• Countermeasures for reducing communication delays (V⇔N)	(a) Priority control of wireless communication (b) Securing dedicated frequency bands (c) Securing dedicated bandwidth end-to-end (d) Appropriate placement of edge processing
Issue (2) Communication traffic during remote monitoring and operation (video, etc.)	• Measures for reducing commu nication delays (V->N)	(a) Priority control of wireless communication (e) Securing uplink (V->N) communication capacity (b) Securing dedicated frequency bands (c) Securing dedicated bandwidth end-to-end (d) Appropriate placement of edge processing
	• Measures for reducing commu nication traffic (V->N)	(f) Optimization of communication traffic
Issue (3) Frequency of communication of location information for determining information transmission vehicle	• Measures for reducing frequen cy of communication (V->N)	(g) Consideration of feasibility of each communication technology (d) Appropriate placement of edge processing
Issue (4) Feasibility of communication technologies according to the use case and feasibility of number of vehicles that can be accommodated and frequency of communication according to the communication technologies	• Measures for reducing commu nication traffic (N->V)	(g) Consideration of feasibility of each communication technology (d) Appropriate placement of edge processing

3.1.4 Case studies on remote control (reference)

In section 3.1.3, use case h-1. was given as a typical example in terms of communication delay, and several countermeasure proposals for remote control were covered. This section introduces examples of system demonstrations that have been conducted in recent years as case studies of remote control. It also covers concepts in system requirements in the current situation.

(1) Anticipated system image (remote control)

Fig. Fig. 3.1.1-1 shows the overall system anticipated in realizing use cases using wide-area communication, and Fig. Fig. 3.1.4-1 shows the system image specified as a remote control system. In remote monitoring, it is assumed that a remote operator monitors video information, etc., sent from the vehicle and gives control instructions to the vehicle via a management server on the network (assumed to be a base station or a network wired to a base station). In addition to communication delay, processing delay and recognition, judgment, and operation by operators can be delay factors for the overall system.

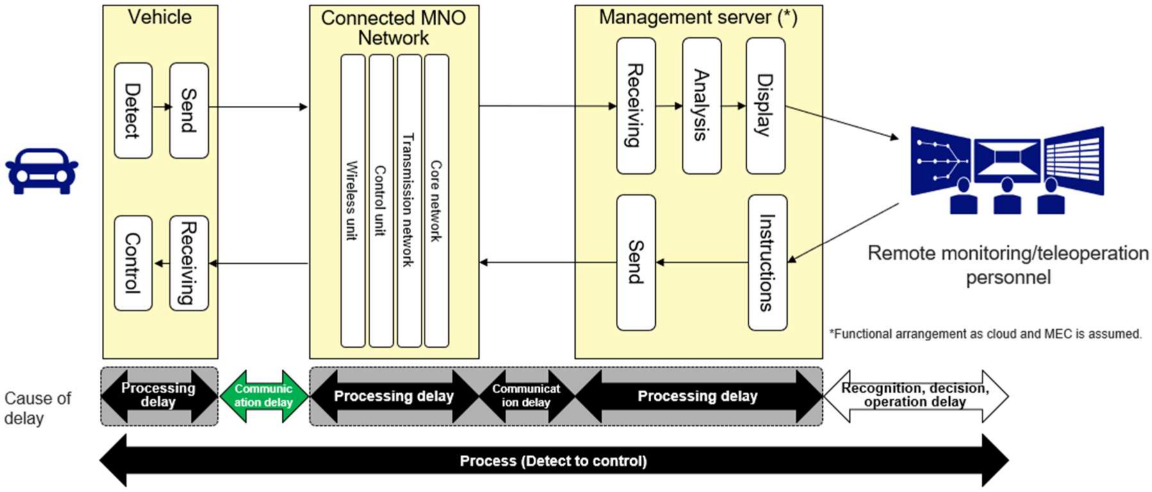

Fig. 3.1.4-1 System image in remote control (anticipated)

(2) System demonstration examples

Examples of major system demonstrations for remote control in Japan and other countries are shown in Table 3.1.4-1.

Table 3.1.4-1 System demonstration examples[10] (1/3)

No	Name	Lead operating entity of plan	Main providers of the system	Location	Road type	Term	Max. speed	Remote monitoring / remote control	Major content of demonstration
1	FY 2008 Automated Driving Demonstration Promotion Project [11]	Aichi Prefecture	AISAN TECHNOLOGY, AXE, OKAYA & CO, KDDI, THREED, Sompo Japan, TIER IV, EmbIV, Nagoya University	Toyohashi City, Tokoname City, Ichinomiya City, Aichi Prefecture	General roads	Toyohashi: Nov. 21st to 24th, 2021 Ichinomiya: Feb. 9th to 10th, 2019 Tokoname: March 3rd to 9th, 2021	Toyohashi: 20 km/h Ichinomiya: 60 km/h Tokoname: 40 km/h	Remote monitoring / remote control (stop instruction)	Remote automated driving demonstration testing using multiple vehicles (two vehicles) utilizing 5G
2	Evaluation of Influence of Delay of Image Information on Steering Maneuver in Remotely Controllable Automated Driving System [12]	Keio University	Keio University	(simulator)	Closed space	2019	10km/h	Remote control (maneuver)	Verify how much steering deviation occurs by delaying the video on the simulator
3	R&D and demonstration projects for social implementation of advanced automated driving systems[13]	Ministry of Economy, Trade and Industry, National Institute of Advanced Industrial Science and Technology	Machidukuri Motor, Hitachi, Keio University, Toyota Tsusho	Eiheiji Town, Fukui Prefecture	Bicycle- and pedestrian-only road	Weekends after March 25, 2021	12km/h	Remote monitoring / Remote control (stop, start, steering)	Remote control (up to 3 vehicles per person) with no driver or security personnel on board

[10] From contractor survey (as of September 2021)

[11] Reference materials: https://www.pref.aichi.jp/uploaded/attachment/299708.pdf

[12] Reference materials: https://www.jstage.jst.go.jp/article/jsaeronbun/50/3/50_20194372/_pdf

[13] Reference materials: https://www.aist.go.jp/aist_j/news/au20210323.html

Table 3.1.4-1 System demonstration examples (2/3)

No	Name	Lead operating entity of plan	Main providers of the system	Location	Road type	Term	Max. speed	Remote monitoring / remote control	Major content of demonstration
4	Local 5G demonstration [14]	Ministry of Internal Affairs and Communications, Maebashi City	Gunma University, Nippon Mobility, NEC, NTT Docomo	Maebashi City, Gunma Prefecture	General roads On university property	February 2021	30km/h	Remote monitoring / remote control (stop instruction)	Demonstration of a mechanism to support safety assurance of automated vehicles (buses) using L5G (identification of other vehicle behavior in remote control room, identification of information not within line of sight, collision detection by I2V coordination)
5	5G demonstration (construction machinery)[15]	Ministry of Internal Affairs and Communications, KDDI, Obayashi Corporation, NEC	KDDI, Obayashi Corporation, NEC	Ibaraki City, Osaka Ai River Dam	Closed space	December 3rd to 14th, 2018	-	Remote monitoring / remote control (steering)	Two different construction machines (backhoe and crawler dump truck) remotely linked using the features of 5G to transport earth and sand.
6	Demonstration in Shanghai, China[16]	China Mobile, SAIC, Huawei	China Mobile, SAIC, Huawei	Shanghai, China	(Unknown)	(Unknown)	(Unknown)	Remote control	Demonstration test of remote control using 5G network was conducted
7	5G, IOWN related technology demonstration[17]	Hokkaido University, Iwamizawa City, NTT, NTT East, NTT Docomo	Hokkaido University, Iwamizawa City, NTT, NTT East, NTT Docomo	Iwamizawa City	Closed space	(Unknown)	(Unknown)	Remote monitoring / remote control (steering)	Demonstration of automatic travel between fields and remote monitoring and control of farm machinery using robot farm machinery, and technologies related to 5G and IOWN

[14] Reference materials: https://www.gunma-u.ac.jp/information/84393
[15] Reference materials: https://jpn.nec.com/press/201812/20181214_02.html
[16] Reference materials: https://www.sip-adus.go.jp/rd/rddata/rd03/213.pdf
[17] Reference materials: https://group.ntt/jp/newsrelease/2020/11/16/201116b.html

Table 3.1.4-1 System demonstration examples (3/3)

No	Name	Lead operating entity of plan	Main providers of the system	Location	Road type	Term	Max. speed	Remote monitoring / remote control	Major content of demonstration
8	Demonstration related to automated vehicle use cases[18]	SoftBank, Subaru	SoftBank, Subaru	Subaru Research and Experiment Center Bifuka Proving Ground (Bifuka-cho, Nakagawa-gun, Hokkaido)	Closed space	August 2020	(Unknown)	Remote monitoring / remote control (deceleration instruction)	Field demonstration of vehicle assistance at merging using 5G and C-V2X

[18]Reference materials: https://www.softbank.jp/corp/news/press/sbkk/2020/20201124_01/

(3) System requirement examples

Examples (excerpts) of system requirements for remote control that are being considered by concerned parties are as follows.

- "Guidelines for Public Road Testing of Automated Driving Systems" (National Police Agency)

  Remote monitoring/operation personnel must be able to simultaneously monitor video and sound to assess the status of all experiment vehicles and the direction in which they are traveling.

- "Criteria Easing Certification System for Automobiles Equipped with Remote Automated Driving System (Demonstration)" (Ministry of Land, Infrastructure, Transport and Tourism)

  Remote monitoring/operation personnel must be able to simultaneously monitor video and sound to assess the status of all experiment vehicles and the direction in which they are traveling.

1) Time lag that occurs when information necessary for driving operation is transmitted

   The distance required for the vehicle to come to a stop (free running distance + braking distance) must be safe in light of the surrounding traffic environment, etc.

2) Requirements for steering devices

   The remote operation personnel seat must have operations the same as those of the driver's seat when riding in the vehicle.

   The tell-tale on the remote operation personnel must be visible on the display like with the driver's seat in a compliant vehicle, etc.

3) Field of view requirements

   Direct and indirect field of view similar to that of the driver's seat in a compliant vehicle must be shown as video on a display at the remote operation personnel seat. Also, measures must be taken so that there are no obstructions present in a portion of the similar field of view that is not shown on the display as video in the remote operation personnel seat, and other field of view must be shown on the display as video.

- Case studies on remote control in 3GPP(TS22.186)

  3GPP (TS22.186) specifies the performance requirements for remote running as shown in Table 3.1.4-2.

Table 3.1.4-2 Performance requirements for remote running (TS22.186)

Communication scenario description	Req #	Max end-to-end latency (ms)	Reliability (%)	Data rate (Mbps)
Information exchange between a UE supporting V2X application and a V2X Application Server	[R.5.5-002]	5	99.999	UL: 25 DL: 1

(4) System requirement concepts

Currently, remote monitoring/remote control using V2N being operated for demonstration purposes and the like is being conducted with restrictions on operational vehicle speeds and remote monitoring/remote control contents depending on the communication environment and communication performance that are feasible for implementation.

Remote control from the perspective of communication performance requires improved communication capacity and communication quality from the viewpoint of implementing remote control under remote monitoring. Meanwhile, remote control from the standpoint of automated driving performance requires improved automated driving performance (autonomous driving, infrastructure coordination) from the perspective of remotely monitoring automated vehicles. In considering system requirements for remote control in the future, it is assumed that it will be necessary to define requirements considering not only wide-area communication (V2N) but also the optimization of the overall system, taking into account progress in both communication performance and automated driving performance as well as the location (expressways, general roads) where the service is provided, as shown in Fig. 3.1.4-2.

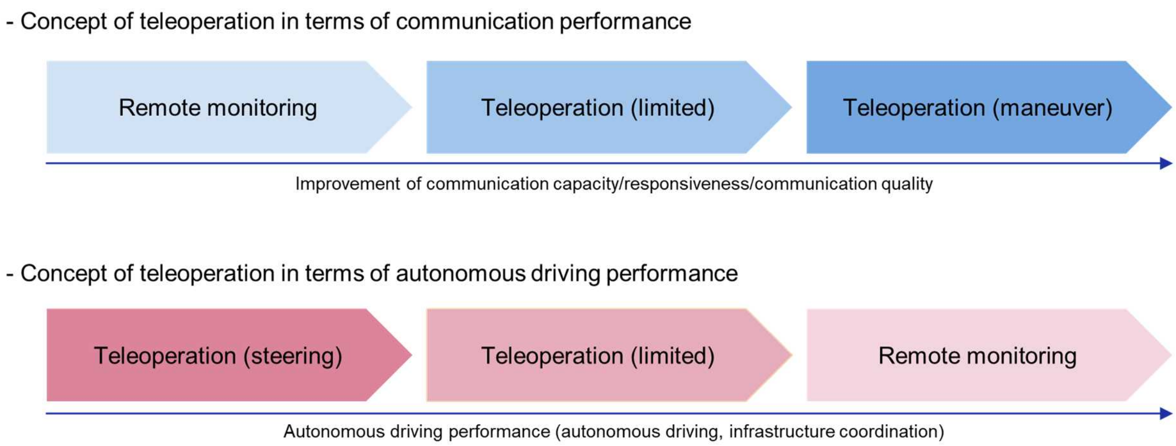

Fig. 3.1.4-2 Concepts of system requirements in remote control

3.2 Examination of problems and countermeasures for narrow-area communication

This case summarizes issues based on points to consider extracted in study of communication shown in 2.2.1 and covers the countermeasures against them.

3.2.1 Anticipated system image

An image of the system anticipated in realizing use cases using narrow-area communication is shown in Fig. 3.2.1-1.

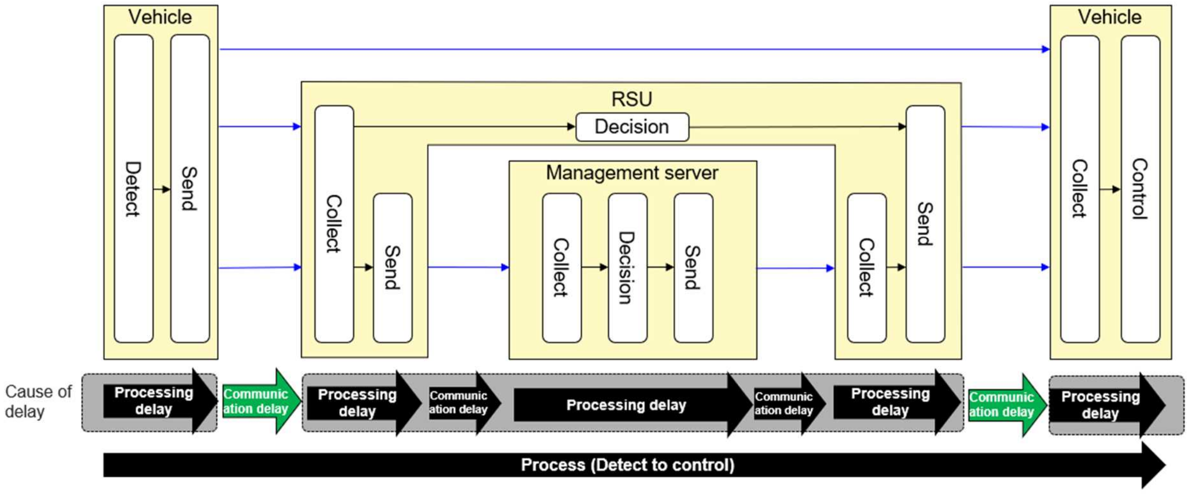

Fig. 3.2.1-1 System image for narrow-area communication

Assume as own vehicle the cooperative driving automation system defined in the cooperative driving automation use cases, i.e., “a system that enables safer and smoother automated driving control by providing information outside the detection range of on-board sensors and information of one’s own vehicle, as well as communicating V2V and I2V interaction, based on an autonomous driving system”.

Assume other vehicles in the vicinity to be “cooperative driving vehicles” that are driving automatically with the cooperative driving automation system, and assume vehicles not equipped with a cooperative driving automation system and that are driven by the driver (including vehicles driven by the driver without using a cooperative driving automation system) or vehicles that are driving automatically with an autonomous driving system to be “V2X non-supported vehicles”.

3.2.2 Considerations on problems

Section 2.2 describes the perspective for evaluating the selection of use cases using narrow-area communication to be considered when examining problems and countermeasures for narrow-area communication, and the results of the selection of use cases to be considered.

- Perspective for evaluating selection of use cases
  - Communication traffic

    In b-1-1. Driving assistance by using traffic signal information (V2I), c. Lookahead information: Collision avoidance, and e. Lookahead information: Emergency vehicle notification, it is necessary to secure large capacity communication bandwidth since simultaneous occurrence of use cases is expected around intersections.

  - Communication delay

    In a. Merging / lane change assistance, b-1-1. Driving assistance by using traffic signal information (V2I), c. Lookahead information: Collision avoidance, and g. Platooning / adaptive cruise control, the system must have low delay in order to perform immediate driving operations based on information collected from surrounding vehicles.

  - Number of signaling devices / Frequency of communication

    When performing driving support in a. Merging / lane change assistance, multi-vehicle and bi-directional communication is performed, so the number of signaling devices and frequency of communication need to be studied in advance.

- Selection of use cases
  1) Communication congestion due to frequent bidirectional communication
     Use case where communication between vehicles and RSU is used, and communication congestion is expected to occur due to multiple vehicles performing bidirectional communication with RSU.
  - a-1-3. Cooperative merging assistance with vehicles on the mainline by roadside control
  2) Communication congestion due to conflicting multiple use cases
     Cases where multiple use cases are expected to occur simultaneously around intersections
  - b-1-1. Driving assistance by using traffic signal information (V2I)
  - c-1. Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly
  - c-2-2. Driving assistance based on intersection information (V2I)

In this section, considerations on problems are organized for the use cases selected.

(1) Communication congestion due to frequent bidirectional communication

Of the aforementioned use cases using narrow-area communication covered in section 2.2, communication requirements of selected use case a-1-3. are excerpted and summarized in Table 3.2.2-1, and items to be considered for each item are organized below.

Table 3.2.2-1 communication requirements in use case a-1-3. (Excerpted from 2.2)

Item	Message name			
	Location information	Control request	Agreement request Update request	Agreement response Update response
Communication format	V2I (I -> V)	V2I (V -> I)	V2I (I -> V)	V2I (V -> I)
Communication counterpart	Non-specified vehicles	RSU	Specified vehicles	Specified vehicles
Target area (minimum range)	From 6 seconds before merging starting point to merging starting point	Within control request range	Within control request range	Within control request range
Number of transmitting vehicles per area	1 vehicle	1 vehicle	1 vehicle (× control number)	48 vehicles *2 (control number, when traffic is heavy)
Required communication distance	Connecting route: 67.8 to 118.6 m Mainline: 112.5 to 270 m	67.8 to 118.6 m	Connecting route: 67.8 to 118.6 m Mainline: 112.5 to 270.0 m	Connecting route: 67.8 to 118.6 m Mainline: 112.5 to 270.0 m
Maximum relative speed (Consideration (1))	Connecting route 20 to 70 km/h Mainline: 20 to 120 km/h	Connecting route 20 to 70 km/h Mainline: 20 to 120 km/h	Connecting route 20 to 70 km/h Mainline: 20 to 120 km/h	Connecting route 20 to 70 km/h Mainline: 20 to 120 km/h
Maximum data size	5236 bytes (4986+250) Anticipated vehicles: 184	287 bytes (37+250)	369 bytes (119+250) *1	287 bytes (37+250)
Cyclic or acyclic	Cyclic	Acyclic	Acyclic	Acyclic
Transmission cycle (Consideration (2))	100 ms	Not specified		
PAR per packet	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)
Allowable delay of radio communication section	Not specified	Assume 100 ms as allowable delay of radio communication section	Assume 100 ms as allowable delay of radio communication section	Assume 100 ms as allowable delay of radio communication section

*1 In the control response message, the information element of the scheduled time to start action (2 bytes) is added, for 121+250=371 bytes.

*2 Cases where vehicle density is estimated at 12 vehicles/lane for three lanes (mainline) and one lane (connecting route). With six lanes (mainline) and two lanes (connecting route), the number of transmitting vehicles is 96 vehicles.

- Consideration (1) based on communication requirements

  There is concern about communication congestion due to an increase in the number of vehicles (communication terminals) present within the required communication distance as the relative speed of vehicles (driving speed) decreases.
- Consideration (2) based on communication requirements

  There is concern about communication congestion due to messages being frequently sent and received due to agreement processing between merging vehicles, RSU, and mainline vehicles triggered by control request messages sent from merging vehicles to RSU triggered by the 100 ms transmission cycle and vehicles reaching 5.9 seconds before the merging position.
- Consideration (3) based on communication requirements

  Examples of road geometries for mainlines and connecting routes on expressways and general roads that are assumed to be the target locations are shown in Fig. 3.2.2-1. The geometry of the connecting route where the merging vehicles are located is close to perpendicular to the mainline while the distance from the merging point is far, gradually curving as it gets closer to the merging point, and finally becoming close to parallel to the mainline. Therefore, if an RSU is placed at the merging point, it is expected to be in a "non-line-of-sight (NLoS) environment" due to the greater distance, and there is concern about the impact on communication in this environment.

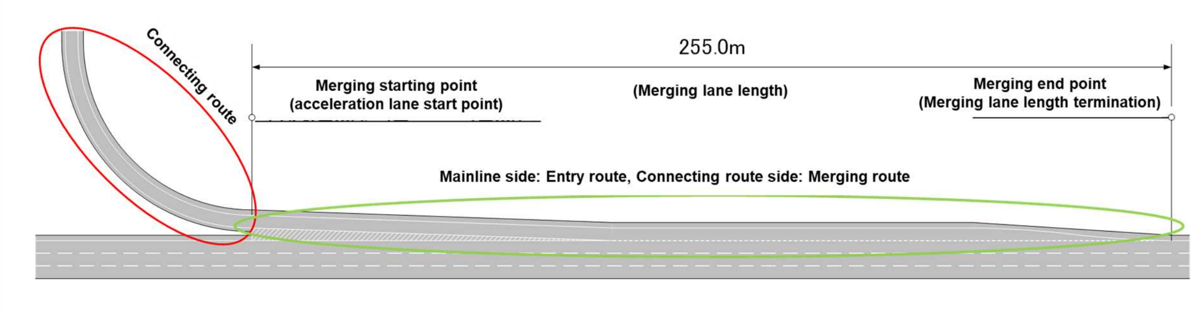

Fig. 3.2.2-1 Example of road assumed to merge with inter-city expressway[19]

(2) Communication congestion due to conflicting multiple use cases

Of the aforementioned use casers using narrow-area communication covered in 2.2, communication requirements of selected use cases b-1-1., c-1., and c-2-2. are excerpted and summarized in Table 3.2.2-1, and items to be considered for each item are organized below.

[19] Study report on communication scenarios and requirements for "SIP Use Cases for Cooperative Driving Automation" (RC-017)

Table 3.2.2-2 communication requirements in use cases b-1-1., c-1., and c-2-2. (Excerpted from 2.2)

Item	Use case		
	b-1-1. Driving assistance by using traffic signal information (V2I)	c-1. Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly	c-2-2. Driving assistance based on intersection information (V2I)
Message name	-	-	-
Communication format (Consideration (4))	V2I (I -> V)	V2V (V -> V)	V2I (I -> V)
Communication counterpart	Non-specified vehicles	Non-specified vehicles	Non-specified vehicles
Target area (Minimum range)	Passenger vehicles: Approx. 138.5 m (provisional) Large vehicles: Approx. 206.3 m (provisional) (yellow 4 sec. 60 km/h)	• Direct V2V communication: 250 m upstream from point where event occurs • If relay: 1 km upstream from point where event occurs	• Upstream side: upstream from location right-turning vehicle turns on turn signal (point 30 m upstream stop line) • Downstream side: last stopping point at right turn destination (oncoming vehicle range in which right-turning vehicle needs information) *Target lanes are all straight ahead lanes
Number of transmitting vehicles per area	See RSU installation model	(Vehicle speed: 120 km/h; intervehicle distance: 2 s) 79 vehicles (Vehicle speed: 60 km/h; intervehicle distance: 1 s) 277 vehicles (Total vehicles for six lanes in 1 km section from point where emergency action occurs)	N/A
Required communication distance	Passenger vehicles: Approx. 138.5 m (provisional) Large vehicles: Approx. 206.3 m (provisional) (yellow 4 sec. 60 km/h) Note, 700 MHz band system request value is 240 m	• Direct V2V communication: 250 m upstream from point where event occurs • If relay: 1 km upstream from point where event occurs	Dependent on road infrastructure antenna location. The following if roadside infrastructure antenna installed at side of intersection and antenna height 6 m: (No. of lanes on one side: 6) 75.2 m (No. of lanes on one side: 3) 52.4 m
Maximum relative speed (Consideration (5))	70 km/h	Up to 120 km/h	up to 70 km/h
Maximum data size	About 1K byte / intersection	312 bytes	(No. of lanes on one side: 6) 1534 bytes (No. of lanes on one side: 3) 1150 bytes [*2]
Cyclic or acyclic	Cyclic	Cyclic	Cyclic
Transmission cycle (Consideration (4))	100 ms	100 ms	100 ms
PAR per packet	At least 99% in 5 m evaluation section [*1] (same as 700 MHz band system)	PAR ≥ 99% in direct V2V communication	PAR ≥ 99%
Allowable delay of radio communication section	Delay not specified. Fluctuation within ±300 ms	• Up to 255 m upstream from place where emergency avoidance action occurs: within 100 ms	Assume 100 ms as allowable delay of radio communication section

		• Points upstream from the above: up to 1 km upstream, relax to as much as 30 s based on distance	

*1 70 km/h is approx. 20 m/s. 250 ms required in 5 m evaluation section. Two 100 ms cycle transmissions occur within 250 ms. Cumulative PAR of 99% can be met with at least 90% packets arriving per packet, derived from 1-(0.1*0.1) = 0.99. Thus, allowable delay of radio communication section is PAR of 90% at 100 ms.

*2 Message size when traffic signal information, intersection identification information, and vehicle detection information are sent together in a single message. If each piece of information is sent in a separate message, the security overhead is taken into account for each piece of information.

- Consideration (4) based on communication requirements

In cases where the communication format is mixed with V2I (RSU -> vehicle) and V2V (vehicle -> vehicle), there is concern about the impact on communication quality due to the timing of message sending and receiving since messages are sent and received in 100 ms cycles.

- Consideration (5) based on communication requirements (Same as consideration (1) in section (1), above)

The number of vehicles present within the required communication distance increases as the relative speed of vehicles (driving speed) decreases. In addition to communication congestion caused by the increase in the number of vehicles, there are concerns about the impact on communication quality due to the presence of vehicles blocking radio waves (especially for vehicle-to-vehicle (V2V) communication).

(3) Summary of considerations

The following shows items of concern, in relation to considerations organized, for consideration regarding the impact on communication of the selected use cases, i.e., communication congestion due to frequent two-way communications and communication congestion due to conflicts among multiple use cases.

- Communication congestion due to increase in number of vehicles (communication terminals)
- Communication congestion due to various messages being sent and received
- Impact of radio wave non-line-of-sight (NLoS) environment and shadowing (vehicles blocking radio waves)

3.3 Evaluation of the appropriateness of countermeasures

This section covers the contents and results of verification and evaluation based on communication simulations in accordance with the selected use cases for the considerations organized in section 3.2.

3.3.1 Overview of appropriateness evaluation

(1) Purpose of verification

Communication simulation is conducted for the considerations “Communication congestion due to increase in number of vehicles (communication terminals),” “Communication congestion due to various messages being sent and received,” and “Impact of radio wave non-line-of-sight (NLoS) environment and shadowing (vehicles blocking radio waves)” based on the selected use cases. The objective is to, from the results obtained, identify communication problems, examine causes and improvement measures, and evaluate the effectiveness of proposed improvements through additional verification.

(2) Overview of implementation

- The communication scenario of the selected use case is applied to the communication simulation environment, its theoretical phenomenon is reproduced, and it is evaluated.
- In the simulation, communication between vehicle (OBU) and vehicle (OBU) and between vehicle (OBU) and RSU is performed using the LTE V2X (PC5) communication technology specified by 3GPP.
- Messages and sequences used for communication are created for verification in accordance with the simulator based on communication scenarios, and simulations are performed based on these messages and sequences.
- The evaluation parameters in the simulation are as follows.
  Packet arrival rate (PAR)
  Received signal strength indication (RSSI)
  Amount of communication delay
- PAR is calculated from the number of packets sent and the number of packets received out of the message transmissions.
- For the road environment in the simulation, the environment for verification is defined, and vehicles used for communication on the road are placed. Vehicles will conduct communication at the positions where they are placed (fixed).
- The specifications of wireless communication are compared with the recommended values in the guidelines[20] established by the ITS Forum in Table 3.3.1-1 and with the guideline parameter setting examples in Table 3.3.1-2.
- For simulators, use Scenargie 2.2（from Space-Time Engineering). The simulator operating environment is shown in Table 3.3.1-3.

Table 3.3.1-1 Wireless communication specifications used in simulation

Item	Values used for verification		Guideline recommended values	
	RSU	OBU	RSU	OBU
Frequency	5.90GHz		6GHz	
Bandwidth	10 MHz		10 MHz	
Transmission power	20dBm		-	
Modulation method	QPSK/16QAM/64QAM		QPSK/16QAM	
Antenna height	6m	1.5m	6m	1.5m
Antenna gain	0 dB	0 dB	-	0 dB
Diversity	N/A	Not applied	Applicable	-
No. of continuous transmissions	1 (no continuous transmissions)	1 (no continuous transmissions)	1 (no continuous transmissions) to 5	1 (no continuous transmissions) to 5
Power loss	0 dB	4dB	-	-
Propagation loss model	ITU-R P.1411	ITU-R P.1411	ITU-R P.1411	ITU-R P.1411
Fading	Rayleigh (NLoS), Nakagami (LoS)			

[20] Extracted from ITS Info-communications Forum ITS FORUM RC-015 Ver. 1.0 Table A4-1 and Table A4-5 https://itsforum.gr.jp/Public/J7Database/p64/ITS_FORUM_RC-015_v10.pdf

Reasons are given below for items where there is a difference between values used for verification and the guideline recommended values.

- Diversity
  Because simulator used for verification does not have the ability for multiple antennas to be set.
- No. of continuous transmissions
  Because the simulator used for verification does not support a continuous transmission function.

Table 3.3.1-2 Comparison with guidelines for wireless communication parameters used in verification

Parameter name		Values used for verification	RC-015 Example setting*1
SL-V2X-PreconfigFreqInfo-R14			
*2	syncPriority-r14	Not set	Gnss
SL-PreconfigGeneral-r12			
-	carrierFreq-r12	5.9GHz	To be set experimental frequency
-	maxTxPower-r12	RSU：23dBm Vehicle: 19 dBm (power loss 4dB)	23 dBm
-	sl-bandwidth-r12	n50 (10MHz), n100(20MHz)	n50 (10MHz), n100(20MHz)
SL-V2x-PreconfigCommPool-r14			
*3	sizeSubchannel-14	Functions as 1 subchannel per Resource Block	n10
*3	numSubchannel-r14	Functions as 1 subchannel per Resource Block	n5
-	threshS-RSSi-CBR-r14	9 (-94 dBm)	9 (-94 dBm)
SL-CommTxPoolSensingConfig-r14			
-	probResourceKeep-r14	v0dot8	v0dot8
SL-PSSCH-TxParameters-r14 for parametersBelowThres-r14			
*4	minMCS-PSSCH-r14	QPSK (Coding Rate 0.44) / 16QAM (Coding Rate 0.48) / 64QAM (Coding Rate 0.45)	5(QPSK (Coding Rate 0.57))
*4	maxMCS-PSSCH-r14	QPSK (Coding Rate 0.44) / 16QAM (Coding Rate 0.48) / 64QAM (Coding Rate 0.45)	11(16QAM (Coding Rate 0.57)

*1 Extracted from ITS Info-communications Forum ITS FORUM RC-015 Ver. 1.0 Table 3.2-1 RRC Layer (TS 36.331) parameter setting examples
https://itsforum.gr.jp/Public/J7Database/p64/ITS_FORUM_RC-015_v10.pdf
*2 No setting function in the simulator because the verification assumes perfect synchronization.
*3 On the model, SINR per Resource Block is calculated and resources allocated.
*4 Either one is used according to the modulation method used.

Table 3.3.1-3 Comparison between recommended simulator environment and actual operating environment

Item	Recommended environment	Actual operating environment
OS	Windowd10 64bit	Windows10 64bit
Clock	1.8 GHz or greater	3GHz
Installed memory	1G byte or greater	32G bytes
HDD capacity	50G bytes or greater	1T byte

Environment necessary for the simulator to operate built as described and simulation conducted.

(3) Verification details

In the verification, evaluation was conducted based on the following indicators.

- PAR
- RSSI
- Amount of communication delay

(4) Measurement of basic data

As basic data prior to the verification, PAR measurements are made for the use case of communication congestion caused by frequent two-way communication in a communication environment without the influence of surrounding vehicles, etc., and those are compared with the verification results in question. The measurement conditions and results for the basic data are shown below.

The PAR measurements were made according to the communication distance to the mainline and to connecting routes as shown in Table 3.3.1-4.

Table 3.3.1-4 Details of verification as basic data

Verification item	Verification details
Communication distance	No other vehicles are placed between RSU and vehicle being measured or in the surroundings, and only the effect of communication distance on communication is verified.

1) Verification conditions

- Road conditions

  Shown in Fig. 3.3.1-1, Fig. 3.3.1-2, and Table 3.3.1-5.
- Wireless communication specifications, parameters

  Refer to Table 3.3.1-1 and Table 3.3.1-2 mentioned above. The bandwidth used was 10 MHz, and modulation used was QPSK and 16QAM.
- Message

  Agreement request/agreement request (273 bytes) sent from RSU to measured vehicle.
- Message transmission cycle

  100 ms
- Measurement method

  Only one vehicle measured for both mainline and connecting route.

  PAR is measured with a vehicle measured placed on a mainline at a communication distance of approximately every 100 m from the RSU and on a connecting route at a distance of approximately every 10 m from the RSU.

  The scenario used for verification is shown in Table 3.3.1-6.

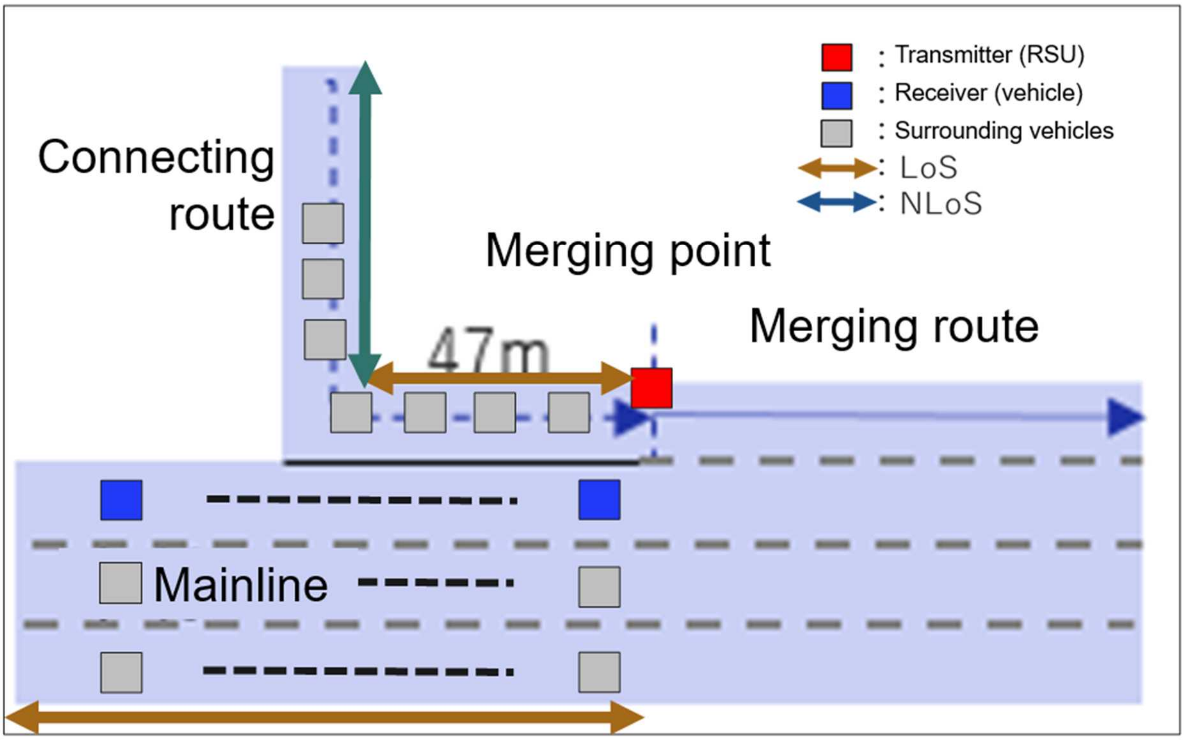

Fig. 3.3.1-1 Image of PAR verification according to communication distance (mainline side)

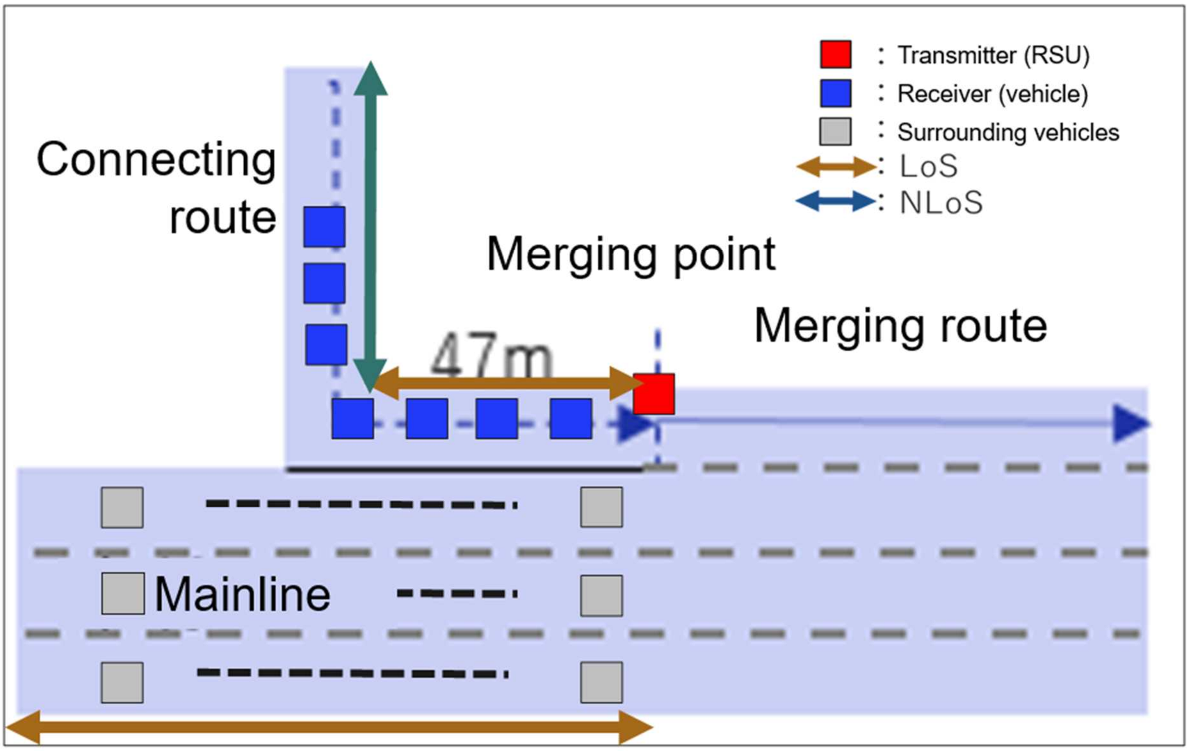

Fig. 3.3.1-2 Image of PAR verification according to communication distance (connecting route side)

Table 3.3.1-5 Verification conditions as basic data (road environment, vehicle)

Item	Content	Condition value
Connecting routes	• Line of Sight (LoS) for merging point to section parallel to mainline • Non Line of Sight (NLoS) for merging point to section not parallel to mainline	-
Connecting route length	4,000m	-
Connecting route width	4.75 m	Lane width 3.5 m × 1 lane + shoulder 1.25 m
Mainline	LoS upstream from merging point	-
Mainline length	350m	-
Mainline width	11.75 m	Lane width 3.5 m × 3 lanes + shoulder 1.25 m
RSU installation location	Merging point	-
Sound-insulating wall	• Set on outside of connecting route (side opposite of mainline) • Not set on section of parallel connecting route and mainline • Set on connecting route side on part where connecting route and mainline are not parallel	-
Vehicle length	5 m	Ordinary vehicle assumed

Table 3.3.1-6 Verification scenario as basic data

Simulation scenario	
Time from start of simulation	Action
Immediately after start	None
10 seconds after start	Implement transmission from the RSU to vehicle with the message and transmission interval indicated in 1) Verification conditions, above.
20 seconds after start	Stop message transmission
30 seconds after start	End simulation

2) Verification results

PAR calculation results graph results shown in Fig. 3.3.1-3 and Fig. 3.3.1-4.

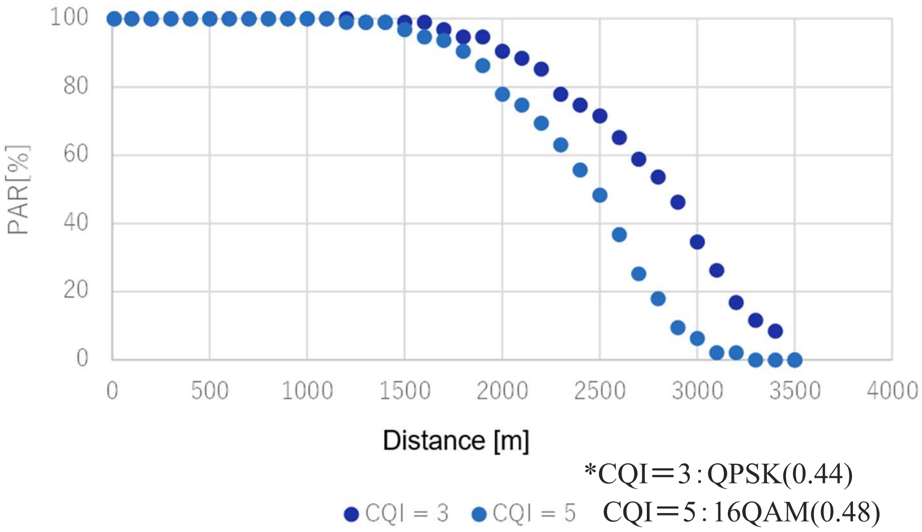

Fig. 3.3.1-3 PAR according to communication distance (mainline side)

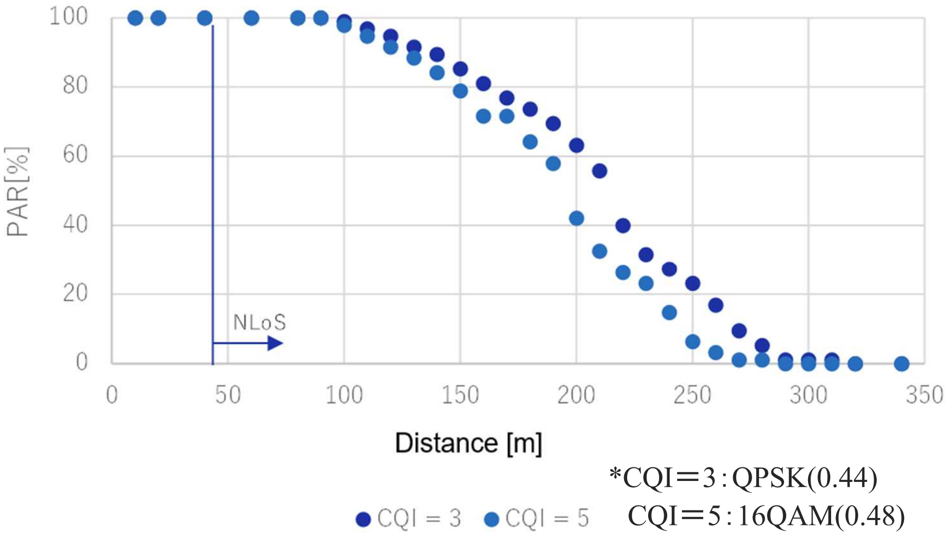

Fig. 3.3.1-4 PAR according to communication distance (connecting route side)

3) Summary of verification results

Verification results are shown below

- The mainline side is all in a LoS environment, and PAR is 100% at communication distances of up to 1,100 m.
- The connecting route side is in an NLoS environment (47 m and beyond) and PAR decreases at communication distances greater than 100 m.

The results obtained are referred to in verification of the communication congestion due to frequent occurrence of two-way communication in section 3.3.2.

3.3.2 Verification (1) Communication congestion due to frequent occurrence of two-way communication

Verification of communication congestion due to frequent occurrence of two-way communication is shown below.

(1) Use case evaluated

The use case to be evaluated is “a-1-3. Cooperative merging assistance with vehicles on the mainline by roadside control.”

The following is an overview of the use case.

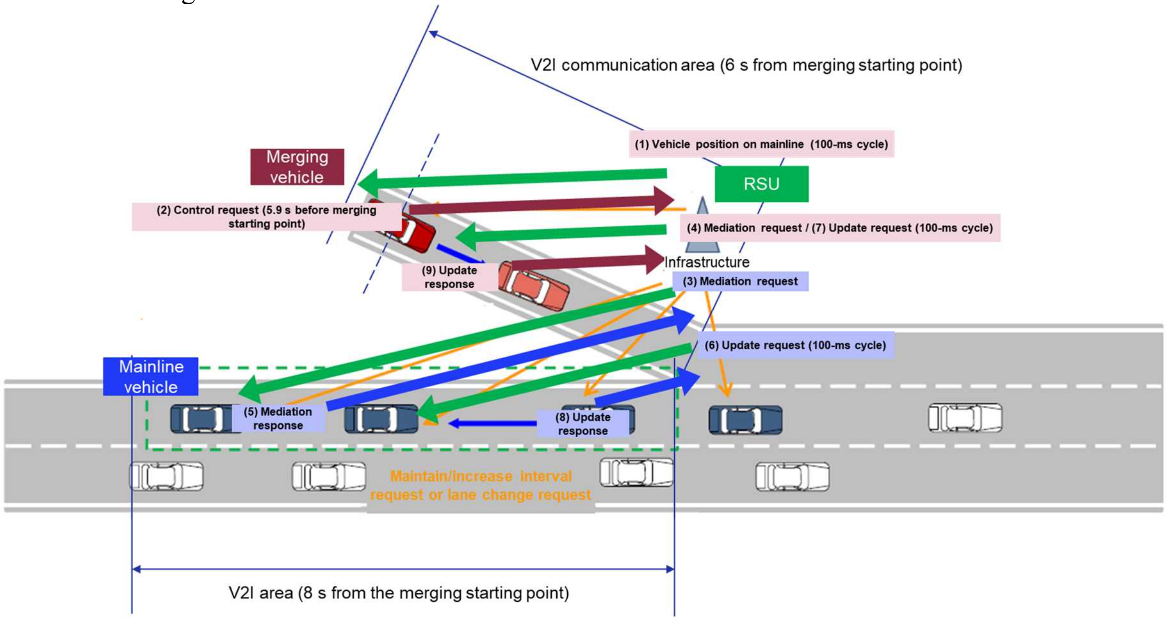

Fig. 3.3.2-1 Verification (1) Overview of evaluation related to communication congestion due to frequent occurrence of two-way communication[21]

(2) Verification details

Frequency of communication and communication traffic are estimated to simulate the communication message and preform simulation evaluation based on the communication requirements and communications messages and sequences of use case a-1-3. Specifically, the following indicators were evaluated per communication message.

- PAR
- RSSI
- Amount of communication delay

(3) Verification conditions

Considerations in simulation verification conditions are as follows.

- Assume as a more stringent conditions that sequences between vehicle to RSU are multiplexed within the assumed communication frequency of 100 ms.
- Assume as the worst-case scenario for communication congestion that simultaneous transmission by multiple merging vehicles or mainline vehicles occurs at the application software level.
  (In actuality, each vehicle interacts individually at the application software level, but under worst-case conditions, it is assumed that all vehicles can be at simultaneous timing.)
- Aggregate the parts that can be aggregated as messages in accordance with the communication sequence of the communication scenario.

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[21]Source: Prepared based on SIP Cooperative Driving Automation Use Cases - 2019 Task Force on V2X Communication for Cooperative Driving Automation Activity Report-

(Estimated wireless resource occupation is approx. 50% of the estimated communication capacity based on the communication scenario.)

Other conditions (road environment and vehicles) are described in Fig. 3.3.1-1, Fig. 3.3.1-2, and Table 3.3.2-1, above.

Table 3.3.2-1 Verification conditions (road environment, vehicle)

Item	Content	Condition value
Connecting routes	Line of Sight (LoS) for merging point to section parallel to mainline Non Line of Sight (NLoS) for merging point to section not parallel to mainline	
Connecting route length*1	116.7m	470km/h×6s
Connecting route width	4.75 m	Lane width 3.5 m × 1 lane + shoulder 1.25 m
Mainline	LoS upstream from merging point	
Mainline length*1	266.7m	120km/h×8s
Mainline width	11.75 m	Lane width 3.5 m × 3 lanes + shoulder 1.25 m
RSU installation location	Merging starting point	
Vehicle length	5 m	Ordinary vehicle assumed
Sound-insulating wall	• Set on outside of connecting route (side opposite of mainline) • Not set on section of parallel connecting route and mainline • Set on connecting route side on part where connecting route and mainline are not parallel	-
Vehicle length	5 m	Ordinary vehicle assumed

*1 TG October 2021 study results used

For wireless communication specifications, see the aforementioned Table 3.3.1-1. However, QPSK is used for the modulation method. And for simulation parameters, see the aforementioned Table 3.3.1-2.
In addition, Fig. 3.3.2-2 shows the communication capacity assumed for verification (estimation), and Table 3.3.2-2 shows the message size, number of resource blocks, and transmission time (all estimations).

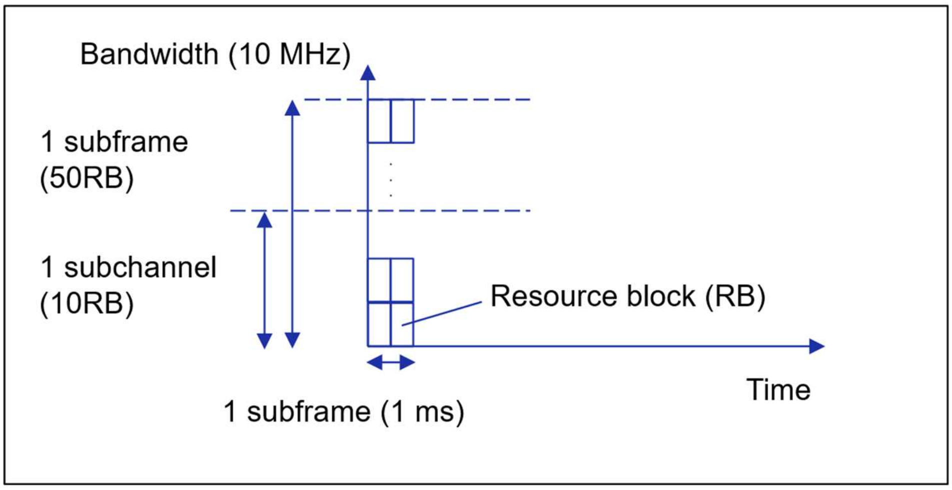


Fig. 3.3.2-2 Assumed communication capacity

- Bandwidth 10M Hz / Modulation method QPSK; Encoding rate 0.44 / No continuous transmissions
- 1 subchannel (10 RB) ≒ Data size 44 [byte]
  1 subframe (1 subchannel × 5 × 2 slots) ≒ Data size 440 [byte]

Table 3.3.2-2 Message size, number of resource blocks, and transmission time for each message

#	Communication direction	Number of transmissions	byte	RB	Transmission time estimate [ms]
1	I -> V (merging vehicle)	1	943	22	3
2	V (merging vehicle) -> I	11	287	7×11	8
3	I -> V (mainline vehicle)	25	273	7×25	18
4	I -> V (merging vehicle)	11	273	7×11	8
5	V (mainline vehicle) -> I	25	287	7×25	18
					Total 55 ms

(4) Verification data

An image of the road model and vehicle placement used in verification is shown in Fig. 3.3.2-3, communication sequence and messages are shown in Fig. 3.3.2-4 and Table 3.3.2-3, and the number of vehicles placed on the mainline and connecting route is shown in Table 3.3.2-4.

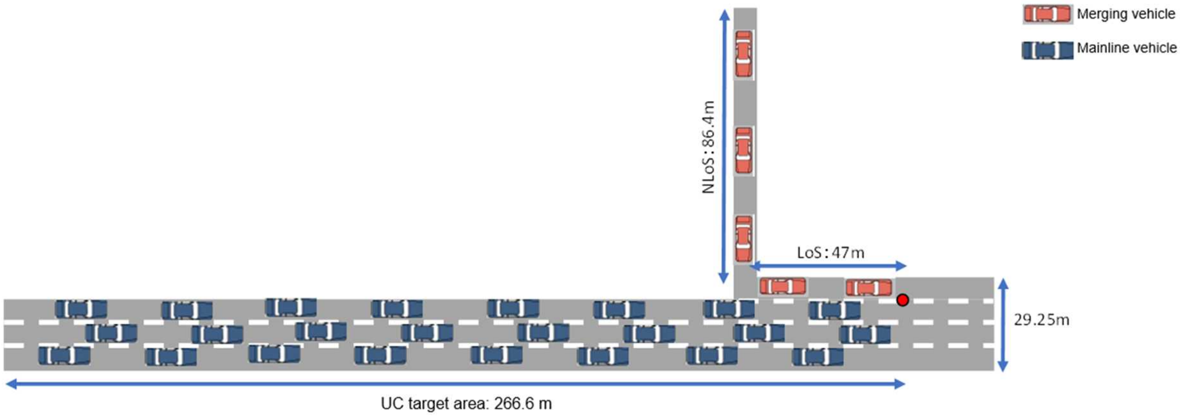


Fig. 3.3.2-3 Image of road model and vehicle placement

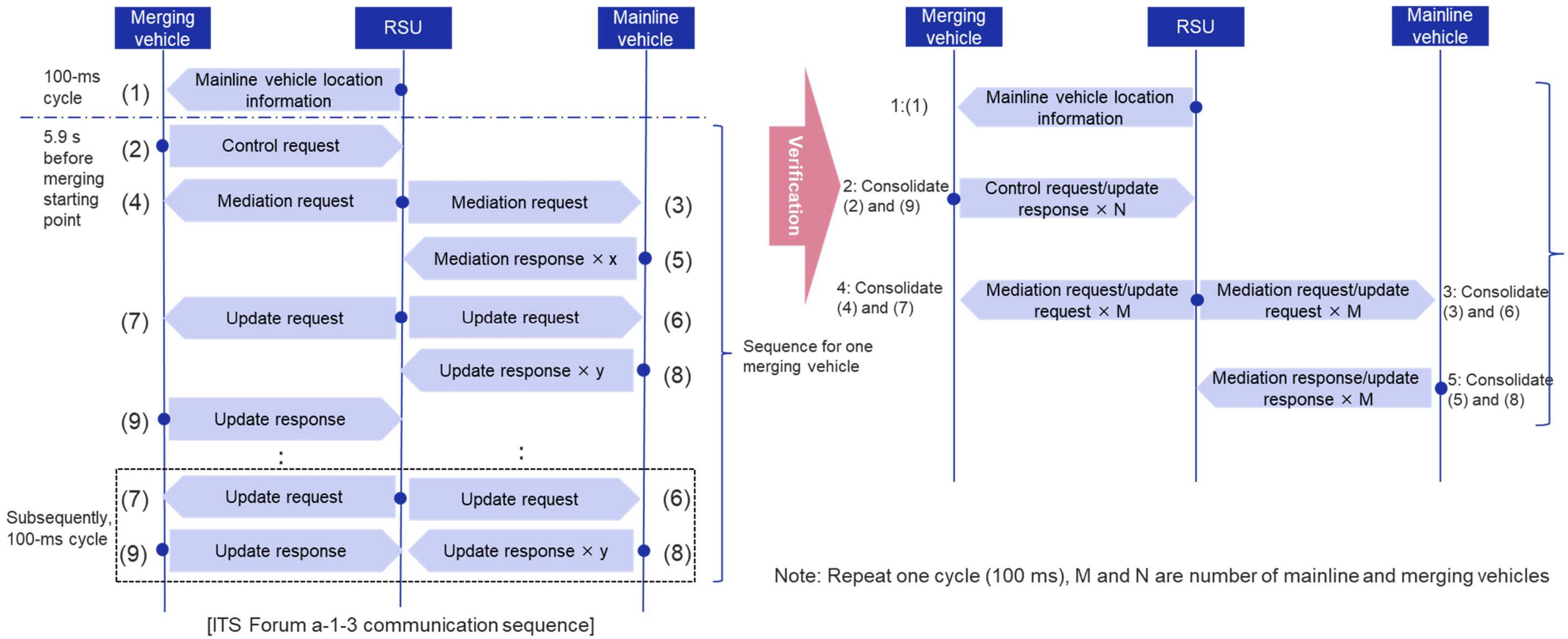


Fig. 3.3.2-4 Communication sequence

The communication sequence was produced for use in the verification based on the messages and sequence studied by TG as of October 2021.

In the verification, data for each indicator was measured as follows.

- In PAR verification, this sequence (one set at 100 ms intervals) is operated for 7 seconds in the simulation, and data is collected periodically for 6 seconds from 1.1 seconds to 7 seconds after the operation.
- In RSSI verification, this sequence (one set at 100 ms intervals) is operated for 60 seconds in the simulation, and data is collected periodically from 10 seconds to 60 seconds after the operation.
- In communication delay verification, this sequence (one set at 100 ms intervals) is operated for 60 seconds in the simulation, and data for one vehicle selected arbitrarily is collected periodically from 10 seconds to 60 seconds after the operation.

Table 3.3.2-3 Transmission messages/cycles used in the communication sequence

Time (s)	Message					Communication direction
	Mp	Name	Size	Size Results of TG study*1	Presence of/reason for difference from TG study results	
0.000	1	Mainline vehicle location information (for 25 vehicles)	943 bytes	5236 byte	Difference present / Difference in number of vehicles for which location information is set (184 vehicles in TG study results)	RSU -> Merging vehicle
0.025	2	Control request, update response x 11 vehicles	287 bytes	287 bytes	No difference	Merging vehicle -> RSU
0.050	3	Agreement request, update request x 25 vehicles	273 bytes	369 bytes	Difference present	RSU -> Mainline vehicle
0.050	4	Agreement request, update request × 11 vehicles	273 bytes	369 bytes	Difference present	RSU -> Merging vehicle
0.075	5	Agreement response, update response × 25 vehicles	287 bytes	287 bytes	No difference	Mainline vehicle -> RSU

*1 TG study results as of March 2022 shown in case 2.2. Difference is occurring in message 3 and message 4. The study progressed in March 2022, resulting in a difference from the study results as of October 2021 applied to the simulation.

Table 3.3.2-4 Concept behind number of vehicles

Condition	Number of merging vehicles: N (Connecting route communication area 116.7 m)*1	Number of mainline vehicles: M (Mainline communication area 266.7 m)*1
High-speed driving	70 km/h, 2 s interval × 1 lane Total: 2 vehicles	120 km/h, 2 s interval × 3 lanes Total: 9 vehicles
Low-speed driving	40 km/h, 2 s interval × 1 lane Total: 4 vehicles	50 km/h, 2 s interval × 3 lanes Total: 24 vehicles
Congestion	20 km/h, 1 s interval × 1 lane Total: 11 vehicles	20 km/h, 1 s interval × 3 lanes Total: 75 vehicles
Maximum	20 km/h, 1 s interval × 2 lanes Total: 22 vehicles	20 km/h, 1 s interval × 6 lanes Total: 150 vehicles
Verification conditions	20 km/h, 1 s interval × 1 lane Total: 11 vehicles	20 km/h, 1 s interval × 1 lane (No. 1 lane only) Total: 25 vehicles

*1 TG study results as of March 2022 shown in case 2.2. Difference in communication area is occurring.
Condition values applied to the simulation are the study results as of October 2021, and difference occurred due to progress of study at TG in March 2022. Although there is a difference in the communication area as described above, it is a small difference and will not affect the number of merging vehicles on the connecting route or the number of vehicles on the mainline.

(5) Verification results

(a) PAR

The PAR per message (average of the respective cycles) used in the sequence for vehicles placed on the connecting route and mainline under the conditions shown in sections 3.3.2(3) and 3.3.2(4) are shown in Fig. 3.3.2-5, Fig. 3.3.2-6, Fig. 3.3.2-7, Fig. 3.3.2-8, and Fig. 3.3.2-9.

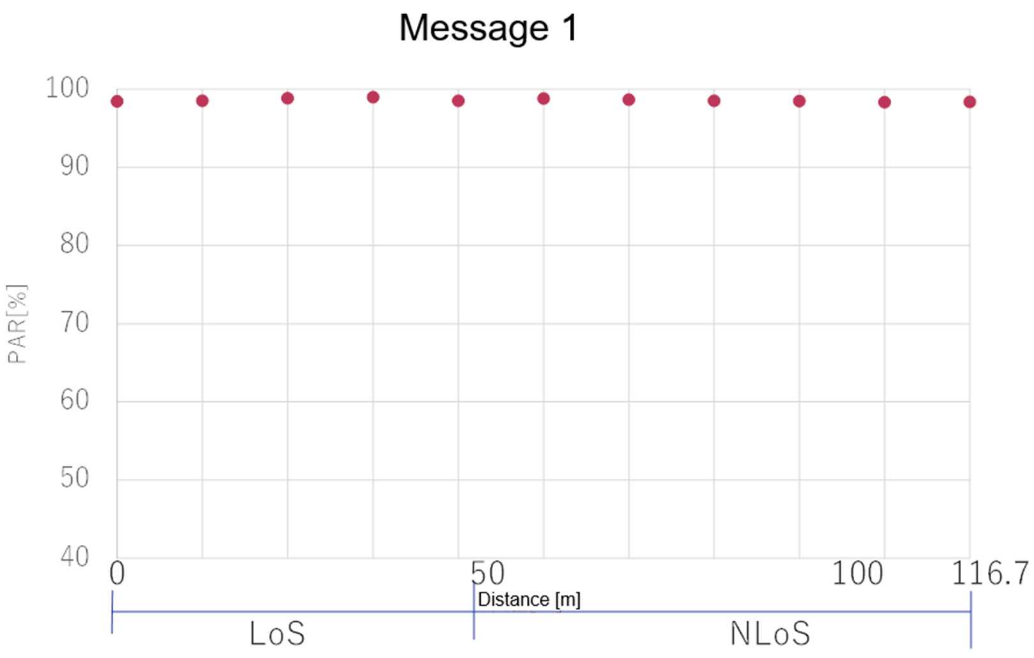


Fig. 3.3.2-5 Verification (1) PAR measurement results (Message 1)

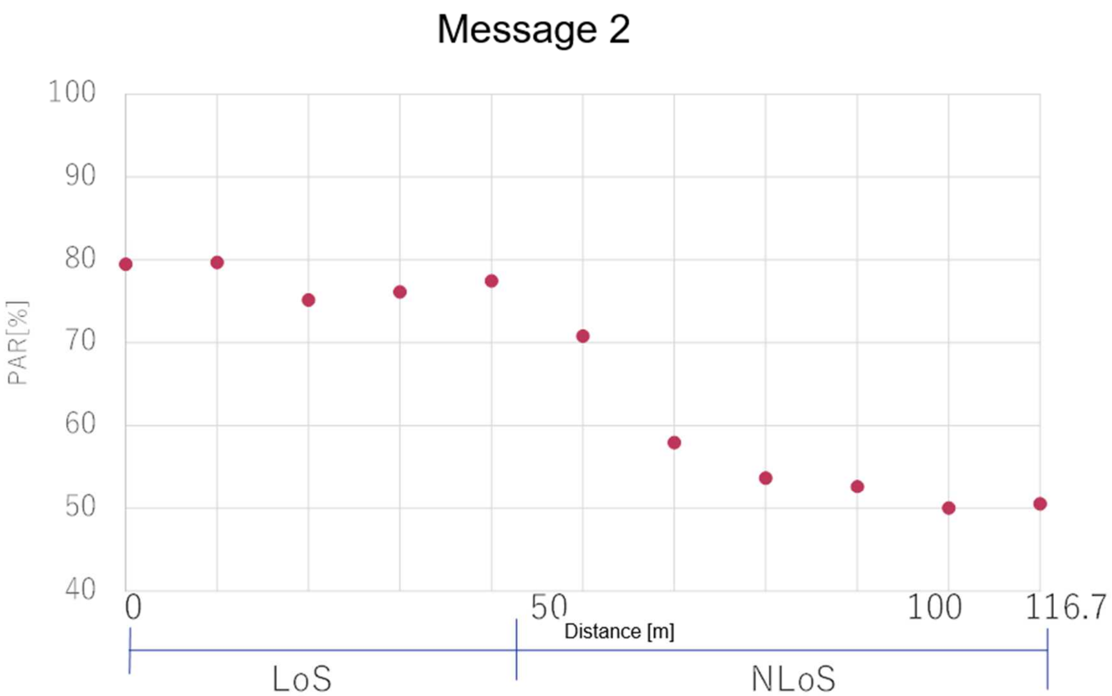


Fig. 3.3.2-6 Verification (1) PAR measurement results (Message 2)

Fig. 3.3.2-7 Verification (1) PAR measurement results (Message 3)

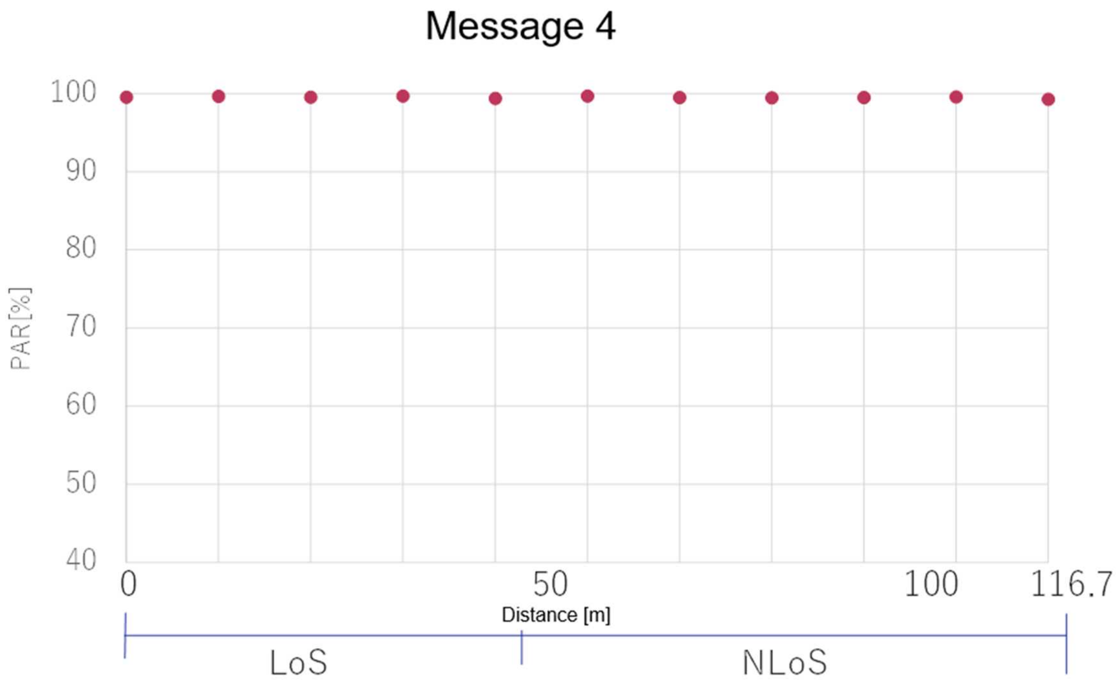


Fig. 3.3.2-8 Verification (1) PAR measurement results (Message 4)

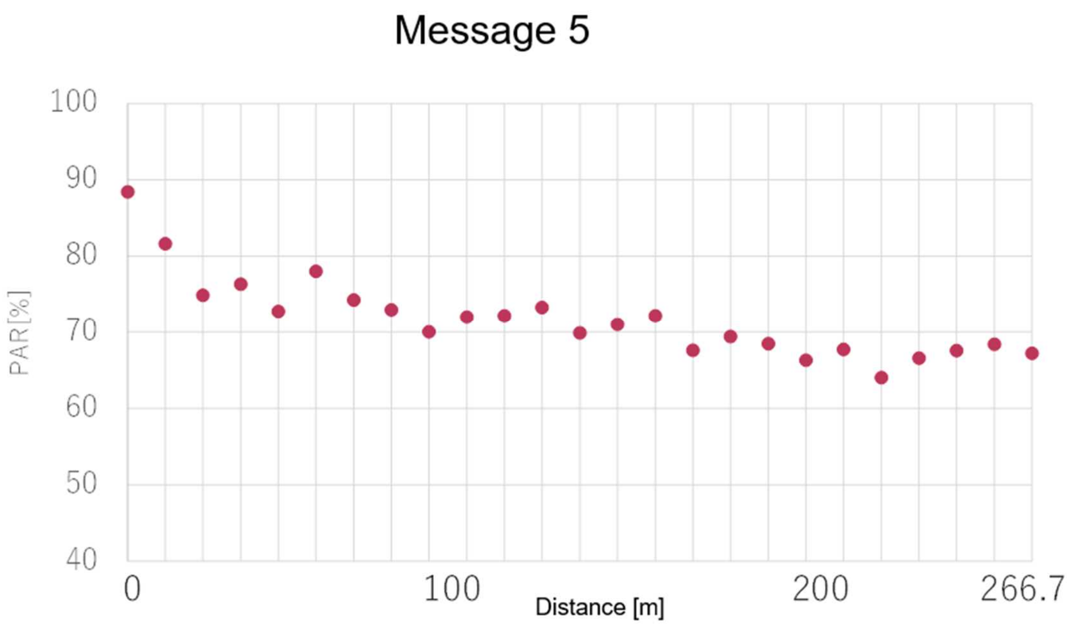


Fig. 3.3.2-9 Verification (1) PAR measurement results (Message 5)

(b) RSSI

The RSSI of messages (average of the respective cycles) used in the sequence for RSU and vehicles placed on the connecting route and mainline under the conditions shown in sections 3.3.2(3) and 3.3.2(4) are shown in Fig. 3.3.2-10, Fig. 3.3.2-11, Fig. 3.3.2-12, and Fig. 3.3.2-13.

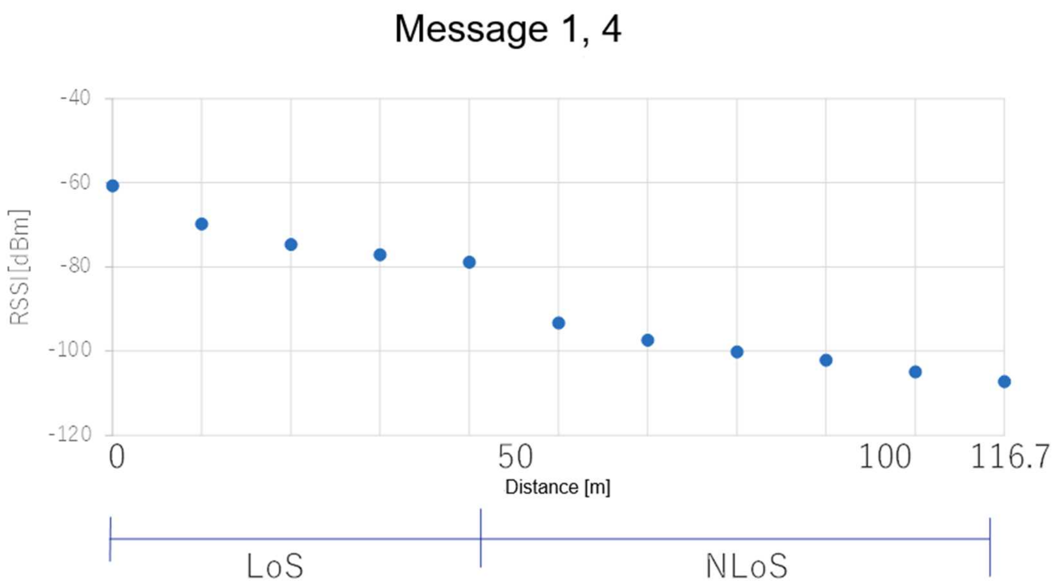


Fig. 3.3.2-10 Verification (1) RSSI measurement results (Message 1, Message 4)

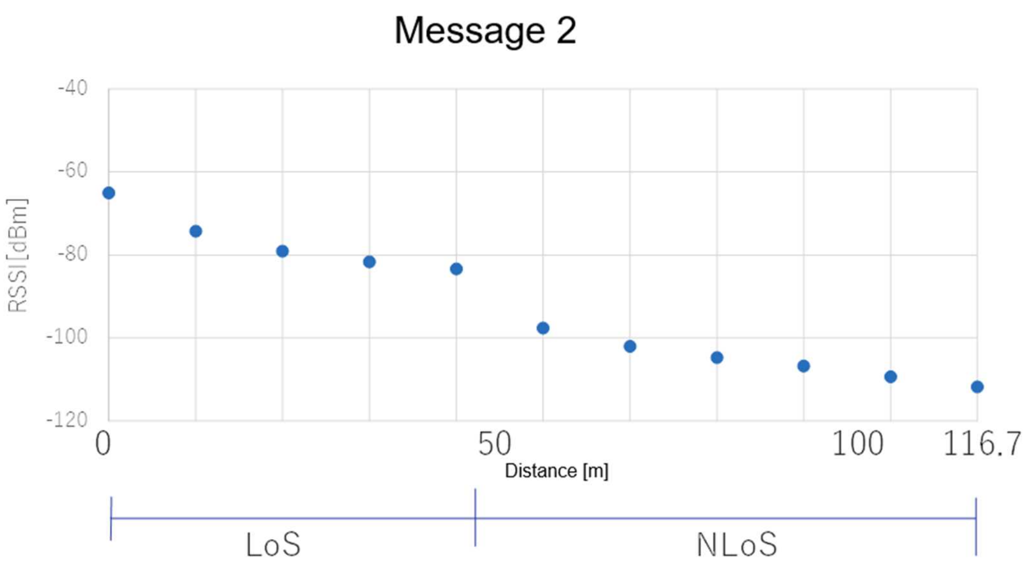


Fig. 3.3.2-11 Verification (1) RSSI measurement results (Message 2)

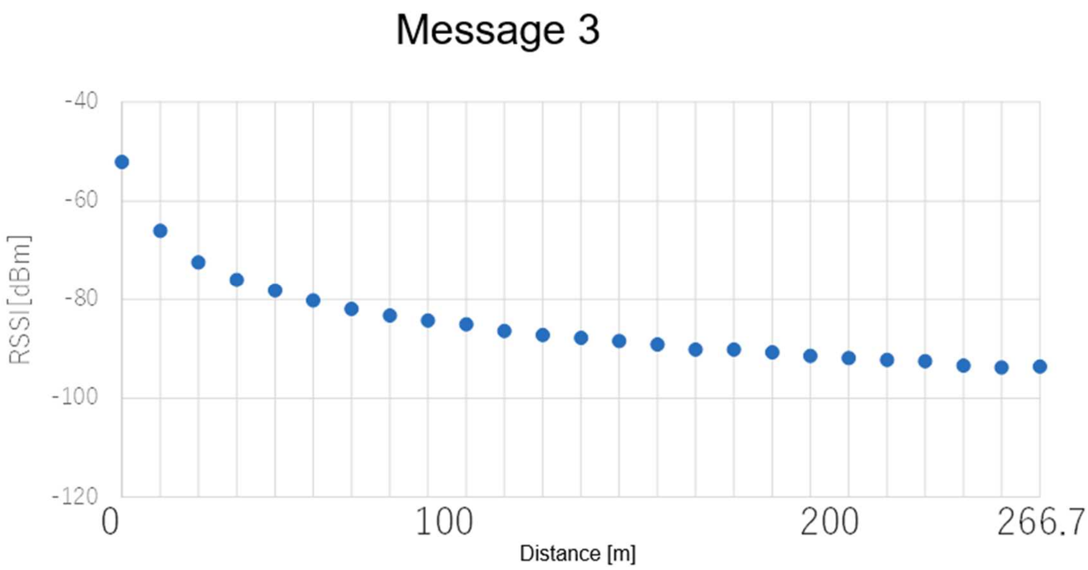


Fig. 3.3.2-12 Verification (1) RSSI measurement results (Message 3)

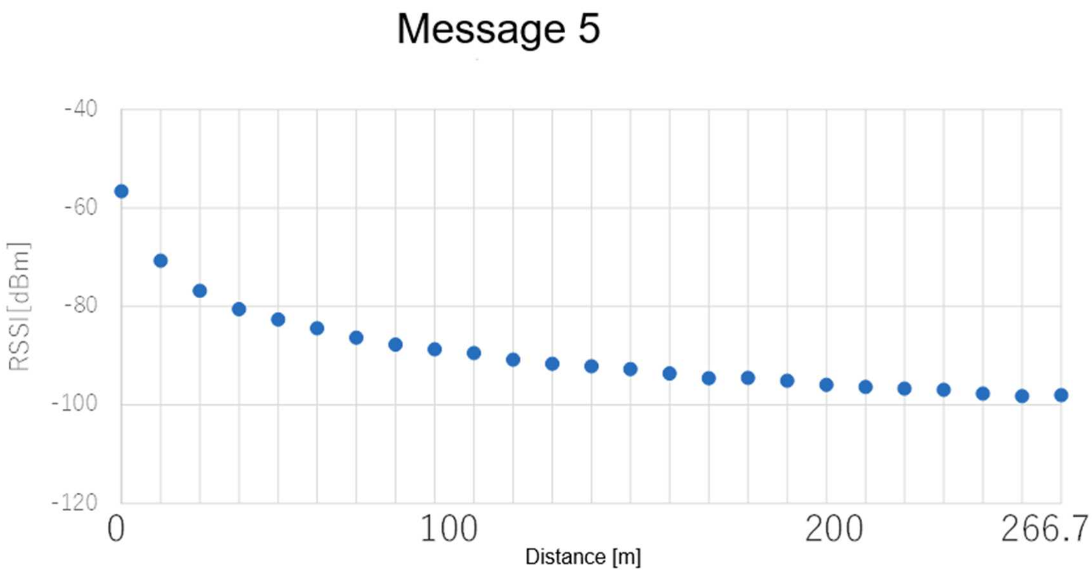


Fig. 3.3.2-13 Verification (1) RSSI measurement results (Message 5)

(c) Amount of communication delay

The message communication delay used in the sequence for vehicles placed on the connecting route and mainline under the conditions shown in sections 3.3.2(3) and 3.3.2(4) are shown in Fig. 3.3.2-14, Fig. 3.3.2-15, Fig. 3.3.2-16, Fig. 3.3.2-17, and Fig. 3.3.2-18. Delay time was collected every 0.1 ms using the simulator's functions, and is shown in the figure as average value in units of 1 second.

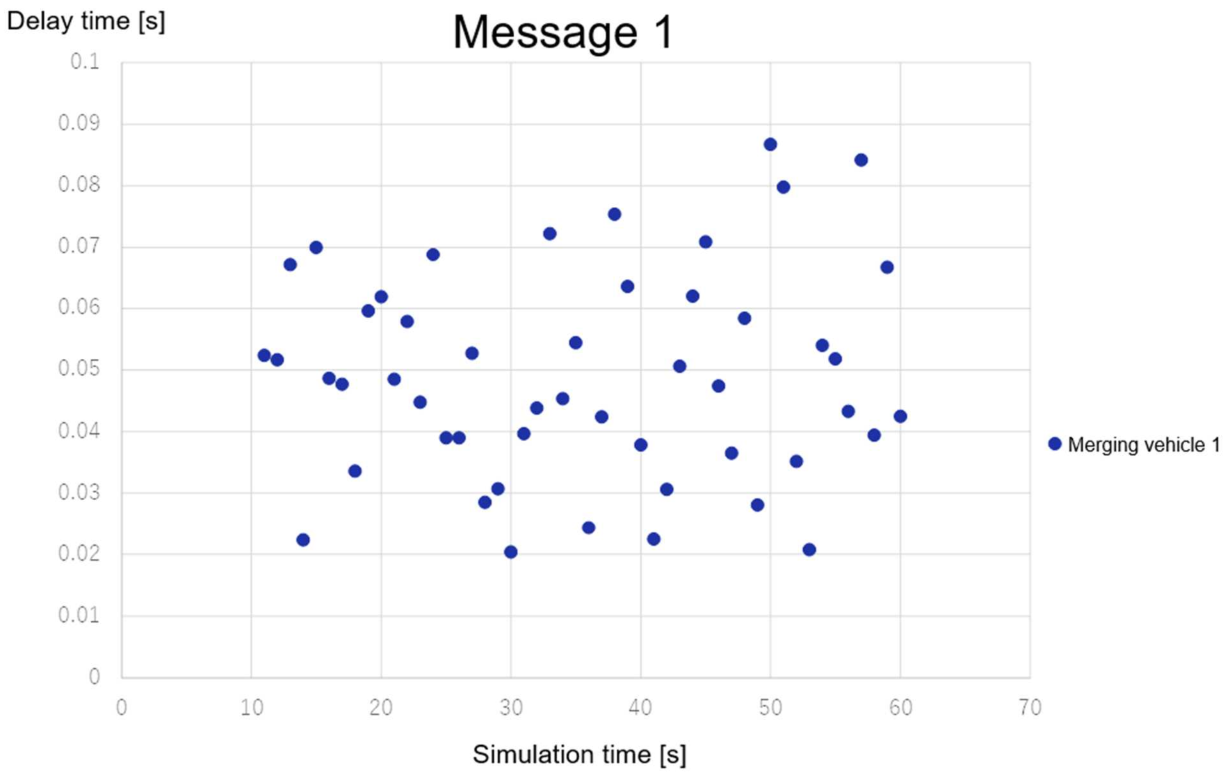


Fig. 3.3.2-14 Verification (1) Communication delay measurement results (Message 1)

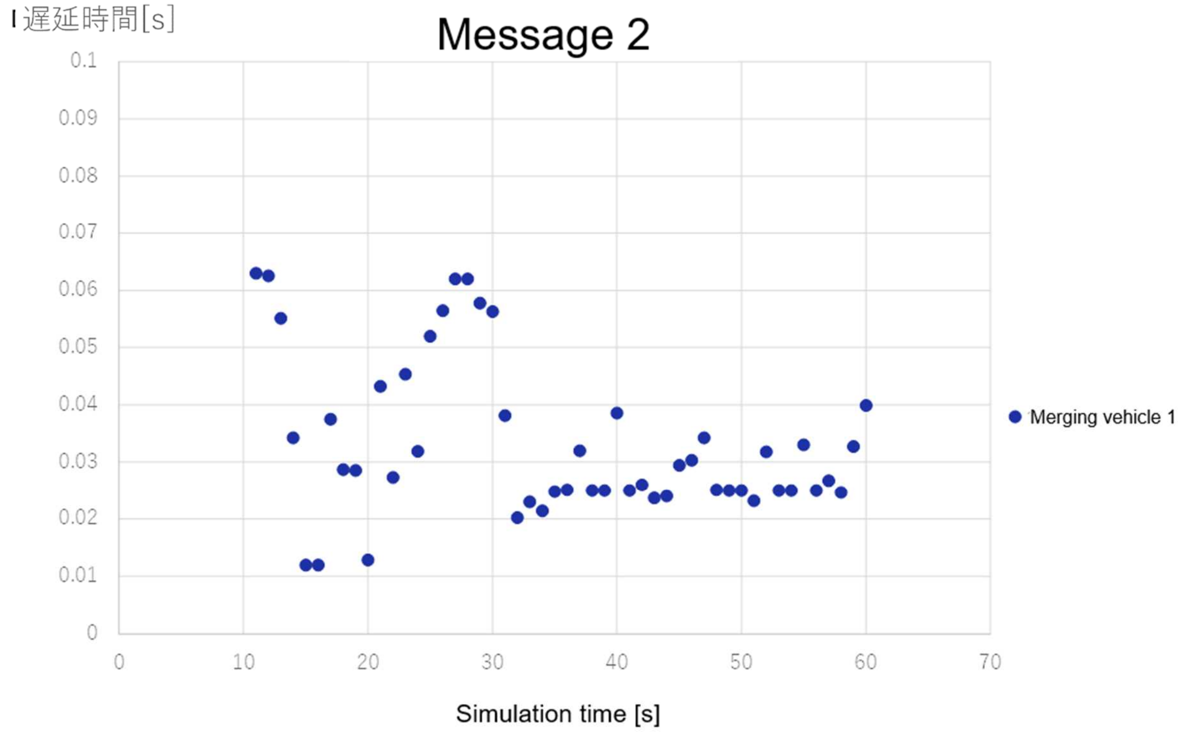


Fig. 3.3.2-15 Verification (1) Communication delay measurement results (Message 2)

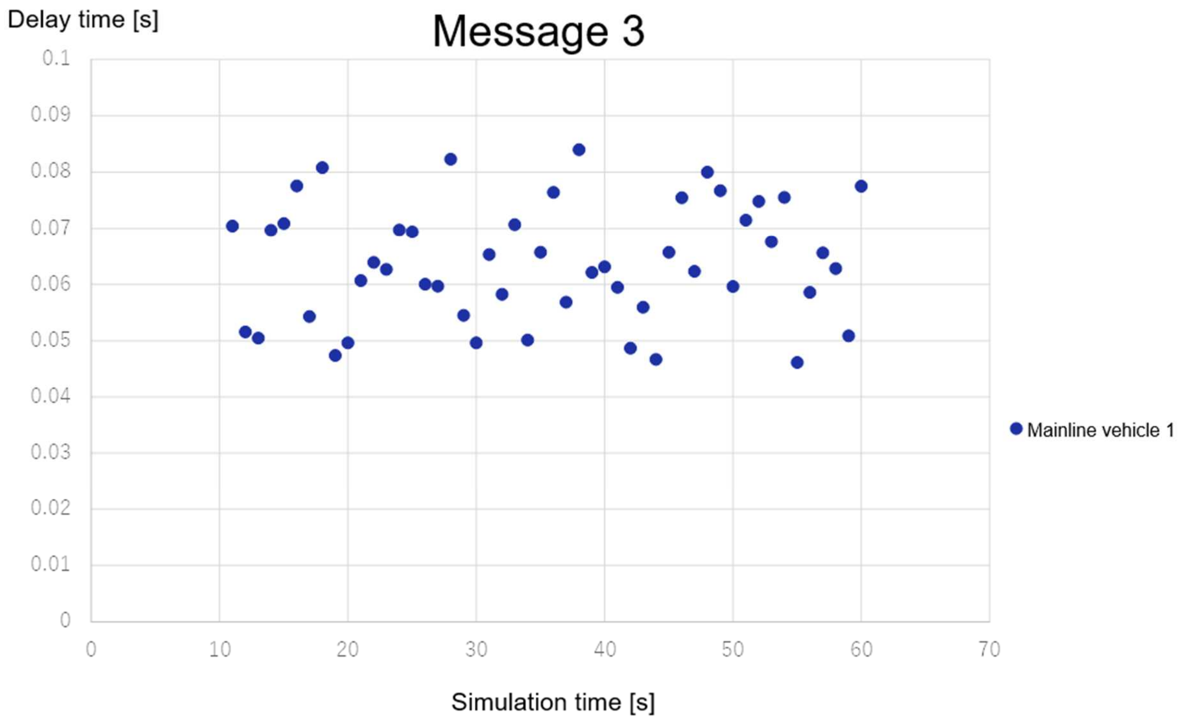


Fig. 3.3.2-16 Verification (1) Communication delay measurement results (Message 3)

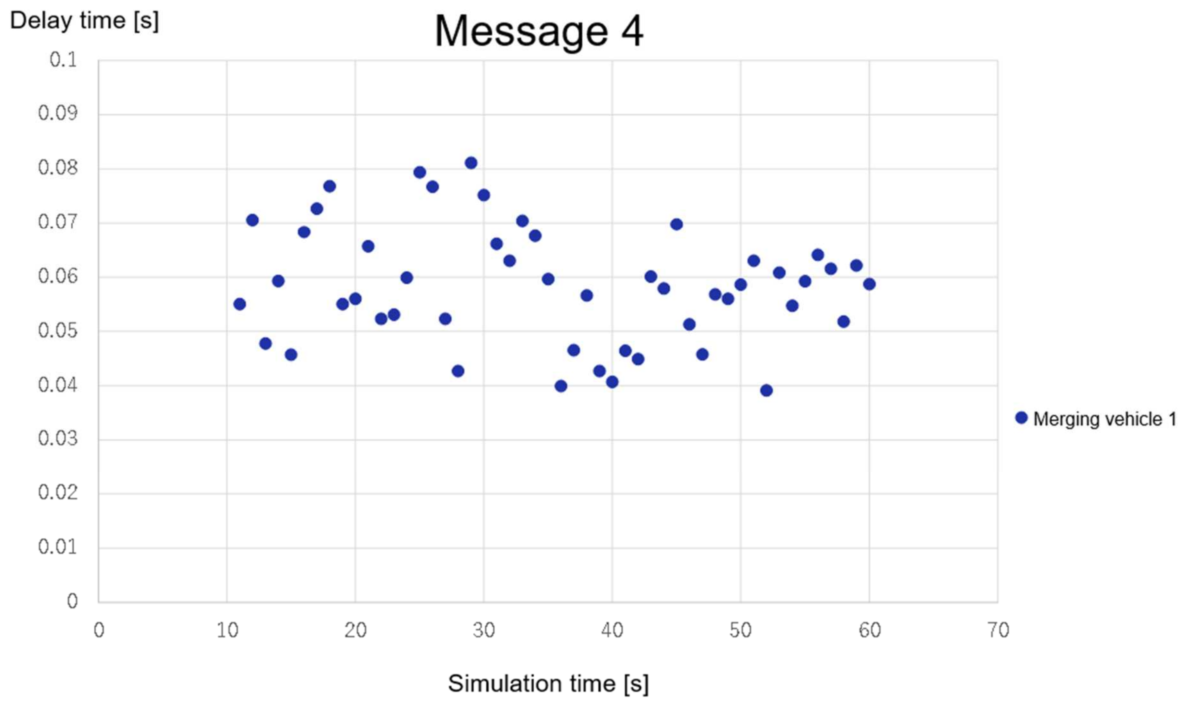


Fig. 3.3.2-17 Verification (1) Communication delay measurement results (Message 4)

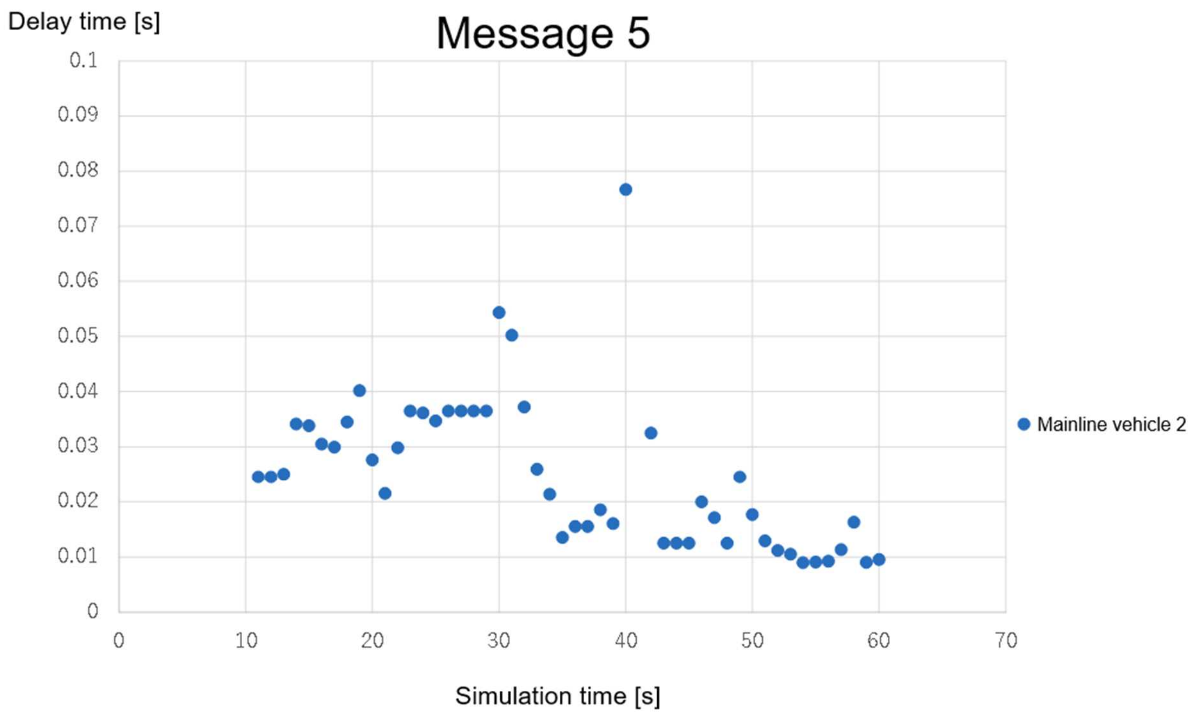


Fig. 3.3.2-18 Verification (1) Communication delay measurement results (Message 5)

(6) Evaluation/analysis

- PAR

For messages 1, 3, and 4 used in RSU to vehicle communications, a PAR of close to 100% was secured throughout the entire communication area, which is similar to the results obtained in section 3.3.1.

On the other hand, for messages 2 and 5, which are used in vehicle to RSU communications, PAR decrease occurs at when the communication distance is short, and PAR also decreases as the communication distance increases.

- RSSI

In communication between merging vehicles and RSU, RSSI drops of approx. -5 dBm were detected for each vehicle in the LoS and NLoS environments for both the RSU to merging vehicle direction (messages 1 and 4) and merging vehicle to RSU direction (message 2), and RSSI is expected to weaken in the same way as the communication distance is increased. Also, a large drop of approx. -15 dBm was detected at the change point from LoS environment to NLoS environment. Comparing in terms of message direction, RSSI in the direction from merging vehicle to RSU is about -5 dBm weaker than from RSU to merging vehicle for all vehicles.

In communication between mainline vehicle and the RSU, all communication was within the LoS environment, and it was confirmed that the drop in RSSI per vehicle was gradually decreasing in both the RSU to mainline vehicle direction (message 3) and mainline vehicle to RSU direction (message 5). Comparing in terms of message direction, RSSI in the direction from mainline vehicle to RSU is about -5 dBm weaker than from RSU to mainline vehicle for all vehicles.

- Amount of communication delay

Although there is some variation, the amount of communication delay is at a constant level regardless of the length of time the simulation is run, and there is no tendency for the cumulative amount of delay to increase as the simulation runs longer or shorter. This means that message sending and receiving processing gradually accumulates over long simulation runs, and there are no delays due to the passage of time.

Based on the above results, the problem in this simulation is the decrease in PAR of messages sent from vehicle to RSU. Causes of decrease in PAR were analyzed as follows.

PAR did not reach 100% for both the lead vehicle on the mainline and the lead vehicle on the connecting route where there are no vehicles interfering with communication with RSU, suggesting that PAR decrease due to frequent communication. As for PAR decreasing as the communication distance increases, the presence of other vehicles between the RSU and the vehicle in question may have had an effect on communication. Therefore, causes are assumed to be the following two.

- Conflicting timing of sending/receiving at RSU due to frequent communication
- When sensing the presence or absence of PC5 signals between vehicles for communication congestion control in vehicles, sensing is not possible due to a drop in the level caused by vehicle shielding loss (condition value: -5 dB/vehicle) and packet collisions occur when other vehicles are transmitting simultaneously (hidden terminal phenomenon)

To confirm the validity of these assumptions, the following additional verifications were performed.

(a) Additional verifications

Details of additional verifications are covered below.

- Additional verification A (conflicting timing of sending/receiving at RSU)

It is assumed that the RSU may not be able to receive messages due to its own transmission/reception timing conflicts is anticipated. To confirm this, PAR was measured for message 2 sent from merging vehicle to RSU and message 5 sent from mainline vehicle to RSU by reducing the number of messages (message 3 and message 4) sent from RSU to mainline vehicle and merging vehicle. Settings for message 3 and message 4 used in additional verification A are shown in Table 3.3.2-5.

Table 3.3.2-5 Settings for message 3 and message 4 sent from RSU to vehicle in additional verification A

	Number of message transmissions		Message size (byte)	
	Verification (1)	Additional verification A	Verification (1)	Additional verification A
Message 3	25	1	273	777
Message 4	11	1	273	483

- Additional verification B (packet collision)

It is assumed that, when sensing PC5 signals between vehicles, the level drop due to vehicle shielding loss may have prevented sensing, resulting in packet collisions and possibly PAR decrease (hidden terminal phenomenon). In order to confirm that, shielding loss per vehicle was changed from -5 dB/vehicle to 0 dB/vehicle and verification was performed.

(b) Additional verification results

- Additional verification A (conflicting timing of sending/receiving messages at RSU)

Fig. 3.3.2-19 and Fig. 3.3.2-20 show measurement results for message 2 and message 5.

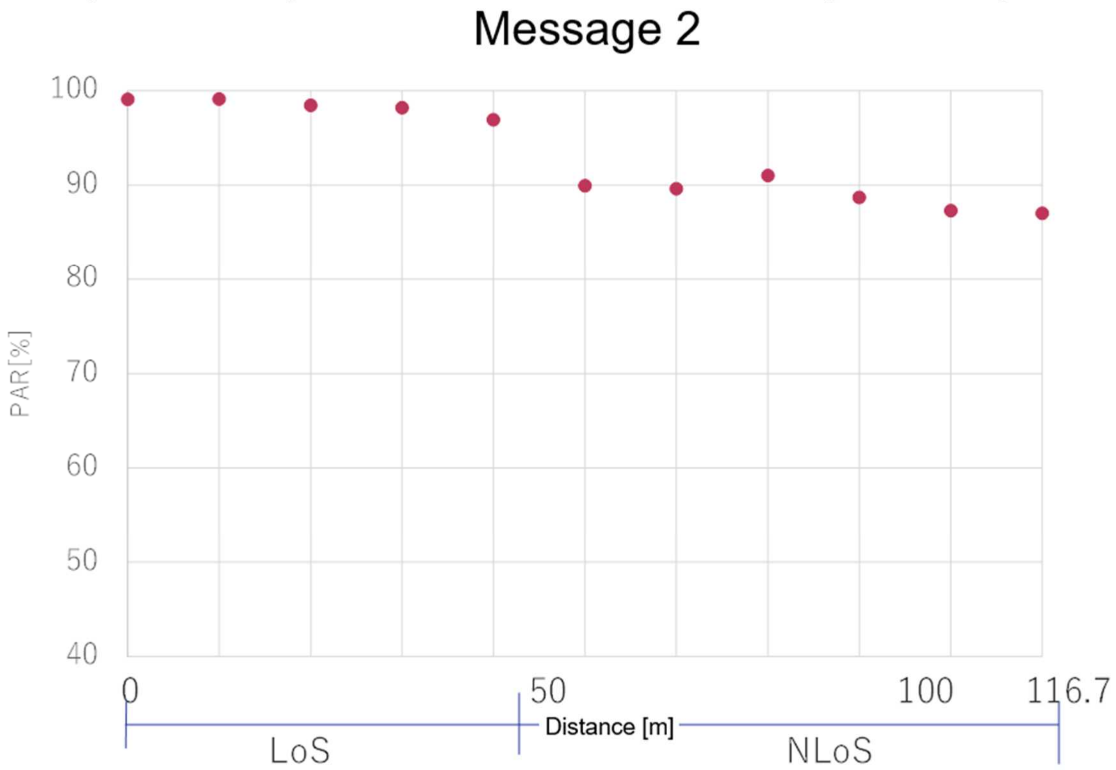


Fig. 3.3.2-19 Additional verification A PAR measurement results (Message 2)

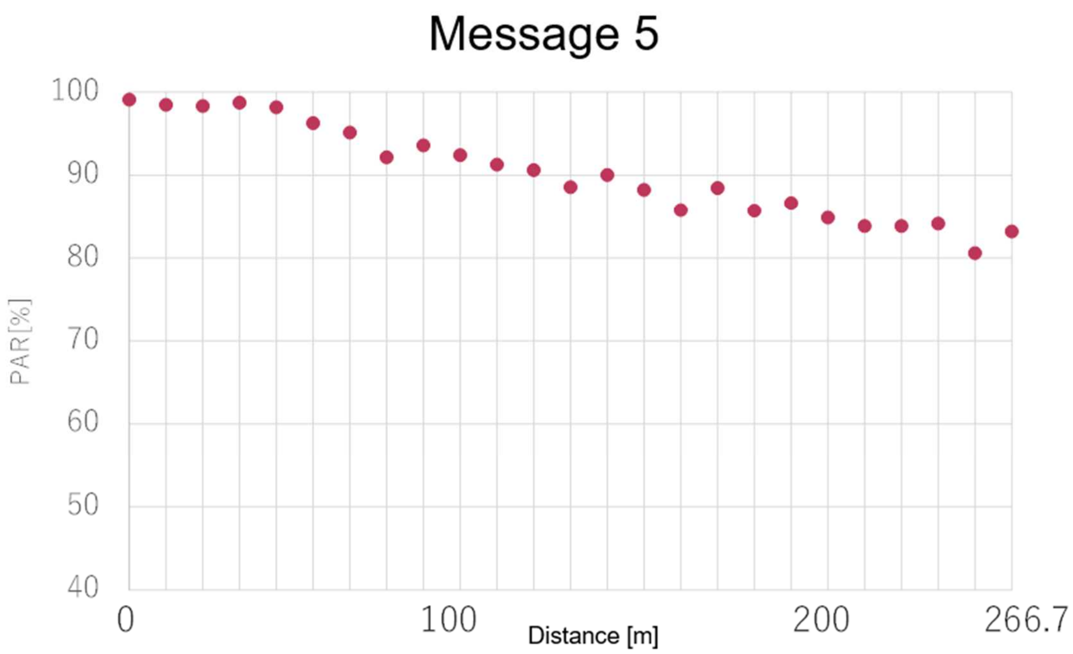


Fig. 3.3.2-20 Additional verification A PAR measurement results (Message 5)

- Additional verification B (packet collision)
  Fig. 3.3.2-21 and Fig. 3.3.2-22 show measurement results for message 2 and message 5.

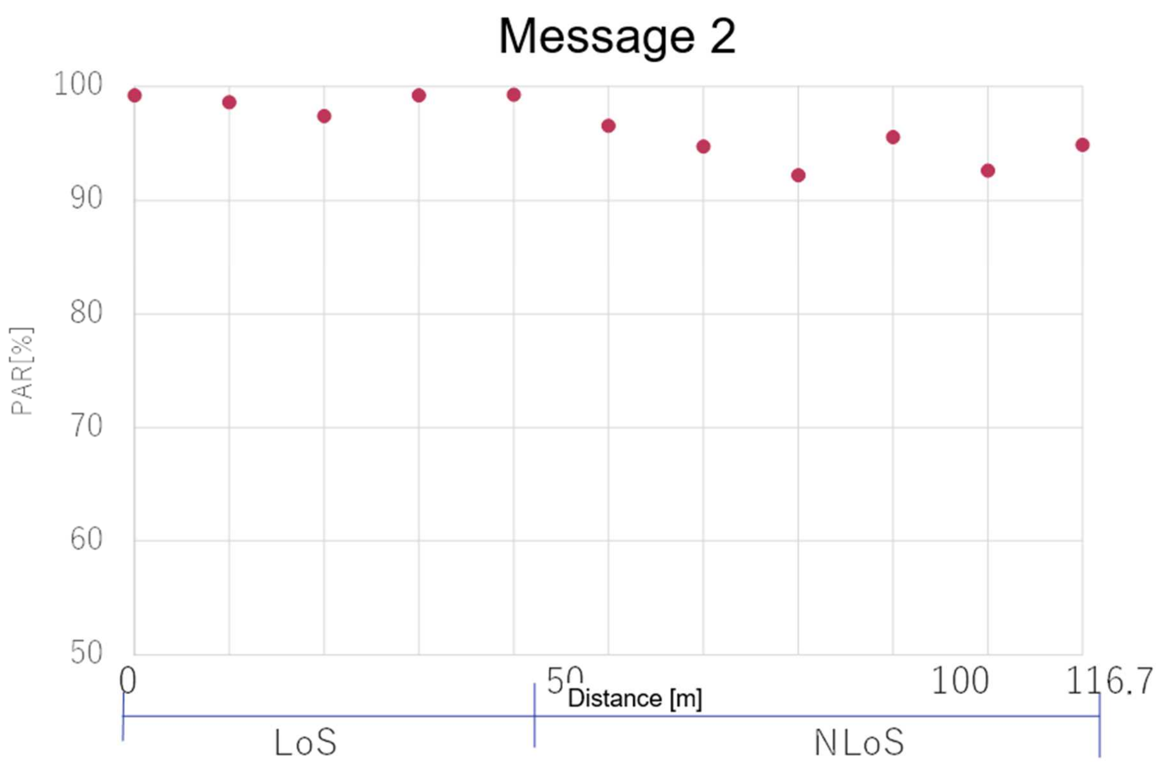


Fig. 3.3.2-21 Additional verification B PAR measurement results (message 2)

Fig. 3.3.2-22 Additional verification B PAR measurement results (Message 5)

(c) Additional verification evaluation/analysis

- Additional verification A (conflicting timing of sending/receiving at RSU)

According to message 2 measurement results in Fig. 3.3.2-19, PAR is between 100 and 95% in LoS and just under 90% in NLoS. In message 2 measurement results in Verification (1) shown in Fig. 3.3.2-6, there is a significant improvement in PAR compared with less than 80% for LoS and about 50% for NLoS at longer communication distances.

From the measurement results of message 5 in Fig. 3.3.2-20, the PAR is generally proportional to the communication distance and decreases gently from 100% to just over 80%. In message 5 measurement results in Verification (1) shown in Fig. 3.3.2-9, there is a significant improvement in PAR compared with about 90 to 75% near the merging point and PAR decreasing to just under about 70% at longer communication distances.

From the results of additional verification A, it is concluded that the PAR decreased due to transmission/reception timing conflicts at the RSU.

- Additional verification B (packet collision)

According to message 2 measurement results in Fig. 3.3.2-21, PAR is generally close to 100% in LoS and just over 90% to about 95% in NLoS. In message 2 measurement results in Verification (1) shown in Fig. 3.3.2-6, results obtained were that there is a significant improvement in PAR compared with less than 80% for LoS and about 50% for NLoS at longer communication distances.

According to message 5 measurement results in Fig. 3.3.2-22, PAR is generally close to 100%. In message 5 measurement results in Verification (1) shown in Fig. 3.3.2-9, results obtained where there is a significant improvement in PAR compared with about 90 to 75% near the merging point and decreasing to just under about 70% at longer communication distances.

3.3.3 Verification (2) Communication congestion due to multiple use cases occurring simultaneously

Verification of communication congestion due to multiple use cases occurring simultaneously is shown below.

(1) Use case evaluated

Target use cases are “c-2-2. Driving assistance based on intersection information (V2I)”, “b-1-1. Driving assistance by using traffic signal information (V2I)”, and “c-3. Collision avoidance assistance by using hazard information.”

The following is an overview of the use case.

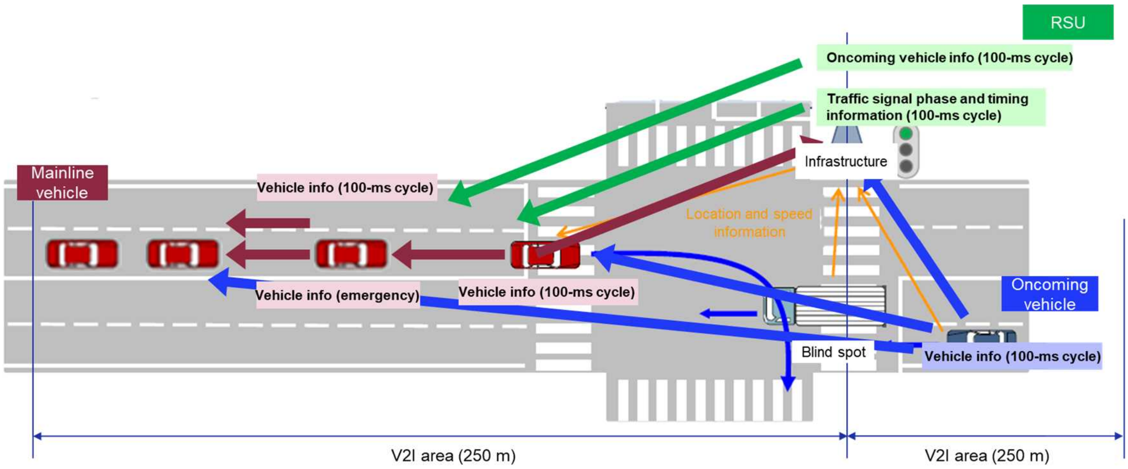


Fig. 3.3.3-1 Overview of communication congestion due to multiple use cases occurring simultaneously[22]

(2) Verification details

Congestion is assumed for c-2-2. and b-1-1. steady services at intersections as well as for c-1. with high priority, the frequency of communication and communication traffic are estimated based on communication requirements and communication messages of those, the communication sequence combining them is created, and simulation is evaluated. Specifically, the following indicators were evaluated per communication message.

- PAR
- RSSI
- Amount of communication delay

[22]Source: Prepared based on SIP Cooperative Driving Automation Use Cases - 2019 Task Force on V2X Communication for Cooperative Driving Automation Activity Report-

(3) Verification conditions

Considerations in simulation verification conditions are as follows.

- Assume as a more stringent conditions that sequences between vehicle to RSU are multiplexed within the assumed communication frequency of 100 ms.
- Assume as the worst-case scenario for communication congestion that simultaneous transmission by multiple merging vehicles or mainline vehicles occurs at the application software level.

(In actuality, each vehicle interacts individually at the application software level, but under worst-case conditions, it is assumed that all vehicles can be at simultaneous timing.)

- Aggregate the parts that can be aggregated as messages in accordance with the communication sequence of the communication scenario.

(Estimated wireless resource occupation is approx. 90% of the estimated communication capacity based on the communication scenario.)

Table 3.3.3-1 Verification conditions (road environment)

Item	Content	Supplement
Form	Four-way intersection	
Mainline: Length	250mm	
Mainline: Width	30.25 m	Lane width 3.5 m × 3 lanes × 2 directions + median strip width 1.25 m + sidewalk 4 m
Crossroad: Length	250m	
Crossroad: Width	30.25 m	
RSU installation location	Four corners of intersection	
Surrounding environment (building height)	19m	Outside of crosswalks around mainline

For wireless communication specifications, see the aforementioned Table 3.3.1-1. However, QPSK is used for the modulation method. And for simulation wireless communication parameters, see the aforementioned Table 3.3.1-2.

Fig. 3.3.3-2 shows an image of the road environment at time of verification.

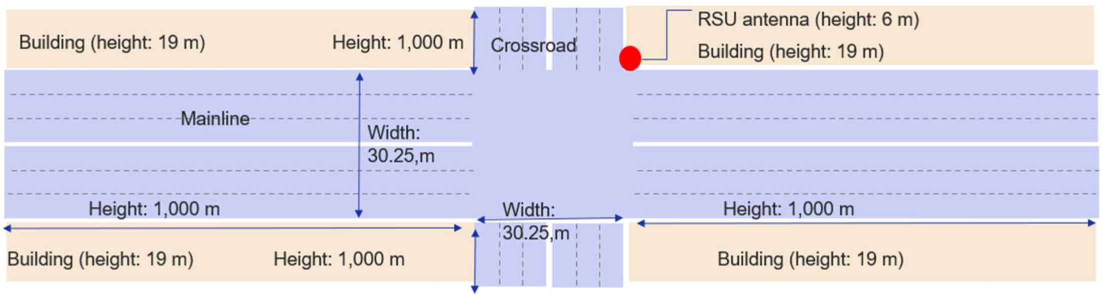


Fig. 3.3.3-2 Verification conditions (road environment)

Fig. 3.3.3-3 shows the communication capacity assumed for verification (estimation), and Table 3.3.3-2 shows the message size, number of resource blocks, and transmission time (all estimations).

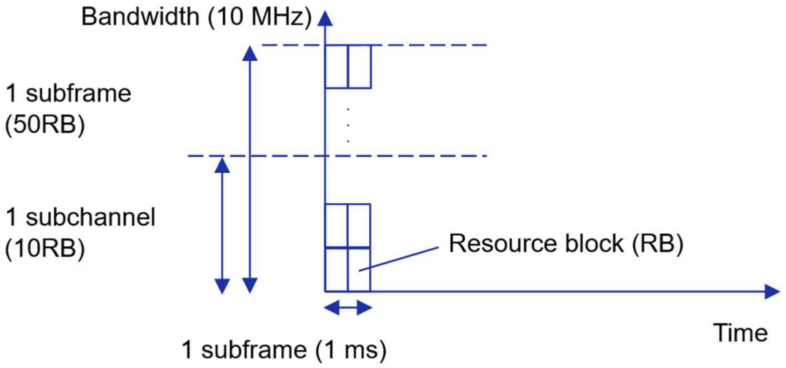


Fig. 3.3.3-3 Assumed communication capacity

- Bandwidth 10M Hz / Modulation method QPSK; Encoding rate 0.44 / No continuous transmissions
- 1 subchannel (10 RB) ≒ Data size 44 [byte]
  1 subframe (1 subchannel × 5 × 2 slots) ≒ Data size 440 [byte]

Table 3.3.3-2 Message size, number of resource blocks, and transmission time for each message

#	Communication direction	Number of transmissions	byte	RB	Transmission time estimate [ms]
1	I -> V (merging vehicle)	1	943	22	3
2	V (merging vehicle) -> I	11	287	7×11	8
3	I -> V (mainline vehicle)	25	273	7×25	18
4	I -> V (merging vehicle)	11	273	7×11	8
5	V (mainline vehicle) -> I	25	287	7×25	18
					Total 55 ms

(4) Verification data

The road model and vehicle placement used in verification is shown in Fig. 3.3.3-4, communication sequence and messages are shown in Fig. 3.3.3-5, and the number of vehicles placed is shown in Table 3.3.3-4.

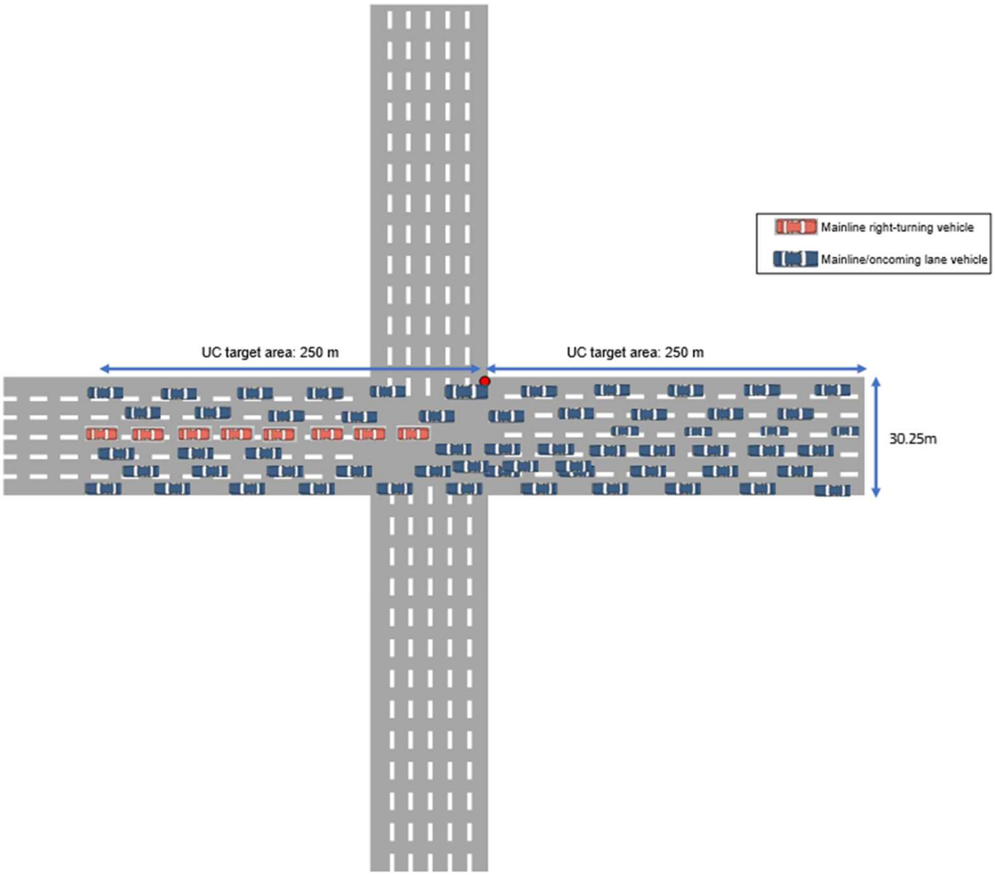
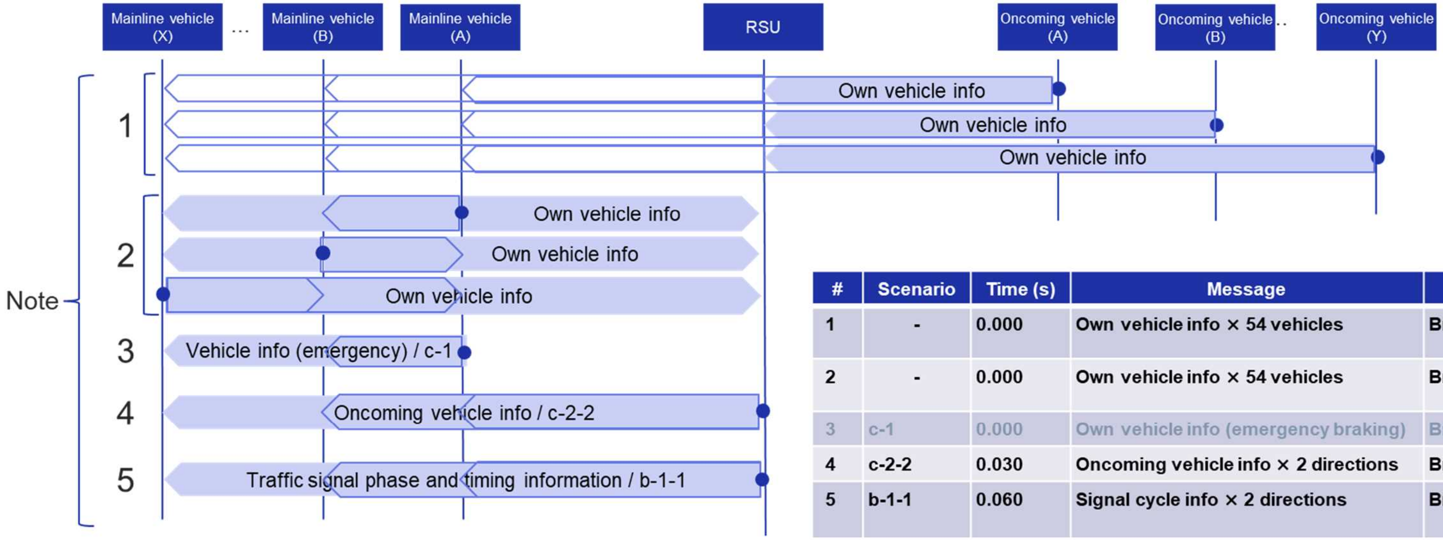


Fig. 3.3.3-4 Road environment and vehicles placed



#	Scenario	Time (s)	Message	Type	byte	Communication direction
1	-	0.000	Own vehicle info × 54 vehicles	Broadcast	312 (provisional)	V (oncoming vehicle) -> I, V
2	-	0.000	Own vehicle info × 54 vehicles	Broadcast	312 (provisional)	V (mainline vehicle) -> I, V
3	c-1	0.000	Own vehicle info (emergency braking)	Broadcast	312	V (mainline vehicle) -> V
4	c-2-2	0.030	Oncoming vehicle info × 2 directions	Broadcast	896	I -> V (mainline vehicle)
5	b-1-1	0.060	Signal cycle info × 2 directions	Broadcast	564	I -> V (mainline vehicle)

Note: Repeat one cycle (100 ms), X and Y are number of mainline and oncoming lane vehicles

Black text: Fixed cycle (100 ms)
Blue text: Event, subsequently fixed cycle (100 ms)

Fig. 3.3.3-5 Communication sequence, messages

The communication sequence was produced for use in the verification based on the messages and sequence studied by TG as of October 2021.

In the verification, data for each indicator was measured as follows.

- In PAR verification, this sequence (one set at 100 ms intervals) is operated for 7 seconds in the simulation, and data is collected periodically for 6 seconds from 1.1 seconds to 7 seconds after the operation. For message 3, which uses vehicle V2V communication as the communication method, the lead vehicle that does not receive the message is excluded from measurement targets.
- In RSSI verification, this sequence (one set at 100 ms intervals) is operated for 60 seconds in the simulation, and data is collected periodically from 10 seconds to 60 seconds after the operation. For message 3, which uses vehicle V2V communication as the communication method, the lead vehicle that does not receive the message is excluded from measurement targets.
- In communication delay verification, this sequence (one set at 100 ms intervals) is operated for 60 seconds in the simulation, and data for one vehicle selected arbitrarily is collected periodically from 10 seconds to 60 seconds after the operation.

The messages used in the communication sequence and their sizes are shown in Table 3.3.3-3, and the number of vehicles placed is shown in Table 3.3.3-4.

Table 3.3.3-3 Transmission messages/cycles used in the communication sequence

Time (s)	Message						Communication direction
	Mp	Scenario	Message name	Size*1	Size Results of TG study*2	Presence of/reason for difference from TG study results	
0.000	1	-	Automobile information for 54	312 bytes	-	Not studied	Oncoming vehicle -> RSU
0.000	2	-	Automobile information for 54	312 bytes	-	Not studied	Mainline vehicle -> RSU
0.000	3	c-1.	Own vehicle info (emergency braking)	312 bytes	312 bytes	No difference	Mainline vehicle -> Mainline vehicle
0.030	4	c-2-2.	Agreement request, update request × 11 vehicles	896 bytes	1,150 bytes	Difference present	RSU -> Mainline vehicle
0.060	5	b-1-1.	Agreement response, update response × 25 vehicles	564 bytes	1K byte	Difference present	RSU -> Mainline vehicle

*1 TG study results as of October 2021 applied.

*2 TG study results as of January 2022. Difference is occurring in message 4 and message 5. The TG study progressed in March 2022, resulting in a difference from the study results as of October 2021 applied to the simulation.

Table 3.3.3-4 Concept behind number of vehicles

Condition[*1]	Number of mainline vehicles: X (Communication area 250 m)[*2]	Number of oncoming lane vehicles: Y (Communication area 250 m)[*2]
High-speed driving	70 km/h, 2 s interval × 3 lanes × 2 directions Total: 30 vehicles	70 km/h, 2 s interval × 3 lanes × 2 directions Total: 30 vehicles
Low-speed driving	40 km/h, 2 s interval × 3 lanes × 2 directions Total: 54 vehicles	40 km/h, 2 s interval × 3 lanes × 2 directions Total: 54 vehicles
Congestion	20 km/h, 1 s interval × 3 lanes × 2 directions Total: 138 vehicles	20 km/h, 1 s interval × 3 lanes × 2 directions Total: 138 vehicles
Maximum	20 km/h, 1 s interval × 2 lanes Total: 22 vehicles	20 km/h, 1 s interval × 2 lanes Total: 22 vehicles
Verification conditions	40 km/h, 2 s interval × 3 lanes × 2 directions Total: 54 vehicles	40 km/h, 2 s interval × 3 lanes × 2 directions Total: 54 vehicles

*1 Direction indicates target lane and opposite lane Crossroads of intersection not taken into consideration.
*2 The longest communication area, c-1., is applied out of the target use cases c-1., c-2-2., and b-1-1.

Low speed driving, considered to have the highest probability of occurring, is adopted out of the conditions of high-speed driving, low-speed driving, congestion, and maximum.

(5) Verification results
(a) PAR
The message PAR used in the sequence for between mainline lead vehicle and following vehicle and for RSU and mainline vehicle under the conditions shown in sections 3.3.2(3) and 3.3.2(4) is shown in Fig. 3.3.3-6, Fig. 3.3.3-7, and Fig. 3.3.3-8.

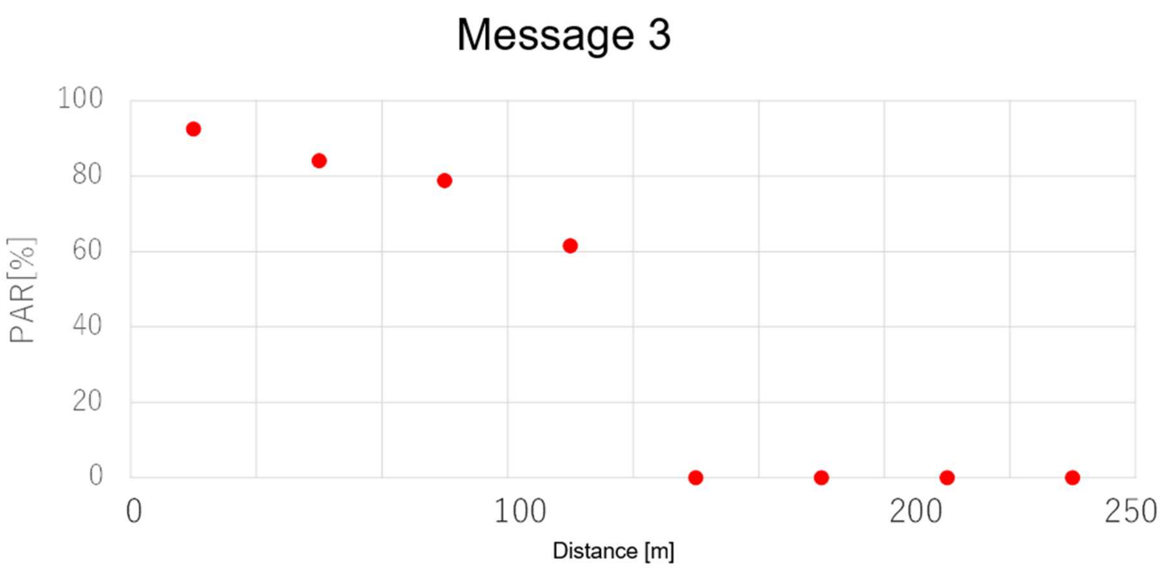


Fig. 3.3.3-6 Verification (2) PAR measurement results (Message 3)

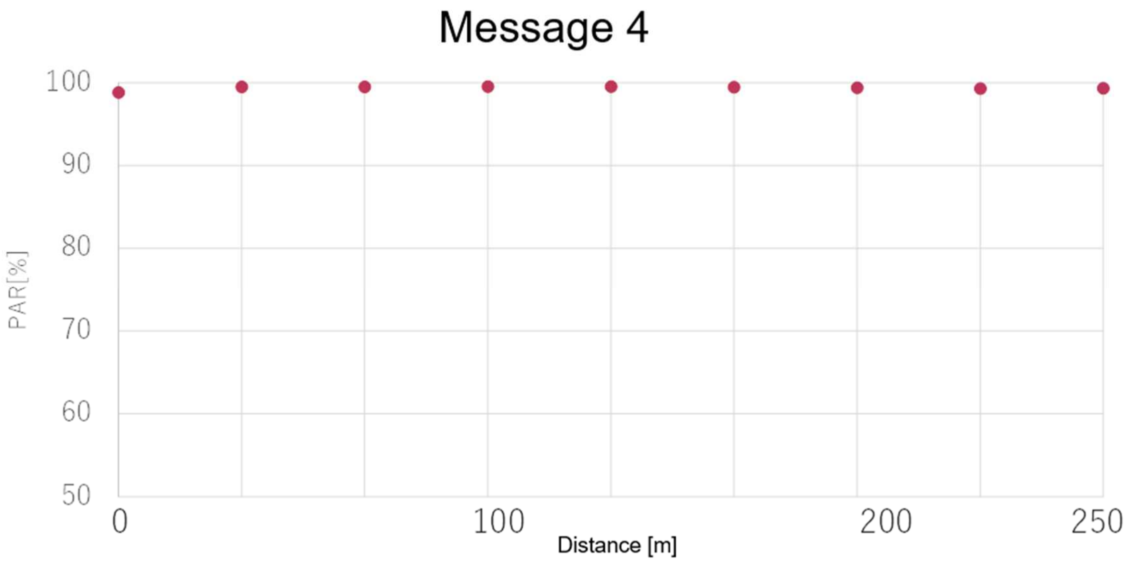


Fig. 3.3.3-7 Verification (2) PAR measurement results (Message 4)

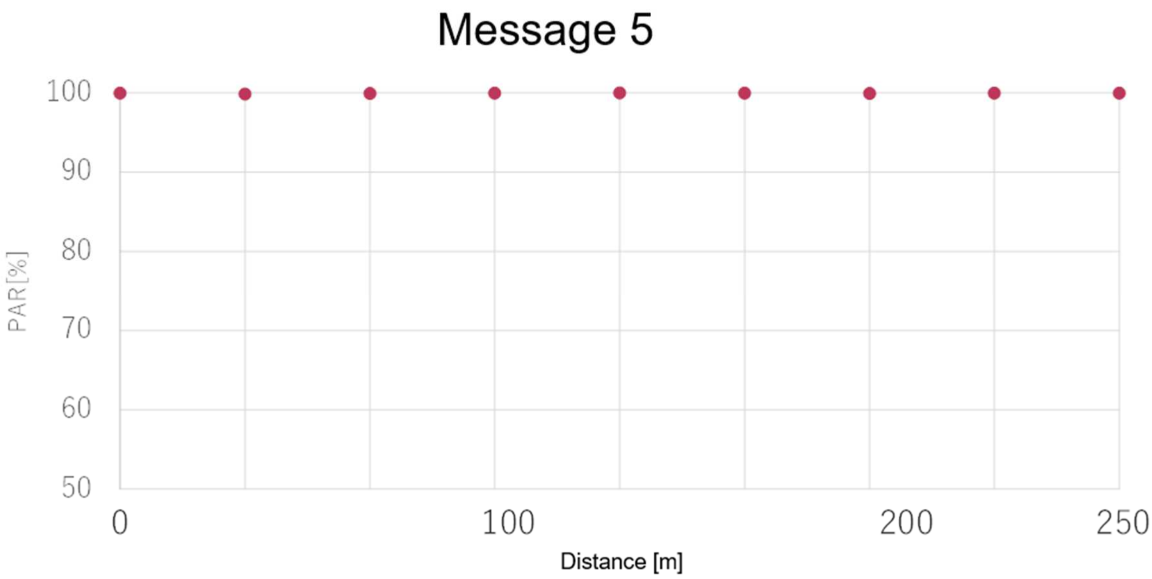


Fig. 3.3.3-8 Verification (2) PAR measurement results (Message 5)

(b) RSSI

The RSSI of messages (average of the respective cycles) used in the sequence for between mainline lead vehicle and following vehicle and for RSU and mainline vehicle under the conditions shown in sections 3.3.2(3) and 3.3.2(4) is shown in Fig. 3.3.3-9 and Fig. 3.3.3-10.

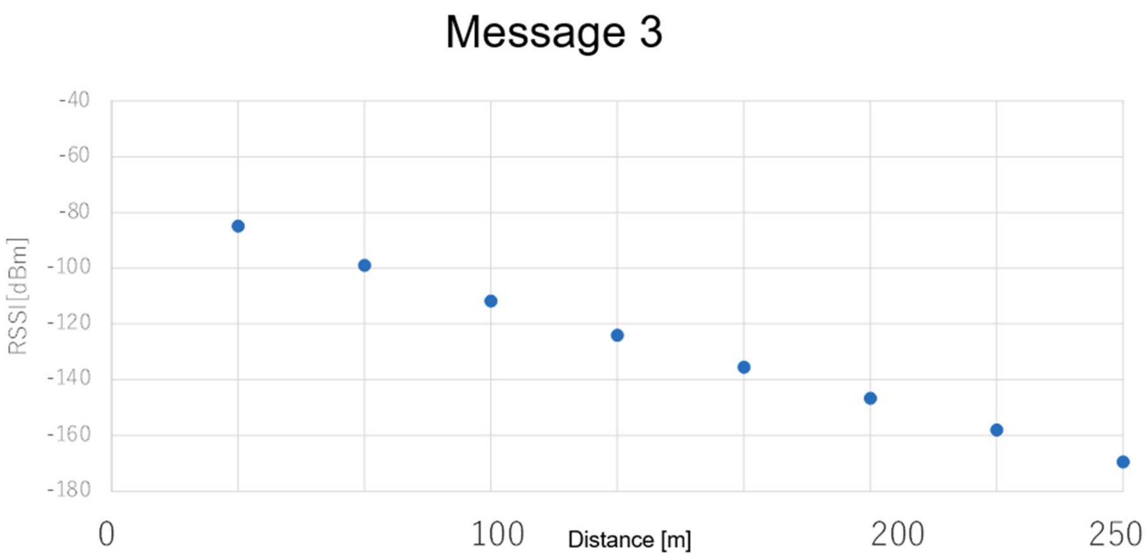


Fig. 3.3.3-9 Verification (2) RSSI measurement results (Message 3)

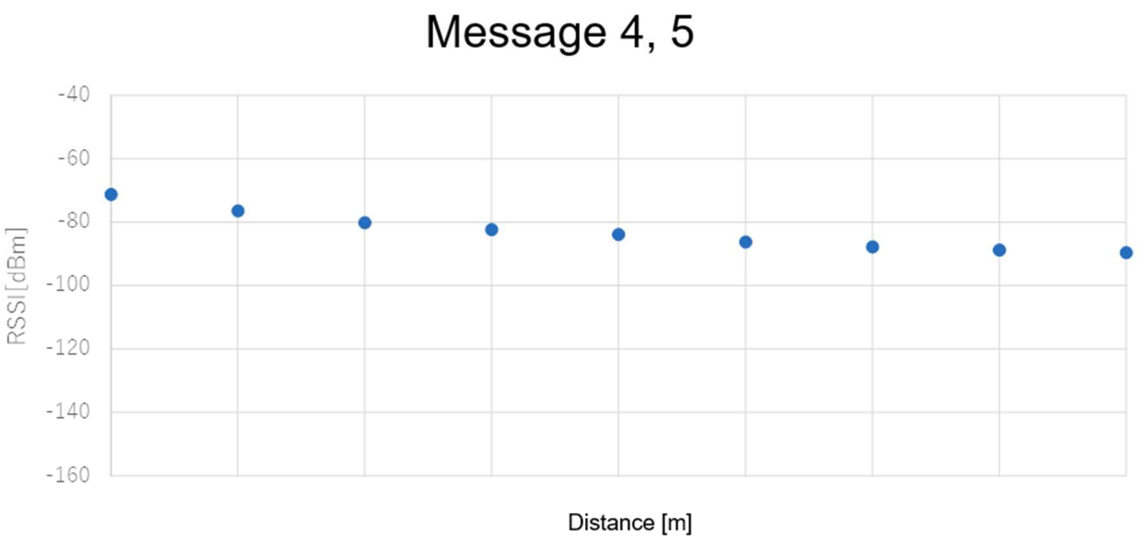


Fig. 3.3.3-10 Verification (2) RSSI measurement results (Message 4, 5)

(c) Amount of communication delay

The message communication delay used in the sequence for vehicles placed on the connecting route and mainline under the conditions shown in sections 3.3.2(3) and 3.3.2(4) is shown in Fig. 3.3.3-11, Fig. 3.3.3-12, and Fig. 3.3.3-13. Delay time was collected every 0.1 ms using the simulator's functions, and is shown in the figure as average value in units of 1 second.

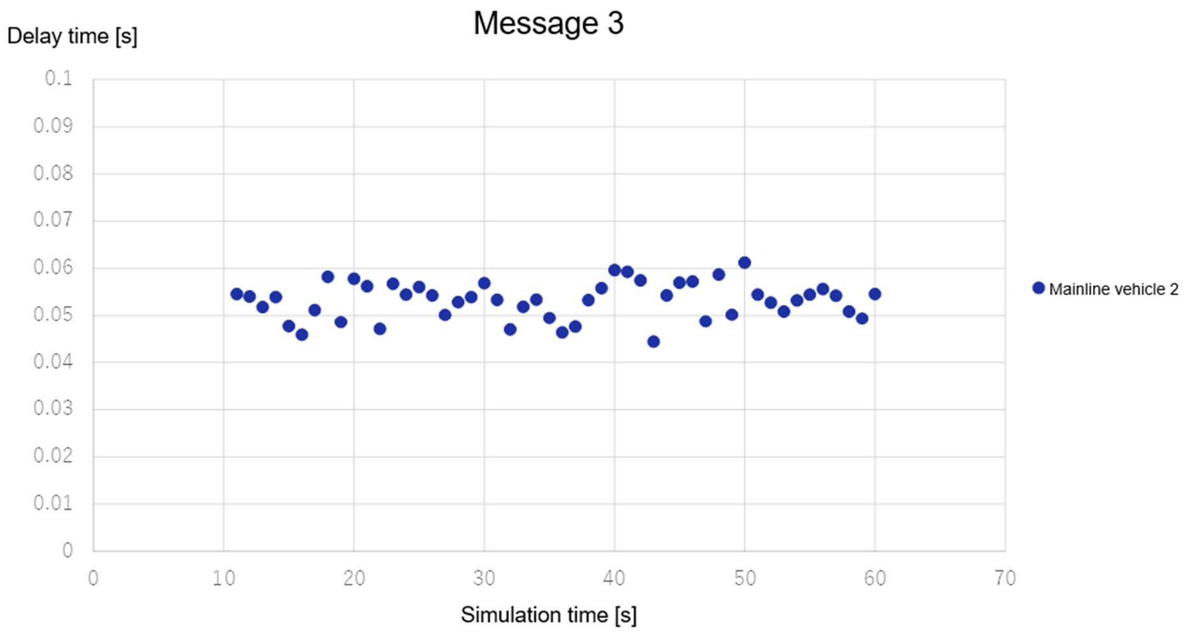


Fig. 3.3.3-11 Verification (2) Communication delay measurement results (Message 3)

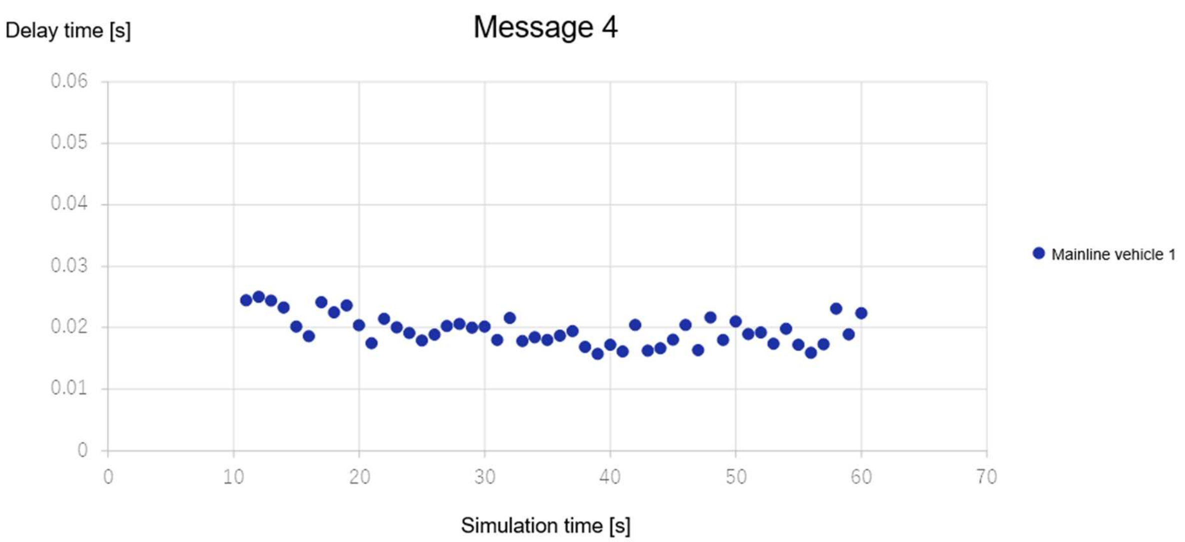


Fig. 3.3.3-12 Verification (2) Communication delay measurement results (Message 4)

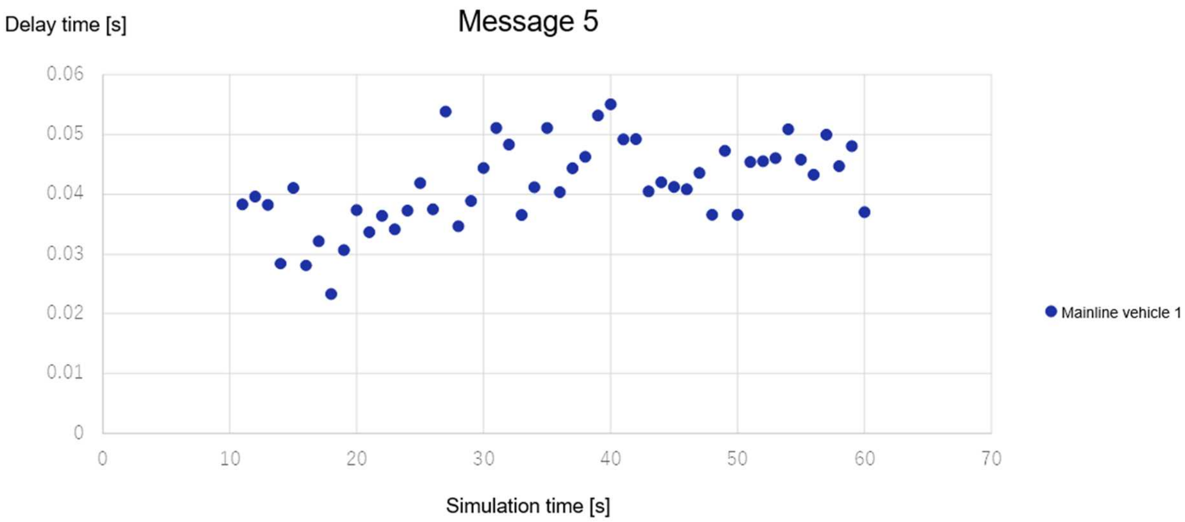


Fig. 3.3.3-13 Verification (2) Communication delay measurement results (Message 5)

(6) Evaluation/analysis

- PAR

For messages 4 and 5 used in RSU to vehicle communications, a PAR of close to 100% was secured throughout the entire communication area, which is similar to the results obtained in section 3.3.1.

On the other hand, the PAR of message 3 used in V2V communication decreased as the communication distance increased and decreased sharply when the communication distance exceeded 100 m.

- RSSI

For V2V communication (message 3), the RSSI was found to be weaker in the range of approximately -15 dBm to -10 dBm as the number of sending and receiving vehicles increased. For communication from RSU to vehicle (messages 4 and 5), it was observed that the range of RSSI drop per vehicle was gradually becoming smaller.

- Amount of communication delay

Although there is some variation, the amount of communication delay is at a constant level regardless of the length of time the simulation is run, and there is no tendency for the cumulative amount of delay to increase as the simulation runs longer or shorter. This means that message sending and receiving processing gradually accumulates over long simulation runs, and there are no delays due to the passage of time.

Based on the above results, the problem in communication congestion due to simultaneous occurrence of multiple use cases is the decrease in PAR of message 3 sent from vehicle to vehicle. Causes of decrease in PAR were analyzed as follows.

As for PAR decreasing as the communication distance increases, the presence of other vehicles between the vehicle sending and vehicle receiving may have had an effect on communication. Therefore, causes are assumed to be the following two.

- When sensing the presence or absence of PC5 signals between vehicles for communication congestion control in vehicles, sensing is not possible due to a drop in the level caused by vehicle shielding loss (condition value: -5 dB/vehicle) and packet collisions occur when other vehicles are transmitting simultaneously (hidden terminal phenomenon)

To confirm the validity of these assumptions, the following additional verifications were performed.

(a) Additional verifications

Details of additional verifications are covered below.

- Additional verification C (packet collision)

Regarding packet collision in vehicle communication, shielding loss per vehicle was changed from -5 dB/vehicle to 0 dB/vehicle and verification was performed.

(b) Additional verification results

Fig. 3.3.3-14 shows measurement results for message 3.

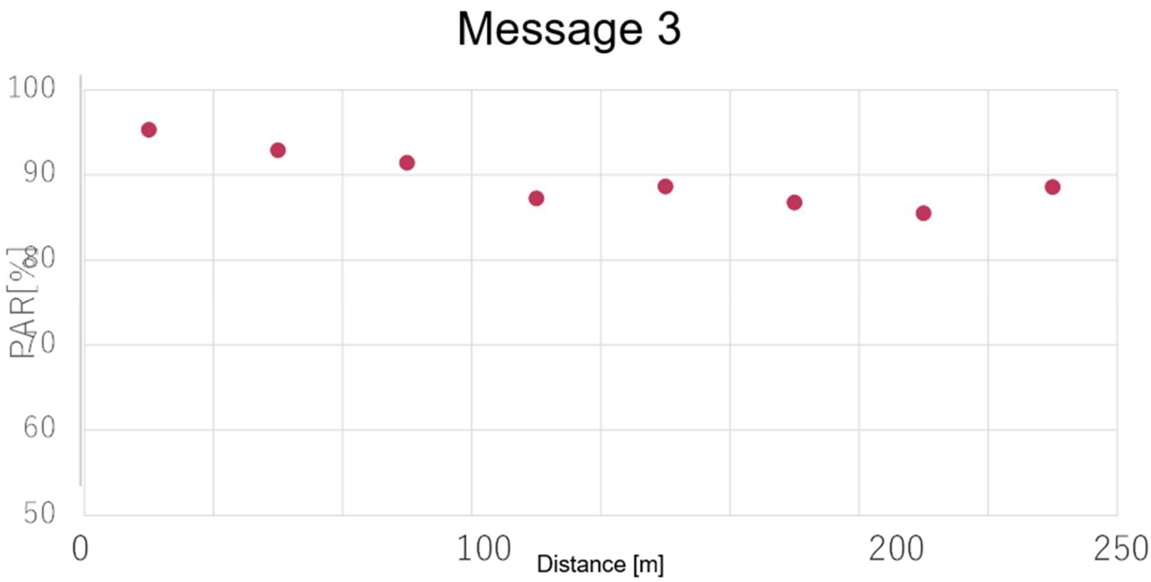


Fig. 3.3.3-14 Additional verification C PAR measurement results (Message 3)

(c) Additional verification evaluation/analysis

Results obtained were that there is a significant improvement in PAR compared with message 3 measurement results in Verification (2) shown in Fig. 3.3.3-6.

Based on the results and evaluation/analysis described earlier, it was determined that sensing was not possible due to the level decrease caused by vehicle shielding loss (-5 dB/unit) in Verification (2), resulting in packet collisions and causing the PAR to decrease with distance.

3.3.4 Summary of verification results

Verification was performed under the traveling vehicle environment (number of vehicles, interval, etc.) assumed in actual operation in accordance with the communication scenario for a use case in which communication congestion is assumed, and communication performance based on the C-V2X/PC5 specification was confirmed. Verification results are shown below.

- In V2I communication, a decrease in PAR occurred due to an increase in the frequency of communication of messages for realizing the use case.
  (Impact of conflicting timing of sending/receiving at the same communication terminal)
- In V2V communication, PAR variation occurred due to conditions for shielding loss by vehicles.
  (Decrease in RSSI due to shielding loss)
- In V2V communication, results were obtained that PAR did not reach 100% even in short-distance communication. In an environment where multiple vehicles and RSU communicate, PAR is thought to have decreased when communication timing of the vehicle or RSU overlaps with the communication of other devices.
  (Hidden terminal phenomenon)

Verification results were further surveyed and studied through demonstrations on test courses regarding the variation in shielding loss due to shadowing and the decline of communication quality due to communication congestion. The results are shown in case 3.4.

3.4 Verification of evaluation results

The results verified in case 3.3 confirm that in an environment where multiple vehicles communicate, the PAR decreases due to communication congestion caused by the presence of hidden terminals. The PAR differences caused by varying the conditions of shielding loss by vehicles indicate that shadowing due to the presence of vehicles or other obstacles between the sending and receiving spaces has a significant impact.

This case describes demonstration evaluation using narrow-area communication in a real environment based on the verified results.

3.4.1 Overview of appropriateness verification

(1) Purpose of demonstration

The appropriateness of evaluation results in verification are confirmed through demonstration evaluation using narrow-area communication in a real environment. Additionally, issues for actual operation are identified and summarized based on the results of verification and demonstration.

(2) Overview of implementation

In this demonstration, evaluation was performed from the following two viewpoints.

- Impact of shadowing in a real environment: Demonstration (1)

  Communication performance is measured by placing a shielding vehicle between two vehicles performing V2V communication to shield the radio waves and check the effect of shadowing.

- Impact of communication congestion due to communication volume: Demonstration (2)

  Communication performance is measured by transmitting interference waves from another vehicle and RSU in the vicinity of two vehicles performing V2V communication to check the impact of communication congestion.

This verification was conducted on a test course with intersections as described below, and it was conducted for use cases around intersections that are use cases c-1 (Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly) and c-2-2 (Driving assistance based on intersection information (V2I)) where communication congestion is expected to occur due to congestion among multiple use cases.

In measuring communication performance, data was collected on PAR and RSSI as measurement items.

- Packet arrival rate (PAR)

  This is the ratio of the number of times data was successfully received at the receiving side in relation to the number of times data was sent at the sending side. In this demonstration, the number of transmissions is counted at the sending side application layer, and similarly, the number of receptions is counted at the receiving side application layer to calculate from the ratio of these two types of data.

- Received signal strength indication (RSSI)

  This is the strength of the radio waves received by a wireless communication device. To obtain RSSI, a dedicated tool was used instead of obtaining by an application, and measurement was done at the same time as PAR measurement.

(3) Demonstration environment

The environment for this demonstration is described below.

(a) Demonstration location

The test location used for this demonstration was the NEC Mobility Test Center (NMTC) in Gotemba City, Shizuoka Prefecture. The test course has a straight course of approx. 130 meters, with one lane on each side of the road. There are two intersections in the test course, and several signal posts are installed around them. C-V2X terminals are installed on two of those signal posts (A and B). Three vehicles (a light van, a small bus, and a small truck) are also located on the test course, and each vehicle is also equipped with a C-V2X terminal. Fig. 3.4.1-1 shows an overview diagram of the test course.

Photos of the vehicles actually used are shown in Fig. 3.4.1-2, Fig. 3.4.1-3, and Fig. 3.4.1-4, and photos of the signal posts are shown in Fig. 3.4.1-5 and Fig 3.4.1-6.

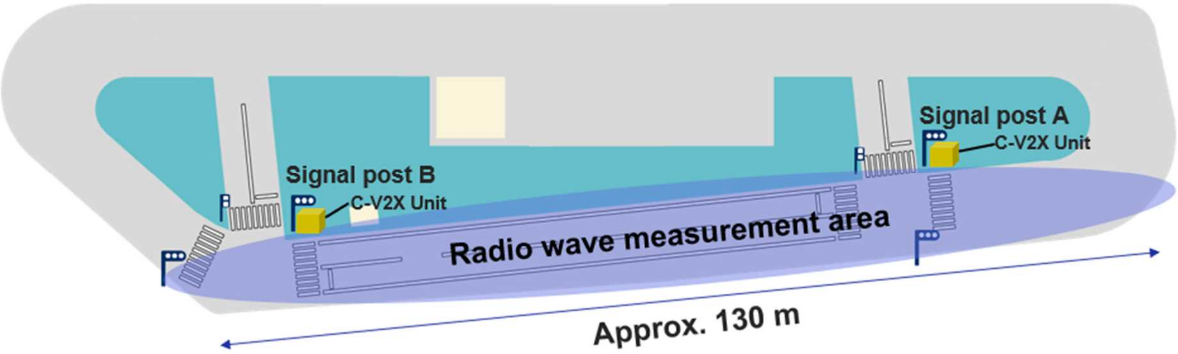


Fig. 3.4.1-1 NMTC test course overview diagram

Fig. 3.4.1-2 Small truck equipped with OBU (radio antenna indicated by the red circle)

Fig. 3.4.1-3 Light van equipped with OBU (radio antenna indicated by the red circle)

Fig. 3.4.1-4 Small bus equipped with OBU (radio antenna indicated by the red circle)

Fig. 3.4.1-5 Signal Post A (radio antenna indicated by the red circle)

Fig 3.4.1-6 Signal Post B (radio antenna indicated by the red circle)

(b) Equipment used

Equipment used in this demonstration is shown in Table 3.4.1-1 and Fig. 3.4.1-7. The radio waves used in the demonstration were those of equipment NMTC was licensed to use as an experimental station. See Table 3.4.1-2 for details of the radio specifications.

The vehicles used in this demonstration are shown in Table 3.4.1-4.

Table 3.4.1-1 Equipment used

No.	Equipment name	Remarks
1	C-V2X Unit (made by Wistron NeWeb Corporation (WNC))	Chipset: MDM9150 made by Qualcomm From Fig. 3.4.1-8
2	C-V2X Unit control PC	

Table 3.4.1-2 Radio specifications

Item	Specifications/values
Device	C-V2X Unit control PC (made by WNC)
Transmission frequency	5780MHz
Bandwidth	10 MHz
Transmission output	10dBm (10mW)
Modulation method	OFDM (SC-FDM)
Radio wave type	X7W
Antenna composition	Dipole antenna
Antenna gain	5.2dBi
Reception power	-93dBm
Antenna height	RSU: Signal pole A approx. 3.5 m, Signal pole B approx. 3.1 m OBU: Light van approx. 1.9 m, small truck approx. 3.0 m, small bus approx. 2.7 m
RRC Layer parameter settings	Set in accordance with ITS Forum Guidelines (RC-015) See Table 3.4.1-3 for details.

Table 3.4.1-3 Table comparing settings with those of ITS Forum Guidelines[23] (1/3)

Item	Recommended value	Demonstration setting value
SL-V2X-Preconfiguration-14		
v2x-PreconfigFreqList-r14	One entry of SL-V2X-PreconfigFreqInfo-r14	Refer to SL-V2X-PreconfigFreqInfo-r14
anchorCarrierFreqList-r14	Not configured	Not configured
Cbr-PreconfigList-r14	Two entries of {65,100}	Two entries of {65,100}
SL-V2X-PreconfigFreqInfo-r14		
v2x-CommPreconfigGeneral-r14	SL-PreconfigGeneral-r12	Refer to SL-PreconfigGeneral-r12
v2x-CommPreconfigSync-r14	Not configured	Not configured
v2x-CommRxpoolList-14	One entry of SL-V2X-PreconfigCommPool-r14	Refer to PreconfigCommPool-r14
v2x-CommTxpoolList-14	One entry of SL-V2X-PreconfigCommPool-r14	Refer to PreconfigCommPool-r14
p2x-CommTxpoolList-14	Not configured	Not configured
v2x-ResourceSelectionConfig-r14	SL-CommTxPoolSensingConfig-r14	Refer to SL-CommTxPoolSensingConfig-r14
zoneConfig-r14	Not configured	Not configured
syncPriority-r14	Gnss	Gnss
thresSL-TxPrioritization-r14	Not configured	Not configured
offsetDFM-r14	Not configured	Not configured
SL-PreconfigGeneral-r12		
profile0x0001-r12	FALSE	FALSE
profile0x0002-r12	FALSE	FALSE
profile0x0004-r12	FALSE	FALSE
profile0x0006-r12	FALSE	FALSE
profile0x0101-r12	FALSE	FALSE
profile0x0102-r12	FALSE	FALSE
profile0x0104-r12	FALSE	FALSE
carrierFreq-r12	To be set experimental Frequency	53090 (5780MHz)
maxTxPower-r12	23 dBm	10 dBm
additionalSpectrumEmission-r12	Ignored	Ignored
sl-bandwidth-r12	n50 (10MHz) or n100 (20MHz)	n50 (10MHz)
tdd-ConfigSL-r12	None	None
reserved-r12	All 0s	All 0s

[23] Comparison table produced excerpting in part ITS FORUM RC-015 RRC Layer (TS36.331) parameter settings example

Table 3.4.1-3 Table comparing settings with those of ITS Forum Guidelines (2/3)

Item	Recommended value	Demonstration setting value
SL-V2X-PreconfigCommPool-r14		
sl-OffsetIndicator-r14	Not configured	Not configured
sl-Subframe-r14	All 1s	All 1s
adjacencyPSCCH-PSSCH-r14	TRUE	TRUE
sizeSubchannel-r14	n10	n10
numSubchannel-r14	n5 (10MHz) or n10 (20MHz)	n5 (10MHz)
startRB-Subchannel-r14	0	0
startRB-PSCCH-Pool-r14	Not configured	Not configured
dataTxParameters-r14	23 dBm	10 dBm
zoneID-r14	Not configured	Not configured
thresS-RSSI-CBR-r14	9	9
cbr-pssch-TxConfigList-r14	Two entries of SL-PPPP-TxPreconfigIndex-r14	Refer to SL-PPPP-TxPreconfigIndex-r14
resourceSelectionConfigP2X-r14	Not configured	Not configured
syncAllowed-r14	gnss	Gnss
restricResource ReservaationPeriod-r14	Not configured	Not configured
SL-CommTxPoolSensingConfig-r14		
pssch-TxConfigList-r14	One entry of SL-PSSCH-TxConfig-r14	Refer to SL-PSSCH-TxConfig-r14
thresPSSCH-RSRP-List-r14	{2,11,2,11}	{2,11,2,11}
restrictResourceReservationPeriod-r14	v1	v1
probResourceKeep-r14	v0dot8	v0dot8
p2x-SensingConfig-r14	Not configured	Not configured
sl-ReselectAfter-r14	n5	n5
SL-PPPP-TxPreconfigIndex-r14		
priorityThreshold-r14	2	2
defaultTxConfigIndex-r14	1	1
cbr-ConfigIndex-r14	0	0
tx-ConfigIndexList-r14	{0,1}	{0,1}
SL-PSSCH-TxConfig-r14		
typeTxSync-r14	Not configured	GNSS
thresUE-Speed-r14	kmph120	kmph120
parametersAbobeThres-r14	SL-PSSCH-TxParameters-r14	Refer to SL-PSSCH-TxParameters-r14
parametersBelowThres-r14	SL-PSSCH-TxParameters-r14	Refer to SL-PSSCH-TxParameters-r14

Table 3.4.1-3 Table comparing settings with those of ITS Forum Guidelines (3/3)

Item	Recommended value	Demonstration setting value
SL-PSSCH-TxParameters-r14 for parametersBelowThres-r14		
minMCS-PSSCH-r14	5	5
maxMCS-PSSCH-r14	11(MCS8,9,10 will be excluded)	7
minSubchannel-NumberPSSCH-r14	1	1
maxSubchannel-NumberPSSCH-r14	2	2
allowedRetxNumberPSSCH-r14	n1	n0 (no retransmission)
maxTxPower-r14	Not configured	10
SL-PSSCH-TxParameters-r14 for parametersAbobeThres-r14		
minMCS-PSSCH-r14	0	0
maxMCS-PSSCH-r14	7	7
minSubchannel-NumberPSSCH-r14	1	1
maxSubchannel-NumberPSSCH-r14	5	5
allowedRetxNumberPSSCH-r14	n1	n0 (no retransmission)
maxTxPower-r14	Not configured	10

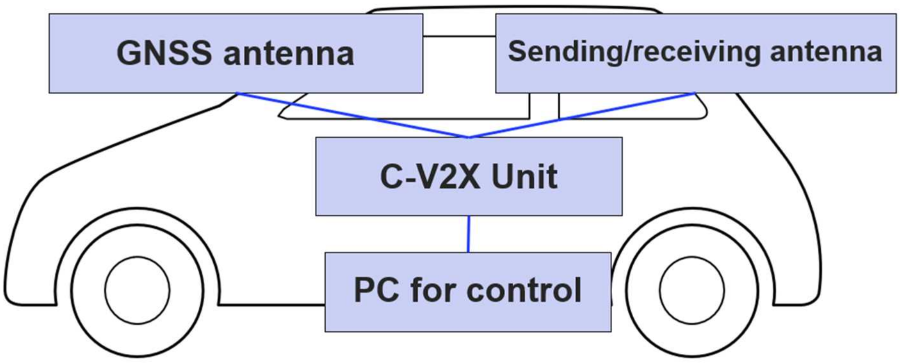


Fig. 3.4.1-7 Overview of equipment on vehicle

Table 3.4.1-4 Size of vehicles

Vehicle type	Vehicle size
Light van	Length: 339 cm; Width: 147 cm; Height: 194 cm
Small truck	Length: 498 cm; Width: 188 cm; Height: 305 cm
Small bus	Length: 669 cm; Width: 208 cm; Height: 282 cm

Fig. 3.4.1-8 C-V2X Unit (made by WNC)

(4) Preconditions and constraints

Preconditions in this demonstration are shown in Table 3.4.1-5.

Table 3.4.1-5 Preconditions

Item	Content
Measurement with vehicle stopped	In this demonstration, communication performance is measured with the vehicle stopped for the purpose of acquiring radio wave propagation data.
Frequency and band	The frequencies and bands used in the demonstration are the values for the experimental station license obtained.
Measurement time	In the calculation of PAR, the data measurement time is set to 80 seconds, and 60 seconds of data is collected by cutting off 10 seconds each immediately after start and immediately before end of communication.
Communication traffic	Communication load in demonstration (2) is measured with the maximum communication traffic that can be achieved in the demonstration environment.
Retransmission control	Communication performance is measured without retransmission, the same as in verification.

3.4.2 Preliminary measurement

In this demonstration, communication performance according to distance between the measurement vehicle (light van) and vehicle A (small bus) was performed as preliminary measurements in order to confirm one-to-one V2V communication performance.

(1) Demonstration item

The measurement vehicle and vehicle A were placed at opposite ends of the test course, and the measurement vehicle was moved closer to vehicle A in 5 m increments where PAR and RSSI were measured at each distance.

An overview diagram of preliminary measurement is shown in Fig. 3.4.2-1, and the evaluation conditions are shown in Table 3.4.2-1. The transmission and reception of the measuring vehicle and vehicle A must simulate and transmit the own-vehicle information of c-2-1.

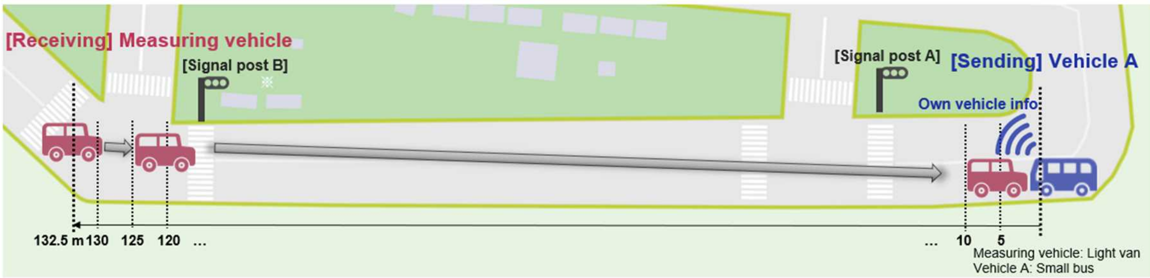


Fig. 3.4.2-1 Overview diagram of preliminary measurement

Table 3.4.2-1 Evaluation conditions of preliminary measurement

Condition	Measuring vehicle (light van)	Vehicle A (small bus)
Transmission packet length [byte]	283	283
Transmission cycle [ms]	100	100
Distance from measuring vehicle [m]	-	Change distance in 5 m increments (132.5, 130, 125, …,10, 5)

(2) Evaluation results

Evaluation results are shown in Fig. 3.4.2-2. The vertical axis shows RSSI [dBm] and PAR [%], and the horizontal axis shows distance to vehicle A and measuring vehicle.

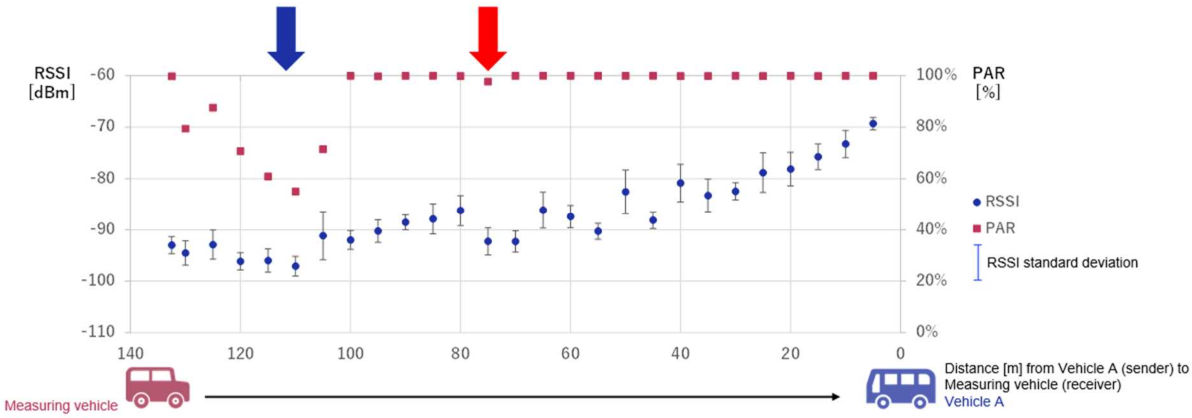
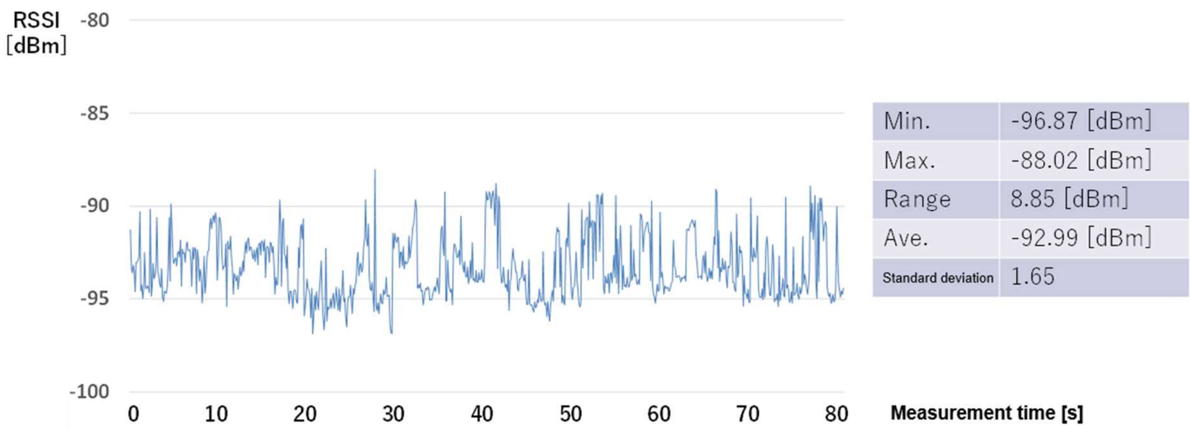


Fig. 3.4.2-2 Preliminary measurement results

The time variation of RSSI at the longest point of the test course (132.5 m) is shown in Fig. 3.4.2-3. And the average and standard deviation of the RSSI measurement values is shown in Table 3.4.2-2.



Min.	-96.87 [dBm]
Max.	-88.02 [dBm]
Range	8.85 [dBm]
Ave.	-92.99 [dBm]
Standard deviation	1.65

Fig. 3.4.2-3 RSSI at 132.5 m point

Table 3.4.2-2 RSSI measurement values of preliminary measurement

Distance	Average [dBm]	Standard deviation
5 m	-69.31	1.23
10 m	-73.27	2.65
15 m	-75.75	2.49
20 m	-78.15	3.27
25 m	-78.84	3.86
30 m	-82.50	1.68
35 m	-83.30	3.22
40 m	-80.89	3.67
45 m	-88.15	1.61
50 m	-82.60	4.24
55 m	-90.28	1.56
60 m	-87.42	2.19
65 m	-86.17	3.53
70 m	-92.30	2.06
75 m	-92.27	2.63
80 m	-86.24	2.92
85 m	-87.90	2.93
90 m	-88.55	1.45
95 m	-90.27	2.21
100 m	-92.01	1.83
105 m	-91.16	4.67
110 m	-97.09	1.92
115 m	-96.00	2.28
120 m	-96.16	1.69
125 m	-92.92	2.83
130 m	-94.53	2.38
132.5m	-92.99	1.65

(3) Evaluation/analysis

- PAR

PAR decreased as the distance between vehicles increased to 100 m or greater. However, PAR at the longest distance on the course, 132.5 m, was 100%.

- RSSI

RSSI decreased with each increase in distance between vehicles.

The preliminary measurement results show that RSSI decreases similarly at locations where PAR decreases.

Fig. 3.4.2-4 shows a graph of the desktop calculation results of a two-wave interference model (direct waves and waves reflected from the road surface) assuming this demonstration environment (vertical axis: RSSI, horizontal axis: distance). RSSI drops sharply in two sections of this two-wave interference model (70 to 80 m and 100 to 130 m). Compared with the preliminary measurement results, PAR similarly decreased at 75 m and at 105 to 130 m. Therefore, it can be considered that the cause of the decrease in PAR in the preliminary measurement results was due to packet loss caused by a decrease in RSSI due to reflections on the road surface and other effects.

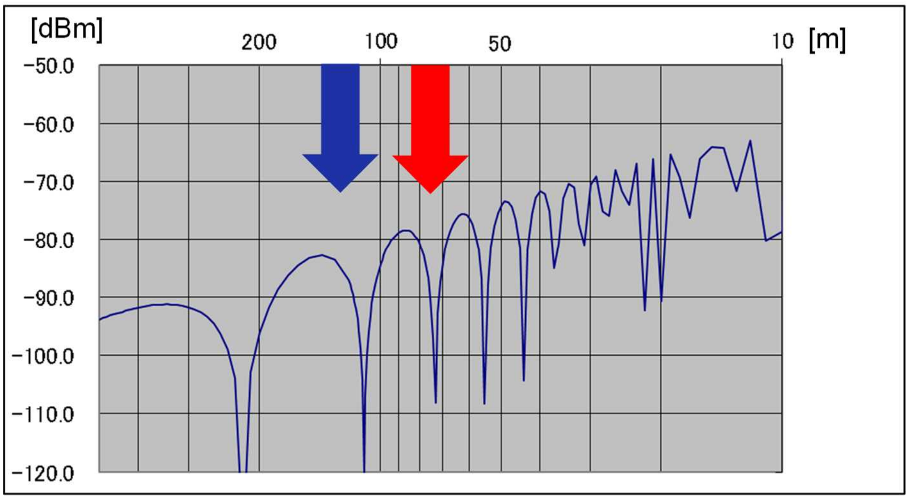


Fig. 3.4.2-4 (Reference) Two-wave interference model (blue and red arrows indicate the same arrow positions as in Fig. 3.4.2-2)

3.4.3 Demonstration (1) Impact of shadowing in a real environment

In Demonstration (1) the impact of shadowing in a real environment is measured. A small truck was placed between two vehicles (light van and small bus) and communication performance was measured.

(1) Demonstration item

In this demonstration, vehicle A (small bus) and the measuring vehicle (light van) respectively are placed at the ends of the course. The position of vehicle B (small truck) is changed every 5 m between those two vehicles, and PAR and RSSI are measured. As for the positional relation of vehicle B, it was positioned in line between vehicle A and the measuring vehicle, and communication was conducted with vehicle A and the measuring vehicle out of sight of each other.

An overview diagram of evaluation is shown in Fig. 3.4.3-1, and the evaluation conditions are shown in Table 3.4.3-1. The transmission and reception of the measuring vehicle and vehicle A must simulate and transmit the own-vehicle information of c-2-1.

For the vehicle positions, based on the results of the preliminary measurements in section 3.4.2, the distance between the measuring vehicle and vehicle A was set to 132.5 m where PAR is 100%.

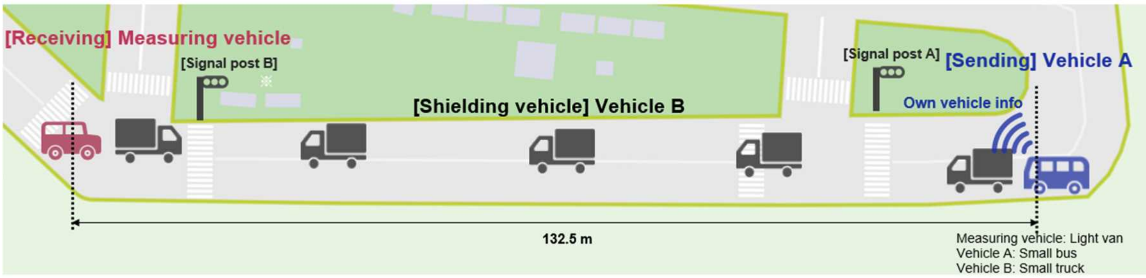


Fig. 3.4.3-1 Overview diagram of Demonstration (1)

Table 3.4.3-1 Evaluation conditions of Demonstration (1)

Condition	Measuring vehicle (light van)	Vehicle A (small bus)
Transmission packet length [byte]	283	283
Transmission cycle [ms]	100	100
Distance from measuring vehicle [m]	-	132.5

(2) Evaluation results

Evaluation results are shown in Fig. 3.4.3-2. The vertical axis shows RSSI [dBm] and PAR [%], and the horizontal axis shows distance to vehicle A and vehicle B. Also, RSSI measurement values are shown in Table 3.4.3-2.

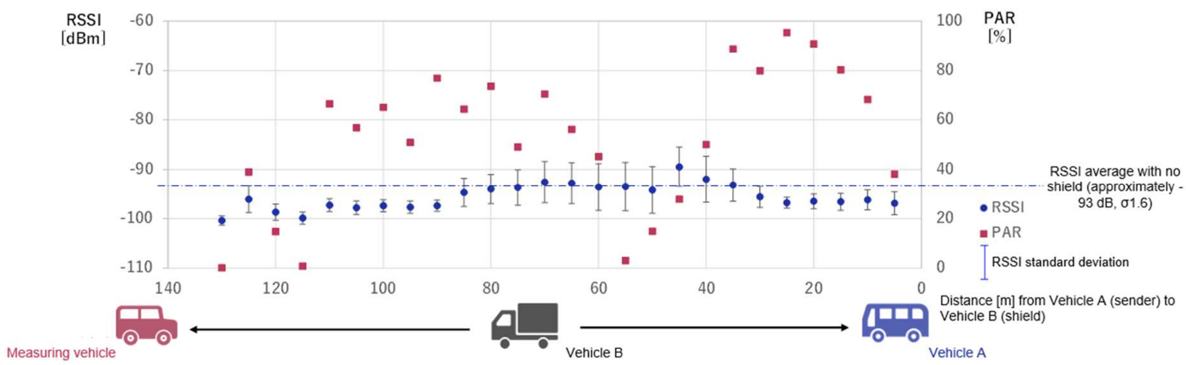


Fig. 3.4.3-2 Measurement results of Demonstration (1)

Table 3.4.3-2 RSSI measurement values of Demonstration (1)

Distance	Average [dBm]	Standard deviation
5 m	-96.90	2.31
10 m	-96.20	2.03
15 m	-96.60	1.73
20 m	-96.50	1.47
25 m	-96.80	1.11
30 m	-95.60	2.13
35 m	-93.20	3.28
40 m	-92.00	4.68
45 m	-89.50	4.01
50 m	-94.20	4.75
55 m	-93.50	4.90
60 m	-93.60	4.74
65 m	-92.80	4.17
70 m	-92.60	4.21
75 m	-93.70	3.61
80 m	-94.00	2.98
85 m	-94.70	2.89
90 m	-97.40	1.12
95 m	-97.70	1.25
100 m	-97.40	1.23
105 m	-97.80	1.37
110 m	-97.30	1.29
115 m	-99.90	1.20
120 m	-98.70	1.62
125 m	-96.10	2.71
130 m	-100.40	0.92

(3) Evaluation/analysis

- RSSI

RSSI decreased when the obstruction was on the transmitting side or near the receiving side. When the obstruction was at an intermediate distance, RSSI decreased less, but the variability increased.

- PAR

In conducting Demonstration (1), PAR comparison was performed with the truck position was shifted 1 m to the left or right from the straight line between vehicle A and the measuring vehicle. An illustration of how evaluation is done is given in Fig. 3.4.3-3, and the results of the reference measurement around 75 m is shown in Table 3.4.3-3.

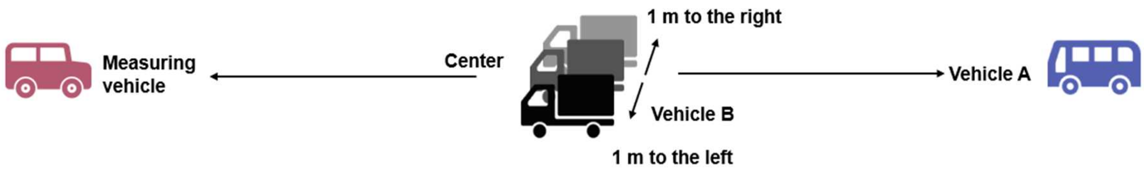


Fig. 3.4.3-3 Illustration of evaluation

Table 3.4.3-3 Reference measurement around 75 m

Location of vehicle B	1 m to the left	Center	1 m to the right
Max PAR[%]	100.0	66.0	84.8
Min PAR[%]	99.8	28.2	73.2

From the results in Table 3.4.3-3 it can be seen that PAR is improved compared with PAR of the center when shifted 1 m to the left and right. From this, it can be inferred that there is influence of multipath caused by radio waves transmitted from vehicle A hitting vehicle B.

As for the result in Demonstration (1) where PAR decreases sharply at a distance of around 40 to 60 m between vehicle A and vehicle B, PAR can be considered to have been affected by the multipath by vehicle B because PAR was 100% in a situation where vehicle B was not placed, whereas PAR decreased sharply when vehicle B was placed.

When considering actual operation, the influence of shadowing and multipath are expected to be even more complex in areas such as urban areas where vehicles are congested and structures around roads vary significantly. Therefore, in addition to radio communication resource control by the lower layers, it is necessary to control wireless communication congestion at a higher level based on the local communication environment, traveling vehicle environment, etc.

3.4.4 Demonstration (2) Impact of communication congestion due to communication volume

In Demonstration (2) the impact of communication congestion with communication volume was evaluated in a real environment. Three vehicles were placed and two signal posts were installed to measure communication performance.

(1) Demonstration item

In this demonstration, three vehicles are placed near an intersection. Three vehicles and two signal posts each transmit and receive to measure PAR and RSSI between a light van and a small bus.

Communication performance of communication terminals, except for light vans and small buses, is conformed when the communication traffic is varied.

An overview diagram of evaluation is shown in Fig. 3.4.4-1, and the evaluation conditions are shown in Table 3.4.4-1. Note that signal post A simulates the oncoming vehicle information in c-2-2, and other terminals simulate and transmit the own vehicle information in c-2-1. Signal post B was also considered to be a following vehicle of the measuring vehicle, and transmission of own vehicle information was simulated and transmitted.

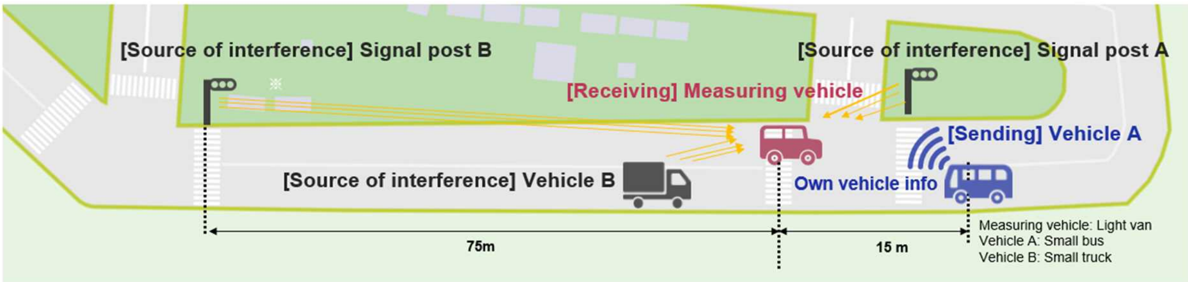


Fig. 3.4.4-1 Overview diagram of Demonstration (2)

Table 3.4.4-1 Evaluation conditions of Demonstration (2)

Condition	Measuring vehicle (light van)	Vehicle A (small bus)	Vehicle A (small truck)	Signal post A	Signal post B
Transmission packet length [byte]	283	283	283	896	283
Transmission cycle [ms]	100	100	100	100	100
Distance from measuring vehicle [m]	-	15	15	10	75

Desktop calculations (estimations) of resource occupancy were performed according to the following procedure.

- Calculate the size of user data that can be sent per SubCH.
- Calculate the number of SubCH required based on the size of packets sent by each terminal.
- Calculate the number of Subframes required for all terminals.
- Calculate resource occupancy from the ratio of 100 ms (100 Subframes) to the number of Subframes derived in the upper row.

(2) Evaluation results

Evaluation results are shown in Fig. 3.4.4-2. The vertical axis shows RSSI [dBm] and PAR [%], and the horizontal axis shows resource occupancy. Also, RSSI measurement values are shown in Table 3.4.4-2.

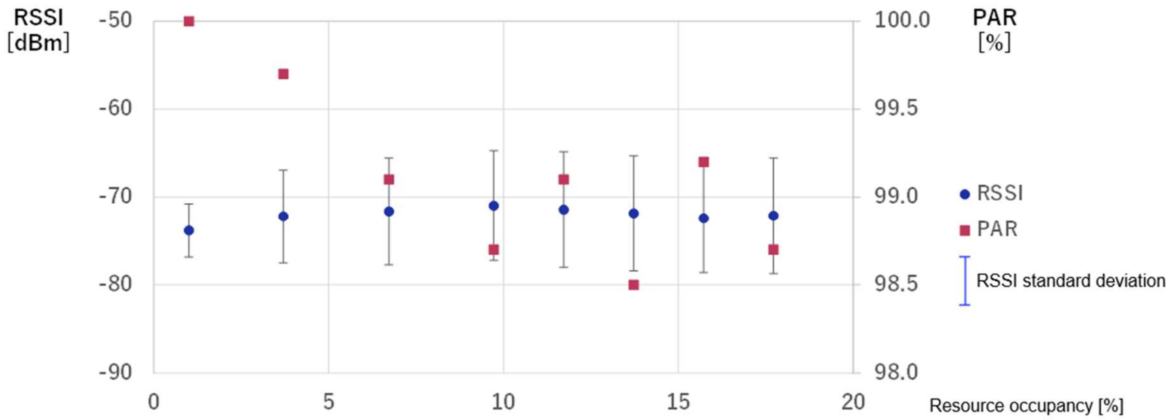


Fig. 3.4.4-2 Measurement results of Demonstration (2)

Table 3.4.4-2 RSSI measurement values of Demonstration (2)

Resource occupancy	Average [dBm]	Standard deviation
1.0%	-72.14	6.57
3.7%	-72.44	6.17
6.7%	-71.87	6.55
9.7%	-71.42	6.58
11.7%	-70.98	6.25
13.7%	-71.64	6.07
15.7%	-72.21	5.28
17.7%	-73.82	3.03

(3) Evaluation/analysis

As a result of the measurements in Demonstration (2), the following were obtained.

- RSSI

  As resource occupancy increased, the fluctuation rate of RSSI increased.

- PAR

  As resource occupancy increased, PAR decreased slightly.

RSSI values are in the range of -70 dBm to -80 dBm when looking at just median values, similar to the results obtained in the preliminary measurements; but in Demonstration (2), packet loss occurs as resource occupancy increases. Regarding this phenomenon, it is believed that packet collisions occur when transmitting the desired packets due to the increased frequency of transmission from surrounding vehicles and signal posts.

When considering actual operation, communication is expected to be even more congested in areas where vehicles are crowded, such as urban areas. Therefore, in addition to radio communication resource control by the lower layers, it is necessary to control wireless communication congestion at a higher level based on the local communication environment, traveling vehicle environment, etc.

3.5 Summary of verification/demonstration results

Simulation was performed under the traveling vehicle environment (number of vehicles, interval) assumed in actual operation in accordance with the communication scenario for a use case in which communication congestion is assumed, and communication performance based on the C-V2X/PC5 specification was confirmed. In addition, the impact of shadowing and the impact of communication congestion caused by communication traffic were measured in the demonstration as actual measurement of the wireless communication environment, which was an uncertain factor in verification.

In actual operation, the wireless communication environment (shadowing, multipath, etc.) and the traveling vehicle environment cannot be uniquely identified or limited. When communication occurs in an environment different from that expected, communication is congested, and as a result, communication delay and communication failure may occur.

Two proposed countermeasures in response to the above are discussed below.

(1) Communication congestion control at a higher level

As shown in Fig. 3.5-1, in addition to communication congestion control at the communication layer, communication congestion control at a higher level depending on the wireless communication environment and the traveling vehicle environment can be performed to reduce the impact of communication congestion.

Communication congestion control at a higher level is being studied in the U.S. and Europe ahead of other countries, and examples of communication congestion control being studied at the SAE (Society of Automotive Engineers), 5GAA (5G Automotive Association), and ETSI（European Telecommunications Standards Institute) are shown in Table 3.5-1.

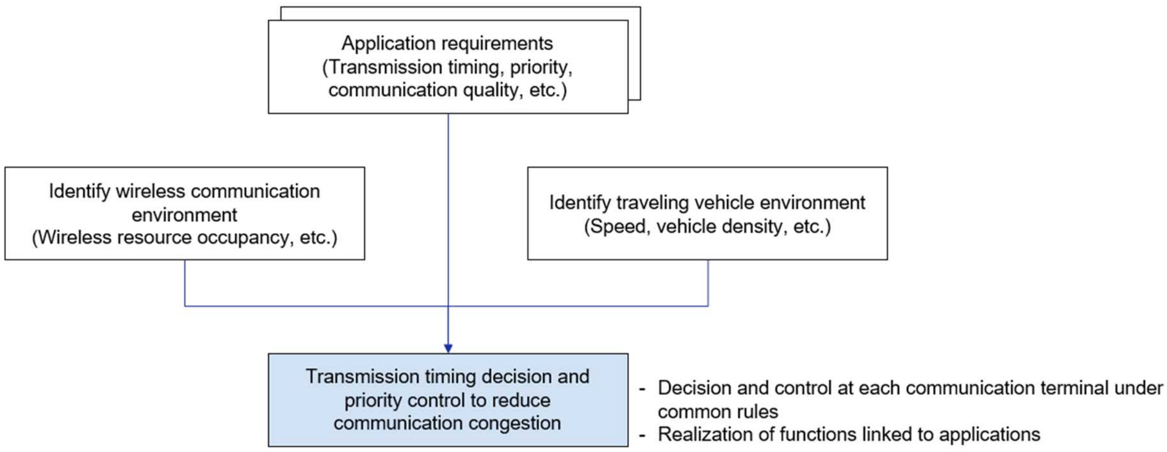


Fig. 3.5-1 Communication congestion control at a higher level

Table 3.5-1 Examples of communication congestion control of individual study organizations

Study organization	Related document	Overview
SAE	J2945/1 (March 2016) On-Board System Requirements for V2V Safety Communications 6.3.8 BSM Scheduling and Congestion Control (BSMCONGCTRL)	• Regulations for communication congestion control against BSM • BSM transmission interval (basic 100 ms cycle) varied (interrupted when critical events occur) based on channel busy ratio (CBR), packet error rate (PER), etc.
5GAA	P-180092 (October 2018) V2X Functional and Performance Test	• Effectiveness of the above communication congestion control verified in LTE-V2X
ETSI	EN302 637-2 v1.4.1 (April 2019) Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service	• Regulation on CAM transmission interval: 100 ms to 1 s range • Variation in transmission interval based on position change (4 m), speed change (±0.5m/s), etc., since the last transmission compared with the default transmission interval • Application of communication congestion control at a higher level (TS103 574, etc.)
ETSI	TS 103 574 (November 2018) Congestion Control Mechanisms for the C-V2X PC5 interface; Access layer part	• Communication congestion control regulation related to LTE-V2X (ITS-G5 is a separate regulation) • Resource usage limits based on channel busy ratio (CBR) • Message priority considered in resource specification limits

(2) Allocation of communication channels

By allocating communication channels according to communication area (lane, inbound or outbound lanes, etc.) or communication content, the impact of communication congestion can be expected to be reduced.

(a) Examples of allocating communication channels by communication area

The traveling vehicle environment (vehicle speed and vehicle concentration) may differ per lane and roadway. Therefore, communication channels are allocated by dividing the communication area per lane and roads to avoid the impact of communication congestion on surrounding roads. Examples of allocating communication channels by communication area are shown in Fig. 3.5-2 and Fig. 3.5-3.

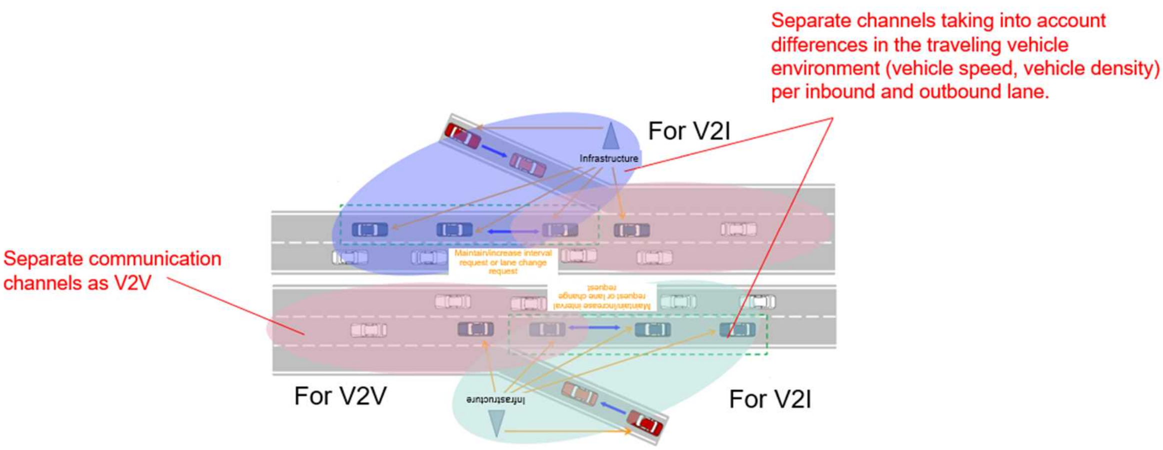


Fig. 3.5-2 Allocation by area example (1)

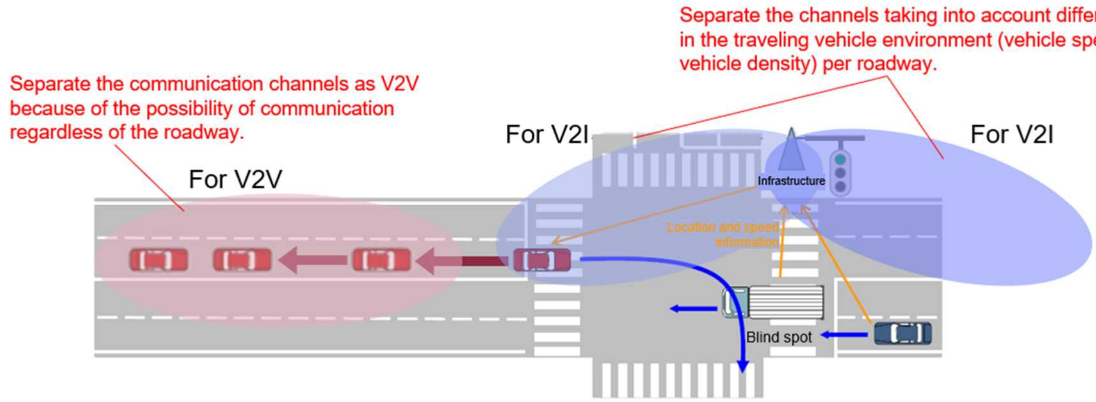


Fig. 3.5-3 Allocation by area example (2)

(b) Examples of allocating communication channels by communication content

Since communication requirements (communication delay, communication quality, etc.) differ by communication content in a use case, communication channels are allocated for each communication content, so communication congestion does not impact other communication.

Examples of allocating communication channels by communication content are shown in Table 3.5-2.

Table 3.5-2 Examples of allocating communication channels by communication content

Category	Content	Example of applicable message
Broadcast communication in fixed cycle	• Broadcast communication with a fixed cycle under certain conditions • Loss and delays of fixed cycle data are acceptable for some applications.	• a-1-1,2,3 ：Mainline vehicle location information (I -> V) • b-1-1: Traffic signal phase and timing information (I -> V) • c-1,2,3: Own vehicle information (V -> V) • c-2-1: Oncoming vehicle information (V -> V) • c-2-2: Oncoming vehicle information (I -> V) • g-1,2: Adaptive cruise control related information (V -> V)
Broadcast communication in event triggers	• Broadcast communication with a fixed cycle for a fixed period of time triggered by the occurrence of an event • Has time constraints between event occurrence and transmission. • Loss of fixed cycle data is acceptable for some applications.	• c-1, 2, 3: Own vehicle information (emergency) (V -> V) • e-1: Emergency vehicle approach information (V -> V)
Two-way communication in control	• Communication for a fixed period of time triggered by the occurrence of an event, etc. • Requires response to request • Has limit to response time on the requesting side	• a-1-3: Agreement request/Agreement response (V⇔I) • a-1-4,a-2,3 Agreement request/Agreement response (V⇔ V)

For reference, an example of allocation based on communication content, which is being studied at the C2C-CC (CAR 2 CAR Communication Consortium) in Europe ahead of other countries, is shown in Fig. 3.5-4.

Table 2: European V2X spectrum needs for safety in 5.9 GHz

Safety spectrum needs for a single short-range V2X communication technology in MHz bandwidth, in 5.9 GHz safety band

message type	environment urban	suburban	Rural (Highway)	min number of 10 MHz Channels
CAM cooperative awareness message	9	10	10	0,9
DENM decentralized environmental notification message	4	2	1	0,1
SPATEM signal phase and timing, **MAPEM** road/lane topology and traffic maneuver , **IVI** in-vehicle-information and other I2V messages	1	1	1	0,5
VAM VRU awareness message	4	0,2	2	0,5
PCM platooning control message	3	6	10	1,0
CPM collective perception message	23	26	24	2,0
MCM maneuver coordination message	23	26	24	2,0
Minimum basic spectrum needs in MHz	**67**	**72**	**72**	
total number of 10 MHz channels required				**7**

CAM : Cooperative Awareness Message
DENM : Decentralized Environmental Notification Message
SPATEM : Signal, Phase, and Timing Message
MAPEM : road/lane topology and traffic maneuver Message
IVI : in-vehicleinformation and other I2V Message
VAM : Vulnerable Road User (VRU) Awareness Message
PCM : Platooning Control Message
CPM : Collective Perception Message
MCM : Manoeuvre Coordination Message

Fig. 3.5-4 Example of allocation at C2C-CC [24]

[24]Source: C2CCC TR2050 Version 2.0 02-26-2020

4. Formulation of a roadmap for the social implementation of communication technologies necessary for realizing an automated driving society

4.1 Overview of roadmap formulation

4.1.1 Study procedure

The study in this part was carried out according to the flow shown in Fig. 4.1.1-1.

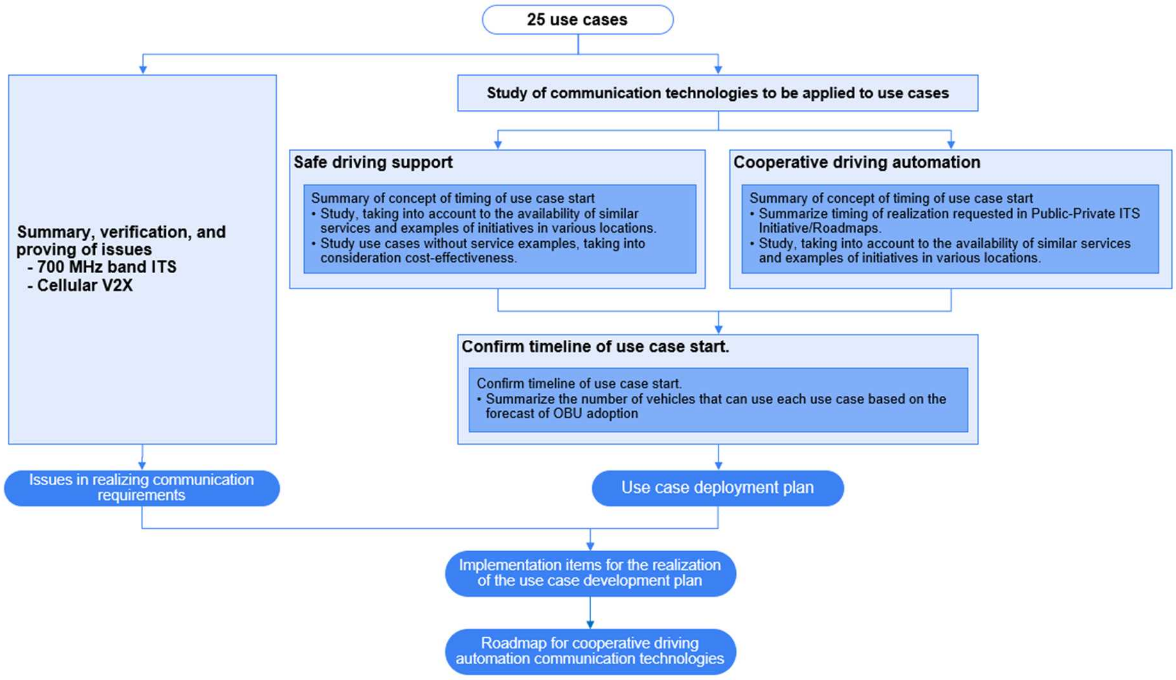


Fig. 4.1.1-1 Study procedure

4.1.2 Overview of implementation

In March 2020, "SIP cooperative driving automation use cases" was issued by the SIP Phase 2 Task Force on V2X Communication for Cooperative Driving Automation. That document defines 25 use cases for cooperative driving automation. In order to realize these use cases, new communication technologies as well as those currently in practical use in Japan are thought to be necessary.

Therefore, in this study, a roadmap for a cooperative driving automation communication technology was considered by the following three steps.

1) Based on the plans already formulated and examples of efforts in various locations, set a timeframe for the realization of each use case and organize a "use case deployment plan" that lists the schedule for realization in chronological order.
2) Organize items needed to realize the deployment plan, taking into account the issues in realizing the communication requirements of the use case.
3) Cooperation among multiple stakeholders, including vehicle manufacturers, traffic administrators, roadway administrators, and telecommunication providers, is essential to realize new communication and to put use cases into practical application. Therefore, implementation items for practical use are compiled as a "roadmap for a cooperative driving automation communication technology."

4.2 Survey of trends necessary for roadmap formulation

At SIP, use cases used in cooperative driving automation and safe driving support projects in Europe, the U.S., and Asia (including Japan) were investigated and collected in the “Study of utilization of new communication technologies including V2X technology to automated driving system” (1) conducted in FY 2018. In Japan, use cases for expressways and use case for general roads have been studied by the Japan Automobile Manufacturers Association (JAMA) and used as reference in considering these use cases.

In response to this, the TF aimed to propose future communication technologies and communication resources, selecting from among the collected use cases those that have potential for practical application in the future. The selection criteria are shown in 1) and 2), below.

1) Take into account preconditions for considering a cooperative driving automation system

The following preconditions for considering a cooperative driving automation system are placed as follows, and those that meet the preconditions are selected as SIP use cases.

a) All traffic participants must comply with laws and regulations.

Reason: Realization of a function to avoid accidents caused by intentional violation of traffic laws by surrounding traffic participants would require the cooperative driving automation system to bear excessive performance and cost burdens.

b) Do not include use cases that can be realized by a cooperative driving automation system

Reason: A cooperative driving automation system based on an autonomous driving system is realized, so functions that can be realized by the autonomous driving system will be redundant functions, and the possibility of practical application as a cooperative driving automation system is thought to be low.

2) Meet the definition of a cooperative driving automation system

The following three items were set as SIP use case selection requirements based on the cooperative driving automation system definition established in the TF.

(1) Information outside the detection range of on-board sensors must be obtained
(2) Information of one’s own vehicle must be provided
(3) V2V and I2V interaction must be ensured

The use cases collected in this way were sorted per selection requirement (three requirements), and categorized into eight functions from a to h (a. Merging / lane change assistance, b. Traffic signal information, c. Lookahead information: Collision avoidance, d. Lookahead information: Trajectory change, e. Lookahead information: Emergency vehicle notification, f. Information collection / distribution by infrastructure, g. Platooning / adaptive cruise control, h. Remote control) to facilitate a bird's-eye view of the entire process. The use cases classified are shown in Table 4.2-1, Table 4.2-2, and Table 4.2-3.

Table 4.2-1 SIP use cases (1) Use cases in which information outside the detection range of sensors must be obtained (1/2)

Classification by function	Use case	Overview
a. Merging / lane change assistance	a-1-1. Merging assistance by preliminary acceleration and deceleration	Information such as the speed of vehicles traveling on the mainline at the measurement points on the mainline and the estimated time of arrival at the merge point is provided from the infrastructure to merging vehicles to support preliminary acceleration and deceleration.
	a-1-2. Merging assistance by targeting the gap on the mainline	Continuously measured information on the location and speed of vehicles traveling on the mainline is continuously provided from the infrastructure to merging vehicles to assist in merging by targeting gaps between vehicles traveling on the mainline.
b. Traffic signal information	b-1-1. Driving assistance by using traffic signal information (V2I)	Current traffic signal color and traffic signal phase and timing information (the next traffic signal color and the time until change), etc., at intersections is provided by the roadside infrastructure to vehicles that enter intersections to assist deceleration and stopping, and thereby avoid a dilemma.
	b-1-2. Driving assistance by using traffic signal information (V2N)	Traffic signal phase and timing information (the next traffic signal color and the time until change), etc., of traffic signals at intersections is provided via a network to vehicles that enter intersections to assist deceleration and stopping, and thereby avoid a dilemma.
c. Lookahead information: collision avoidance	c-1. Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly	Sudden braking information as well as location and speed information are provided by the suddenly decelerating vehicle to following vehicles to encourage them to stop or slow down in advance, thereby preventing pileups.
	c-2-1. Driving assistance based on intersection information (V2V)	Location and speed information of vehicles that approach intersections is provided by approaching vehicles to other vehicles that approach or pass through intersections to assist them to pass through or make a right turn at intersections with many blind spots.
	c-2-2. Driving assistance based on intersection information (V2I)	Location and speed information of vehicles that approach intersections, which is obtained from roadside sensors or vehicles, is provided by the infrastructure to other vehicles that approach or pass through intersections to assist them to pass through or make a right turn at intersections with many blind spots.
	c-3. Collision avoidance assistance by using hazard information	Emergency hazard information is sent to following vehicles when an automated driving vehicle performs emergency deceleration or emergency lane change, thereby supporting smooth avoidance control for following vehicles.

Table 4.2-1 SIP use cases (1) Use cases in which information outside the detection range of on-board sensors must be obtained (2/2)

Classification by function	Use case	Overview
d. Lookahead information: Trajectory change	d-1. Driving assistance by notification of abnormal vehicles	Event information (broken down vehicle, accident vehicle, etc.) and location information (section located, lane) of abnormal vehicles stopped on the road is provided from the infrastructure to surrounding vehicles or from abnormal vehicles to surrounding vehicles to support early lane change and trajectory change.
	d-2. Driving assistance by notification of wrong-way vehicles	Information on the location and speed of wrong-way vehicles and the presence of the wrong-way vehicles is provided from the infrastructure to surrounding vehicles to encourage them to change lanes, etc., in advance to assist in collision avoidance.
	d-3. Driving assistance based on traffic congestion information	Traffic congestion information obtained from vehicles in congestion is provided from the infrastructure to surrounding vehicles to assist driving.
	d-4. Traffic congestion assistance at branches and exits	Information (location and speed) on shoulder congestion is provided from the infrastructure to mainline vehicles to assist them in entering branches.
	d-5. Driving assistance based on hazard information	Obstacle, construction, congestion, and other information is provided from the infrastructure to surrounding vehicles to assist driving.
e. Lookahead information: Emergency vehicle notification	e-1. Driving assistance based on emergency vehicle information	Information on the direction of movement and speed of emergency vehicles and their planned route (planned travel lane) is provided from emergency vehicles to surrounding vehicles to encourage surrounding vehicles to slow down or stop, etc., to support smooth passage of the emergency vehicle.

Table 4.2-2 SIP use cases (2) Use cases in which information of one's own vehicle must be provided

Classification by function	Use case	Overview
f. Information collection / distribution by infrastructure	f-1. Request for rescue (e-Call)	Rescue information is sent from vehicles involved in accident or other abnormal vehicles to the infrastructure to request rescue.
	f-2. Collection of information to optimize the traffic flow	Information on the location and speed of the traveling vehicles is collected via the infrastructure for traffic volume analysis and optimization.
	f-3. Update and automatic generation of maps	Information collected by vehicles is collected by the infrastructure to update and automatically generate map data.
	f-4. Distribution of dynamic map information	Dynamic map information is provided from the infrastructure to vehicles.

Table 4.2-3 SIP use cases (3) Use cases in which V2V and I2V interaction must be ensured

Classification by function	Use case	Overview
a. Merging / lane change assistance	a-1-3. Cooperative merging assistance with vehicles on the mainline by roadside control	Information on the location and speed of vehicles traveling on the mainline measured in a planar manner is provided from the infrastructure to merging vehicles and instruction on adjusting interval between vehicles, etc., is given from the infrastructure to vehicles traveling on the mainline to assist in merging.
	a-1-4. Merging assistance based on negotiations between vehicles	When merging onto a congested mainline, the mainline vehicle and the merging vehicle communicate their location and speed information, request to adjust interval between vehicles, etc., to support merging through vehicle-to-vehicle negotiation.
	a-2. Lane change assistance when the traffic is heavy	When changing lanes to a congested lane, location, and speed information as well as lane change intentions are communicated between vehicles to assist in lane changes.
	a-3. Entry assistance from non-priority roads to priority roads during traffic congestion	At intersections without traffic signals, information on location and speed, as well as the intention to enter, is communicated between vehicles near the intersection to provide driving assistance for entering priority roads from non-priority roads.
g. Platooning / adaptive cruise control	g-1. Unmanned platooning of following vehicles by electronic towbar	Operational information and other information on platooning vehicles is communicated between the trucks forming the column to support platooning (electronic towbar).
	g-2. Adaptive cruise control and manned platooning of following vehicles using adaptive cruise control	Location, speed, driving operation information of the vehicle ahead, etc., are communicated to the vehicle behind to support adaptive cruise control.
h. Remote control	h-1. Operation and management of mobility service cars	In traffic environments where avoidance is difficult with an autonomous driving system, video information, etc., from mobility service cars and remote control instructions from the operation manager are communicated between the operation manager and the mobility service car to operate and manage the vehicle from a remote location.

In cooperative driving automation, communication occurs between multiple participating entities and the equipment owned and operated by those entities. In addition, automation of cooperative driving requires information sharing that contributes to improved safety, efficiency, and reliability, and cooperation among diverse stakeholders beyond the boundaries of the public and private sectors is important to realize that. The use cases envisioned by each stakeholder differ in terms of space-time and spatial axis. Thus, strategic standardization and unification of awareness are essential to realize the automation of cooperative driving automation in such an environment.

For example, in J3216, the U.S. SAE classifies and defines M2M communication that enables cooperative driving. It defines Cooperative Driving Automation (CDA) as “automation of cooperative driving, in which M2M communication enables multiple entities to cooperate with each other for the purpose of moving with high safety and efficiency”.

J3216 also defines four CDA classifications as CDA Class. CDA Class definitions are shown in Table 4.2-4, and an example of Class C is shown in Fig. 4.2-1.

Table 4.2-4 CDA Class definitions [25]

Class	Class A	Class B	Class C	Class D
Name	Status-sharing cooperation	Intent-sharing cooperation	Agreement-seeking cooperation	Prescriptive cooperation
Overview	Provide location and perceptual information of own vehicle for other vehicles to utilize.	Provide other entities with information about actions scheduled be taken in the future, and have the entities use that in their driving, etc.	Influence the planning of specific driving actions through the exchange of messages between specific CDA devices.	Send instructions and orders to specific traffic participants to perform urgent driving tasks or to perform specific tasks by roadway administrators.
Phrase	Here I am, and hear is what I see	That is what I plan to do	Let's do this together	I will do as directed
Example	• Speed of own vehicle and vehicle immediately ahead is transmitted to vehicle behind to optimize traffic flow and ensure safe driving. • Information on approaching pedestrians is received from RSU to assist own vehicle passing through intersection.	• Intention of own vehicle to change lanes (or merge) is sent and an environment created that facilitates lane changes (merging) by surrounding vehicles that receive this information. • RSU transmits signal information to create a situation where vehicles traveling can safely pass through the intersection.	• Vehicle (1) communicates intention to change lanes to vehicles (2) and (3), and vehicles (2) and (3) either accept the request and create a situation where lane change is possible or reject the request (see figure below).	• Information on road closures and speed limits is transmitted in response to accident information, and surrounding vehicles drive accordingly. • Emergency vehicles send information on their approach to surrounding vehicles to make it easier for them to pass, or they to control traffic signals.

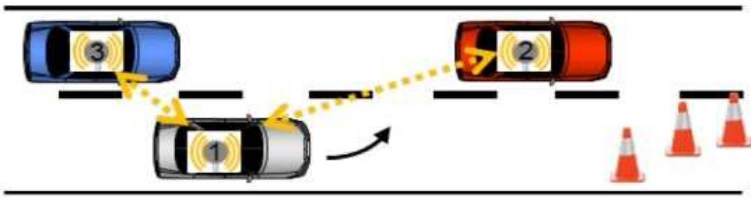


Fig. 4.2-1 CDA Class C example (example of Vehicle 1 communicating its intentions to Vehicles 2 and 3 to form an agreement to change lanes)[26]

In J3216 automation features for Cooperative Driving Automation Features (CDA Features) are also being organized. The features that facilitate coordination among traffic participants are defined as supporting cooperative driving, enabling cooperative driving or being special design-specific functionality for coordinated operation through M2M coordination among CDA devices. An overview of the two types, supporting and enabling, which require coordination by a number of entities, is shown in Table 4.2-5.

[25] Source: SAE "Taxonomy and Definitions for Terms Related to Cooperative Driving Automation for On-Road Motor Vehicle" P. 6 https://www.sae.org/standards/content/j3216_202005/
[26] Source: SAE "Taxonomy and Definitions for Terms Related to Cooperative Driving Automation for On-Road Motor Vehicle" P. 6 https://www.sae.org/standards/content/j3216_202005/

Table 4.2-5 Overview of Supporting CDA Feature and Enabling CDA Feature[27]

Name	Supporting CDA Feature (CDA Feature "supporting" cooperative driving)	Enabling CDA Feature (CDA Feature "enabling" cooperative driving)
Overview	• The objective is to augment operations and tasks performed by road users and roadway administrators.	• The objective is to facilitate road users and roadway administrators so they can operate and perform tasks. • "With this feature, automobiles and roadway administrators are able to perform actions they would not have been able to perform without the feature."
Example	• The vehicle that reaches the intersection first detects the presence of a pedestrian attempting to cross the crosswalk and provides that information to another vehicle approaching the intersection (which detects the presence of some "object" in the crosswalk, but does not know if it is a pedestrian or not), thereby promoting safe passage. • The autonomous vehicle communicates with the RSU at the intersection and receives SpaT information, thereby passing through the intersection at the optimal speed.	• The vehicle that reaches the intersection first detects the presence of a pedestrian attempting to cross the crosswalk and provides that information to another vehicle approaching the intersection (blind spots exist, making it impossible to see what the situation at the crosswalks), thereby promoting safe passage. • Information such as speed and travel interval in platooning is exchanged. • To perform merging at expressway entrances, M2M communication is used to communicate between mainline vehicles and merging vehicles so as not to affect traffic flow on the mainline.

In light of these trends in studies outside Japan, this study classified the use cases organized by SIP and the TF based on the following two considerations.

- Study of communication technologies applicable to use cases
- Study of use cases by function (cooperative driving automation and safe driving support)

[27] Source: Prepared from SAE "Taxonomy and Definitions for Terms Related to Cooperative Driving Automation for On-Road Motor Vehicle" P. 8 https://www.sae.org/standards/content/j3216_202005/

4.2.1 Study of communication technologies to be applied to use cases

In considering the communication technologies to be applied to the use cases, the following three use case images were assumed in order to group the use cases.

- Use cases that target specific locations and require immediacy and reliability, such as automated driving control and traffic control
- Use cases that require immediacy and reliability, such as collision avoidance
- Use cases where time delays are acceptable, such as alerts and information provision

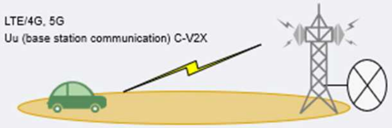
The 25 SIP use cases assumed in each use case image are organized as shown in Fig. 4.2.1-1.

Use case image	Assumed SIP use case	
• Use cases that target specific locations and require immediacy and reliability, such as automated driving control and traffic control	a-1-1. Merging assistance by preliminary acceleration and deceleration a-1-2. Merging assistance by targeting the gap on the mainline a-1-3. Cooperative merging assistance with vehicles on the mainline by roadside control b-1-1. Driving assistance by using traffic signal information (V2I) c-2-2. Driving assistance based on intersection information (V2I)	
• Use cases that require immediacy and reliability, such as collision avoidance	a-1-4. Merging assistance based on negotiations between vehicles a-2. Lane change assistance when the traffic is heavy a-3. Entry assistance from non-priority roads to priority roads during traffic congestion c-1. Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly c-2-1. Driving assistance based on intersection information (V2V)	c-3. Collision avoidance assistance by using hazard information e-1. Driving assistance based on emergency vehicle information g-1. Unmanned platooning of following vehicles by electronic towbar g-2. Adaptive cruise control and manned platooning of following vehicles using adaptive cruise control
• Use cases where time delays are acceptable, such as alerts and information provision	b-1-2. Driving assistance by using traffic signal information (V2N) d-1. Driving assistance by notification of abnormal vehicles d-2. Driving assistance by notification of wrong-way vehicles d-3. Driving assistance based on traffic congestion information d-4. Traffic congestion assistance at branches and exits d-5. Driving assistance based on hazard information	e-1. Driving assistance based on emergency vehicle information f-1. Request for rescue (e-Call) f-2. Collection of information to optimize the traffic flow f-3. Update and automatic generation of maps f-4. Distribution of dynamic map information h-1. Operation and management of mobility service cars

Fig. 4.2.1-1 Uses case images assumed and SIP use case response organization

There are three major types of communication methods that form the premise for SIP: (1) vehicle to infrastructure (V2I), (2) vehicle to vehicle (V2V), and (3) vehicle to network (V2N) communication, each with its own characteristics. The characteristics of each communication technology are organized and the possible use case images each communication technology is applied to are shown in Table 4.2.1-1.

Table 4.2.1-1 Communication technology characteristics and possible use case images they are applied to

Communication technology	Characteristic		Possible use case image that communication technology may be applied to
	Pros	Cons	
V2I Communication through infrastructure operated by service provider ARIB STD T109 ARIB STD T75 IEEE802.11p (WAVE) PC5 (direct communication) C-V2X 	• In practical application. Demonstrated to provide signal information, etc. • Service can be reliably deployed at the installation location. • Communication delays can be identified.	• Limited to service only where infrastructure is installed. • Not suitable for large-volume communication.	• Use cases that target specific locations and require immediacy and reliability, such as automated driving control and traffic control
V2V Direct communication between vehicles ARIB STD T109 IEEE802.11p (WAVE) PC5 (direct communication) C-V2X 	• In practical application • Communication delays can be identified.	• Service opportunities not available unless OBU becomes more widely adopted. • Not suitable for large-volume communication.	• Use cases that require immediacy and reliability, such as collision avoidance
V2N Communication through telecommunication services provided by carrier LTE/4G, 5G Uu (base station communication) C-V2X  *Including cases were coverage is ensured by multiple base stations	• DCM expected to be adopted. • One-to-one or one-to-many communication possible. • In addition to roadside and vehicle sensor information, new value-added information can be provided by data held by servers on network. • Large-volume communication possible.	• Although loopback communication (MEC) and data priority control (QoS) within the network are being studied, there is no guarantee of always-on callability, bandwidth, or latency. • Different telecommunication carriers have different communication performance. • There is a possibility that service cannot be provided due to network-side congestion or communication failures. • The same service is provided by multiple telecommunication carriers (communication resource waste).	• Use cases where time delays are acceptable, such as alerts and information provision

For each use case of SIP, some may be realized with different communication technologies from those assumed above or by linking multiple communication technologies, depending on the assumed scenario, system requirements, and progress in technologies for communication. On the other hand, in order to derive a use case deployment plan, the communication technologies to be applied to the use case need to be assumed. Therefore, in this study, we proceeded based on that assumption after receiving confirmation from the TF.

For reference, a summary of the relationship between driving support systems and the communication technologies described above in the ISO's ITS Technical Committee Intelligent Transport Systems' Working Group Vehicle/Roadway Warning and Control Systems (ISO/TC204/WG14) is shown in Fig. 4.2.1-2.

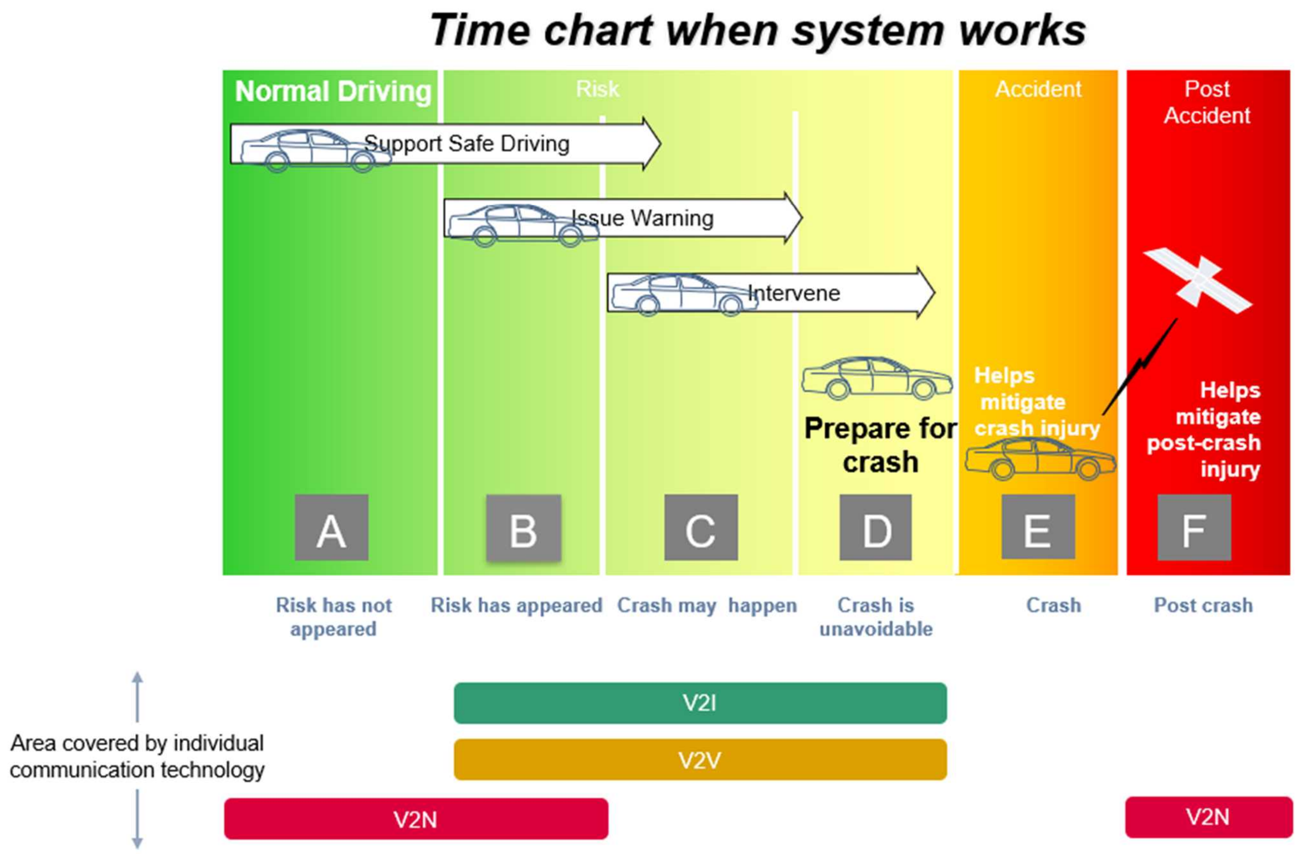


Fig. 4.2.1-2 (Reference) Possible areas of application of driving support and communication technologies in ISO/TC204/WG14

4.2.2 Use cases beneficial to safe driving support

(1) Selection of use cases that contribute to safe driving

Use cases related to safe driving support selected based on the aforementioned assumptions are as follows.

1) Use cases where V2I communication is assumed

- Driving assistance by using traffic signal information (b-1-1)
- Driving assistance based on intersection information (c-2-2)

2) Use cases where V2V communication is assumed

- Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly (c-1)
- Driving assistance based on intersection information (c-2-1)
- Collision avoidance assistance by using hazard information (c-3)
- Driving assistance based on emergency vehicle information (e-1)

3) Use cases where V2N communication is assumed

- Driving assistance by using traffic signal information (b-1-2)
- Lookahead information: Trajectory change (d-1, d-2, d-3, d-4, d-5)
- Driving assistance based on emergency vehicle information (e-1)
- Request for rescue (e-Call) (f-1)
- Collection of information to optimize the traffic flow (f-2)
- Update and automatic generation of maps (f-3)
- Collection of information to optimize the traffic flow (f-4)

(2) Forecast adoption of OBU

In this study, we forecasted the adoption of V2X-supported OBU from 2025 to 2040 based on the actual number of current OBU such as DCMs (Data Communication Modules) and ITS Connect.

The materials referred to in conducting the adoption forecast and the preconditions in the forecast study are shown in Fig. 4.2.2-1. The number of DCM-equipped vehicles for use of V2N services was studied based on the telematics diffusion forecast conducted by Fuji Keizai in 2021, and the number of vehicles with V2I/V2V OBU was studied based on the actual sales figures of ITS Connect in 2020.

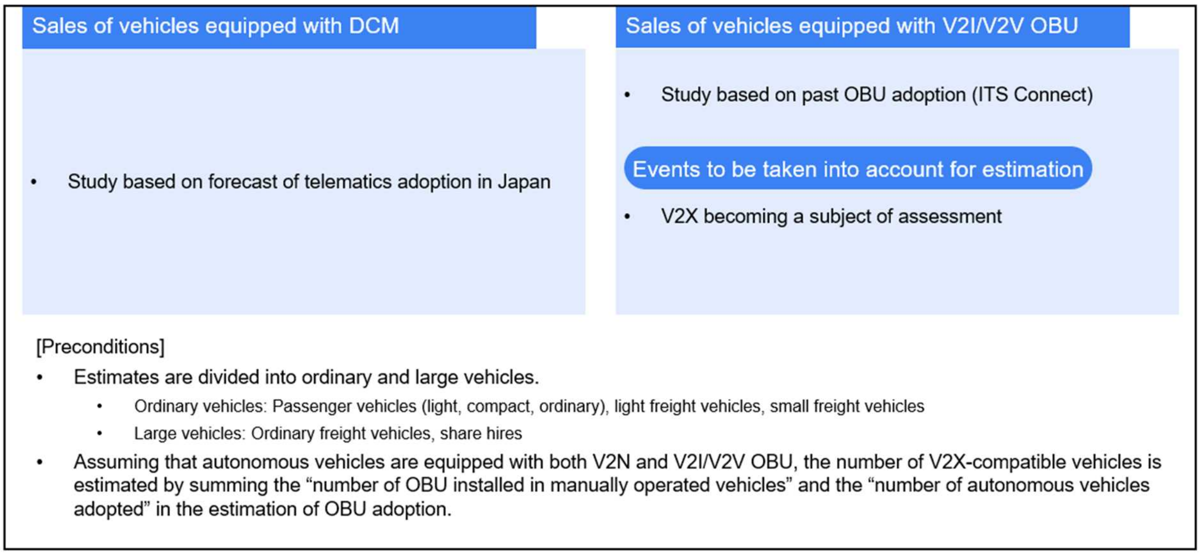


Fig. 4.2.2-1 Items considered in forecast of OBU adoption and assumed preconditions

The forecast for adoption described in this section is based on the estimation of the number of vehicles with OBU, which is divided into two categories: regular vehicles and large vehicles, and large vehicles in particular are assumed to be mainly freight vehicles such as commercial trucks and mobility service vehicles such as buses.

(a) Single-year sales forecast for DCM-equipped vehicles

In forecasting the adoption and development of DCM-equipped vehicles related to the use of V2N services, “Future Outlook for Connected Car, V2X, and Automated Driving Related Markets 2021” published by Fuji Keizai was referenced.

In other words, the number of DCM-equipped vehicles (excluding automated vehicles) sold was assumed in this study by multiplying the “single-year sales of connected cars in new passenger cars and commercial vehicles” and the “percentage of all connected cars with on-board cellular” in the relevant data. As described in the preconditions of Fig. 4.2.2-1, single-year sales volume of DCM-equipped vehicles was forecast for ordinary and large vehicles, assuming passenger cars and commercial vehicles in this document to be the ordinary vehicles and large vehicles respectively in this study.

The single-year sales volume forecast for V2N-supported vehicles was obtained by adding the resulting single-year sales volume forecast for DCM-equipped vehicles and the single-year sales volume forecast for automated vehicles, also discussed in section 4.2.3(2), as shown in Fig. 4.2.2-2 and Fig. 4.2.2-3.

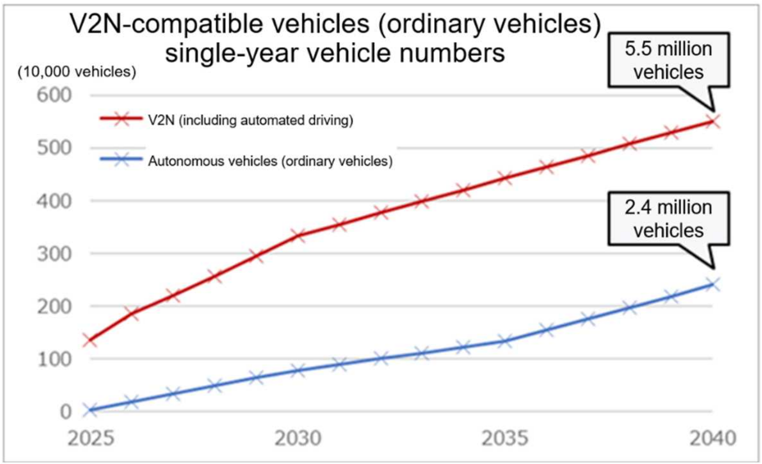


Fig. 4.2.2-2 Forecast single-year sales of V2N-supported ordinary vehicles (DCM-equipped vehicles and automated vehicles)

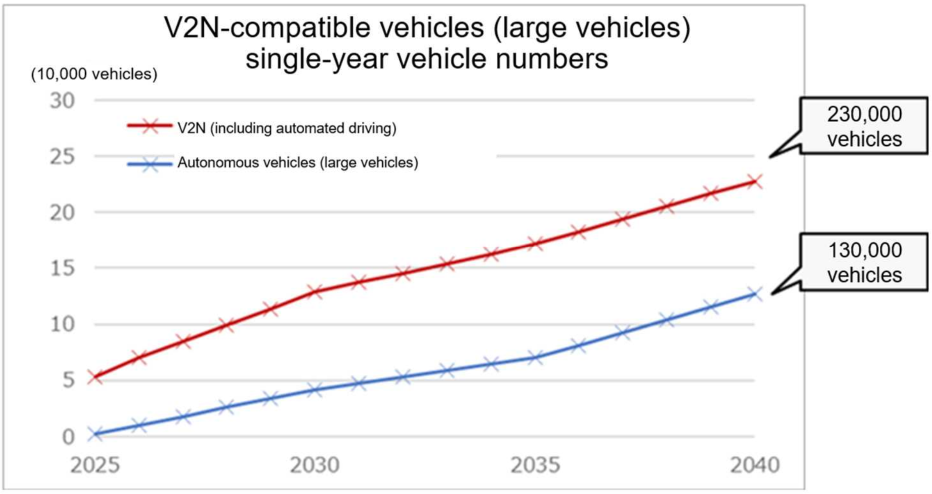


Fig. 4.2.2-3 Forecast single-year sales of V2N-supported large vehicles (DCM-equipped vehicles and automated vehicles)

(b) Single-year sales forecast for V2I/V2V-supported vehicles

In this study, it was assumed that V2I/V2V-supported OBU will be adopted on the same scale as ITS Connect in terms of number of units. At the Ministry of Internal Affairs and Communications "Radio Policy Roundtable in the Age of Digital Transformation (4th meeting)", it was assumed given that the adoption volume of ITS Connect launched in 2015 is reported to be 210,000 units as of 2020, that the single-year sales volume of ITS Connect would trend upward each year linearly as shown in Fig. 4.2.2-4.

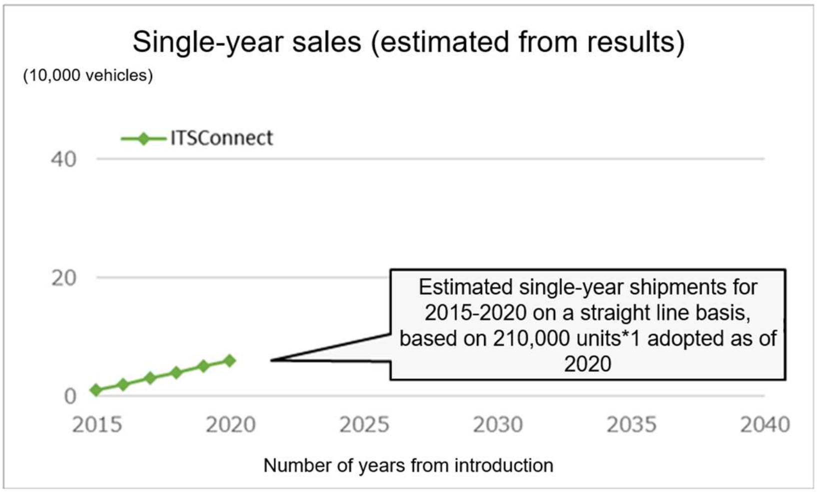


Fig. 4.2.2-4 ITS Connect 2015 to 2020 single-year sales (estimated from 2020 results)[28]

Based on the above two assumptions, and assuming that the sales of V2I/V2V-supported OBU will increase linearly with the single-year sales volume shown in Fig. 4.2.2-4 until 2040, the number of ordinary and large vehicles equipped with V2I/V2V-supported OBU is expected to increase in accordance with the trends shown in Fig. 4.2.2-5 and Fig. 4.2.2-6. Here, Fig. 4.2.2-6 assumes that 95% of the vehicles equipped with V2I/V2V OBU are ordinary vehicles and 5% are large vehicles, and the values on the vertical axis of the graph are the ratio of each to the total number of V2I/V2V OBU sold multiplied by the total number of vehicles sold.

[28] Source for *1 in figure: "Necessity of ITS Wireless" (prepared by ITS Japan), Ministry of Internal Affairs and Communications Radio Policy Roundtable in the Age of Digital Transformation (4th meeting)

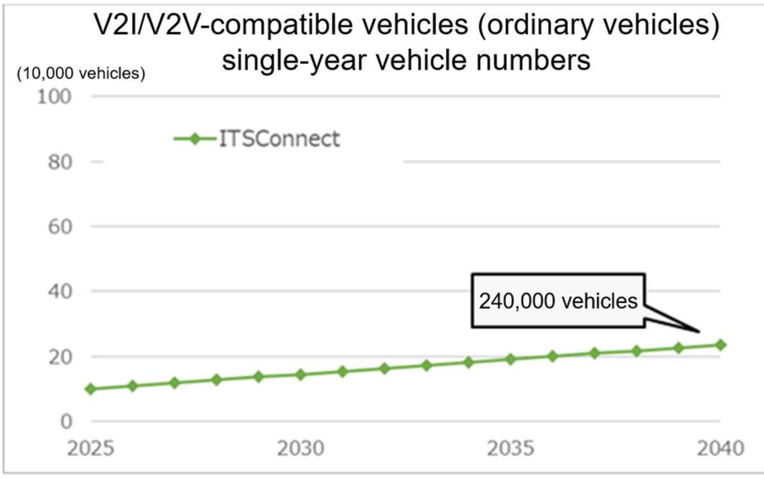


Fig. 4.2.2-5 V2I/V2V OBU-equipped ordinary vehicle single-year volume increase forecast

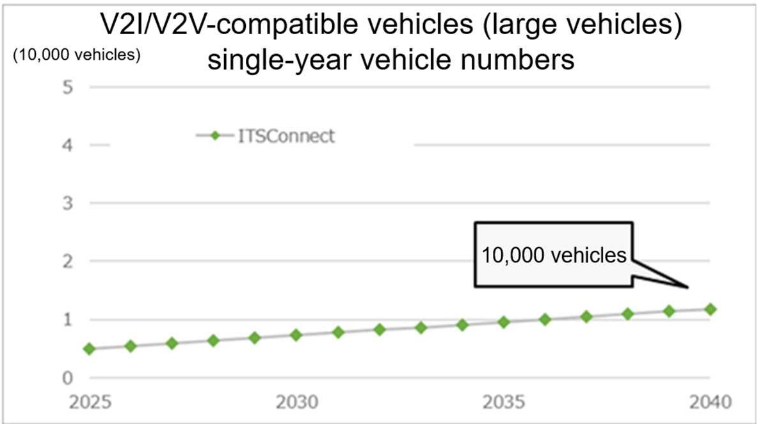


Fig. 4.2.2-6 V2I/V2V OBU-equipped large vehicle single-year volume increase forecast

The forecast increase in the volume of vehicles with V2I/V2V OBU shown in Fig. 4.2.2-5 and Fig. 4.2.2-6 is modeled based solely on the number of ITS Connect vehicles adopted as of 2020. In actuality, however, the adoption of V2V/V2I OBU is assumed to further accelerate when safety evaluation standards for V2X technology are established in the future. Therefore, in this study, the timing of V2X becoming a subject of assessment is assumed to be 2030, and the rate of adoption of OBU is assumed to increase after that time.

In making this assumption, the number of new passenger cars equipped with collision damage reduction brakes is shown in Fig. 4.2.2-7 as an example of safe driving technology whose adoption has been accelerated by the establishment of safety evaluation standards. In this example, braking performance for vehicles was added as a safety evaluation item in for vehicles 2014 and for daytime pedestrians in 2016, and the rate of increase in the number of vehicles equipped (slope of the transition curve) increased approximately fivefold around 2014 to 2016 due to this impact.

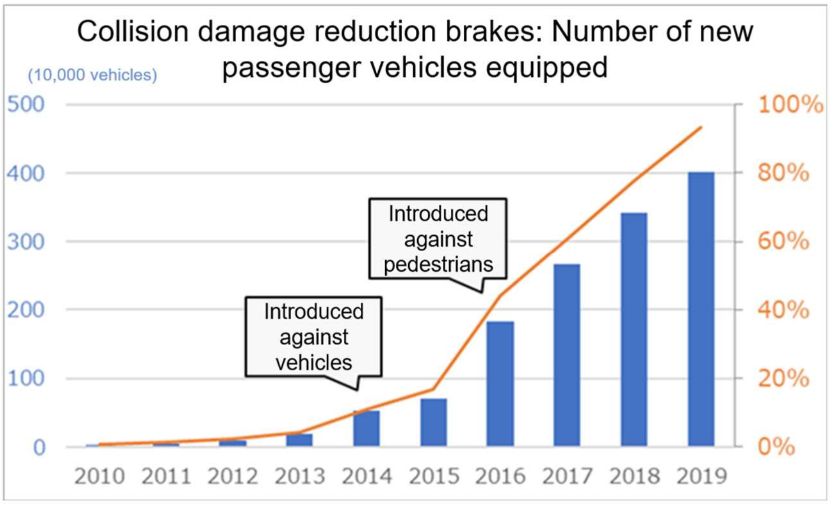


Fig. 4.2.2-7 Collision damage reduction brakes: Number of new passenger vehicles equipped[29]

Taking the example above into consideration, assuming that V2I/V2V vehicles will increase fivefold after V2X becomes a subject of assessment in 2030, the rate of increase of vehicles with V2I/V2V OBU shown in Fig. 4.2.2-5 and Fig. 4.2.2-6 will be adjusted to the graphs shown in Fig. 4.2.2-8 and Fig. 4.2.2-9.

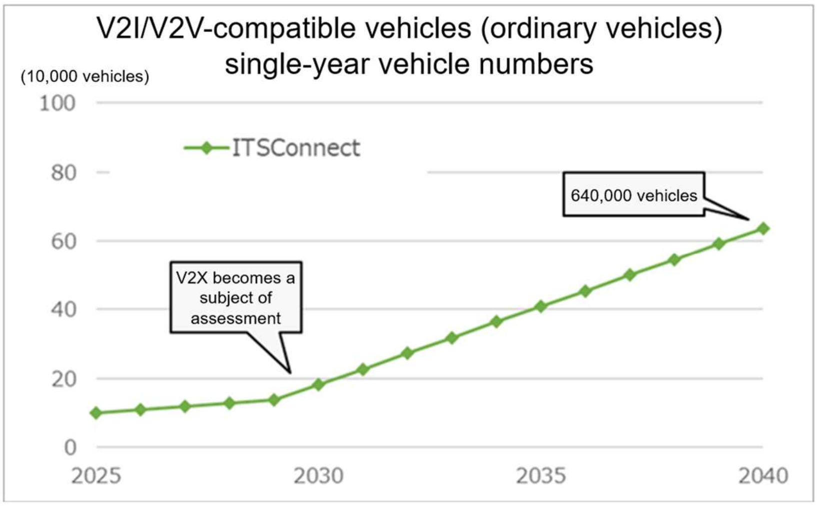


Fig. 4.2.2-8V2I/V2V OBU-equipped ordinary vehicle single-year volume increase forecast (taking into consideration V2X becoming a subject of assessment)

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[29]Source: Ministry of Land, Infrastructure, Transport and Tourism, “Advanced Safety Vehicle (ASV) Technology Adoption Survey 2010-2020”

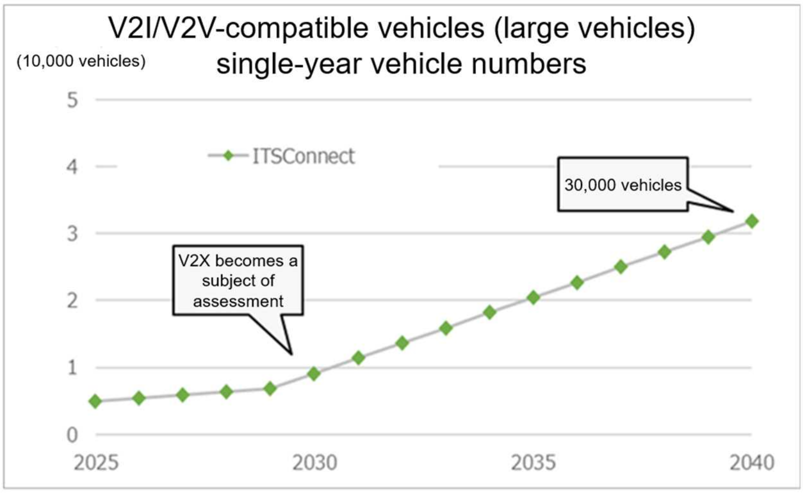


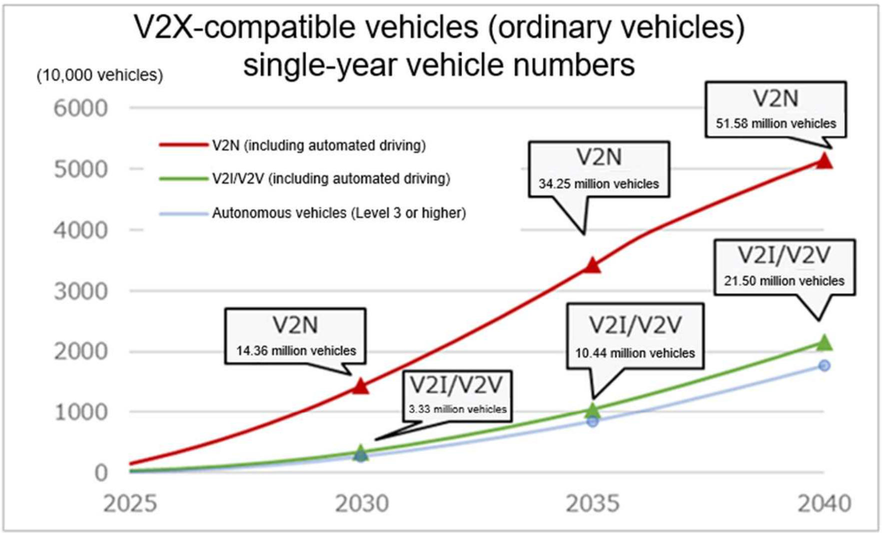
Fig. 4.2.2-9 V2I/V2V OBU-equipped large vehicle single-year volume increase forecast (taking into consideration V2X becoming a subject of assessment)

The adoption volume of V2I/V2V-supported vehicles in the following sections is estimated based on the single-year volume increase forecast shown in Fig. 4.2.2-8 and Fig. 4.2.2-9.

(c) Number of vehicles adopting OBU and forecast adoption rate

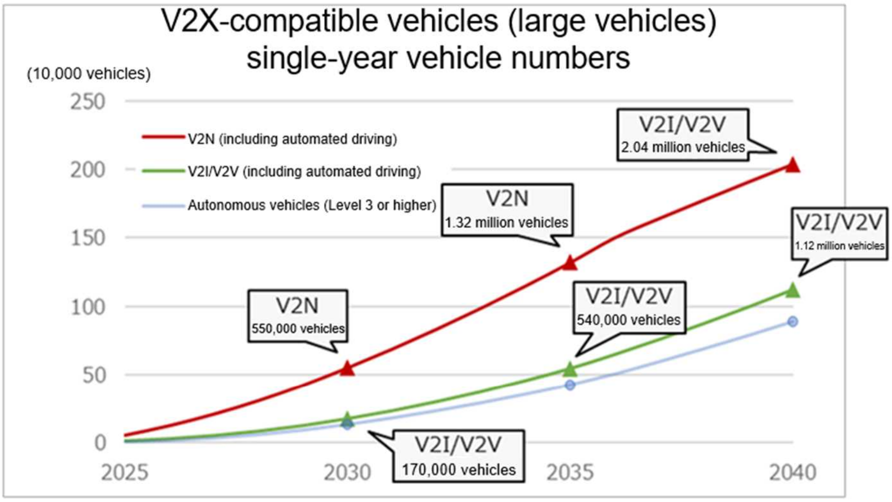
In the previous section, the single-year sales volume of DCM-equipped vehicles and V2I/V2V-equipped vehicles related to the use of V2N services was estimated. By adding up these results and the single-year automated vehicles sales volume covered in section 4.2.3(2), the number of V2N- and V2I/V2V-supported vehicles in circulation in Japan—the number of vehicles adopted - was estimated as shown in Fig. 4.2.2-10 and Fig. 4.2.2-11.

In calculating the number of vehicles adopted, this study assumed that the number of years between the purchase of a new OBU and automated vehicle and replacement is 12 years. The adoption figures shown in Fig. 4.2.2-10 and Fig. 4.2.2-11are the sum of single-year sales figures for the past 12 years for the graphs of single-year sales figures shown in Fig. 4.2.2-2 and Fig. 4.2.2-3 and in Fig. 4.2.2-8 and Fig. 4.2.2-9



Ordinary vehicles (including automated driving)		2025	2030	2035	2040
V2N	DCM	1.44 million	14.36 million	34.25 million	51.58 million
V2I/ V2V	ITS Connect	210,000	3.33 million	10.44 million	21.50 million
Remarks	V2X becomes a subject of assessment from 2030				

Fig. 4.2.2-10 V2X-supported ordinary vehicle adoption volume forecast (sum of single-year sales figures for past 12 years)



Large vehicles (including automated driving)		2025	2030	2035	2040
V2N	DCM	60,000	550,000	1.32 million	2.04 million
V2I/ V2V	ITS Connect	10,000	170,000	540,000	1.12 million
Remarks	V2X becomes a subject of assessment from 2030				

Fig. 4.2.2-11 V2X-supported large vehicle adoption volume forecast (sum of single-year sales figures for past 12 years)

The forecasts for the adoption volume of V2X-supported vehicles (OBU-equipped vehicles and automated vehicles) are as shown in Fig. 4.2.2-10 and Fig. 4.2.2-11, but in this study the adoption of driver notification systems and vehicle control systems related to the realization of safe driving support were additionally forecast.

Among the V2X systems related to safe driving support, V2I/V2V use cases are assumed to involve the operation of systems that directly control vehicles for the purpose of accident prevention. However, such vehicle control systems are technically more difficult to implement than systems that notify drivers of received information, so their adoption and deployment is expected to be delayed to some extent.

Therefore, in this study, systems implemented in V2I/V2-supported vehicles are divided into two types, driver notification systems and vehicle control systems, as shown in Fig. 4.2.2-12, and it is assumed that the existence ratio of driver notification systems and vehicle control systems will gradually increase from 10:1 to 3:1 between 2025 and 2030. In making this assumption, the shipment ratio of Lane Departure Warning (LDW) and Lane Keep Assist (LKA) is referred to as examples of similar cases.

Concept of technical difficulty (vehicle technology viewpoint)

- The system receives information depending on the use case. The following two types of systems are assumed to exist.
  - Driver notification system : Systems that notify the driver of the received information via HMI
  - Vehicle control system : Systems that directly utilize the received information for vehicle control
- Based on the shipment ratio of LDW and LKA, it is assumed that the ratio of "driver notification systems" and "vehicle control systems" will change as follows after the start of the use case.

	LDW : LKA ratio
1st year	1.3 : 1
2nd year	12 : 1
3rd year	10 : 1
4th year	8 : 1
5th year	6 : 1
6th year	4 : 1
7th year and later	3 : 1

	Driver notification system: Ratio of vehicle control systems
1st year	10 : 1
2nd year	8 : 1
3rd year	6 : 1
4th year	4 : 1
5th year and later	3 : 1

Fig. 4.2.2-12 Assumptions on adoption of the V2X technologies that are driver notification systems and vehicle control systems[30]

By applying the assumptions in Fig. 4.2.2-12 to the adoption volume forecast shown in Fig. 4.2.2-10 and Fig. 4.2.2-11, the number of driver notification systems and vehicle control systems in V2I/V2V-supported vehicles can be calculated.

The forecast adoption rate obtained by dividing the adoption volume by the number of vehicles owned in Japan (assumed to be constant at 2019 levels of 59.99 million ordinary vehicles and 2.3 million large vehicles) as the denominator is shown in Fig. 4.2.2-13. According to this adoption rate forecast, approx. 40% of ordinary and large vehicles in Japan will support V2N and V2I/V2V in 2040. V2I/V2V-supported vehicles equipped with vehicle control systems are expected to account for approx. 10% of those.

[30] Source: LDA and KLA shipment ratios calculated from Ministry of Land, Infrastructure, Transport and Tourism, "Advanced Safety Vehicle (ASV) Technology Adoption Survey 2010-2020".

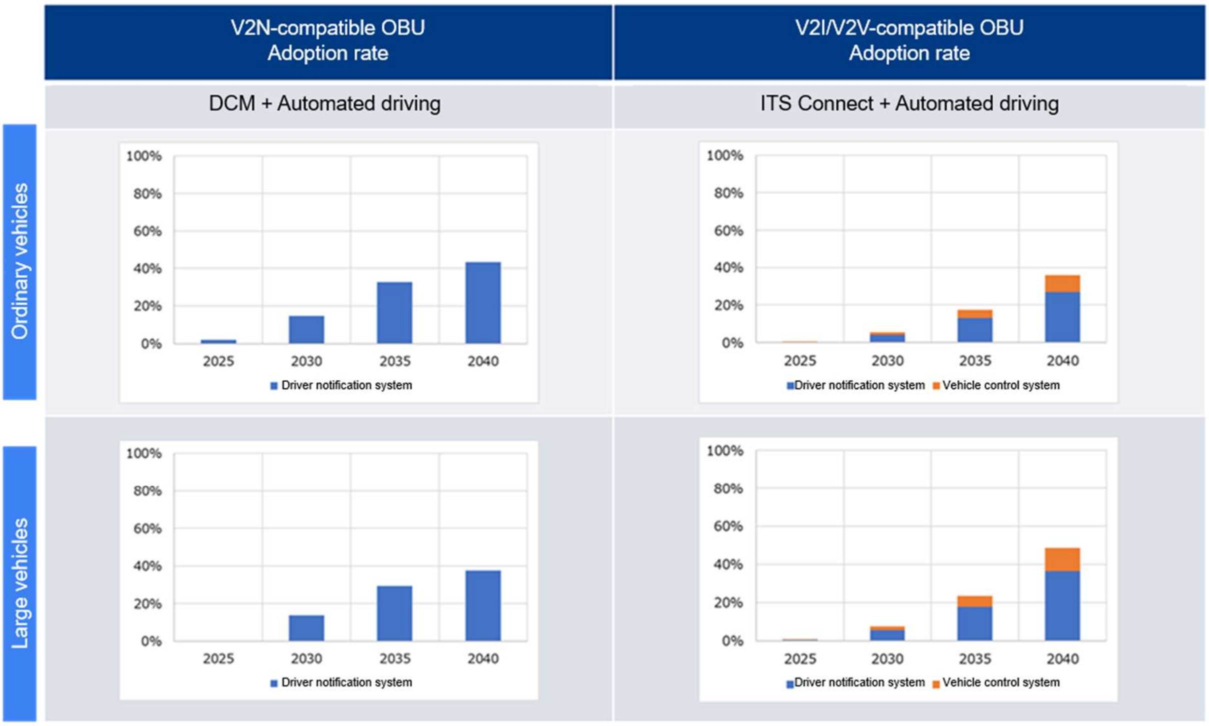


Fig. 4.2.2-13 V2N- and V2I/V2V-supported vehicle adoption forecast (by system)

(3) Concept of timing of use case start

(a) Concept of timing of use case start

Timing of use case start is assumed as below.

i) Use cases where V2I communication is assumed

- Driving assistance by using traffic signal information (b-1-1)

Service has already started to be provided by ITS Connect for some uses cases (red light alert and guidance on preparing to start when waiting at a traffic light), and realization is expected at an early stage based on the status of providing existing services.

- Driving assistance based on intersection information (c-2-2)

Service has already started to be provided by ITS Connect for some uses cases (right turn alert), and realization is expected at an early stage based on the status of providing existing services.

ii) Use cases where V2V communication is assumed

- Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly (c-1)

Although some services are being provided in locations such as outside Japan, study of technical verification of longitudinal avoidance assist technology, as well as institutional aspects such as liability dividing points and handling of insurance in the event of an accident is considered to be necessary.

- Driving assistance based on intersection information (c-2-1)

Service has already started to be provided by ITS Connect for some uses cases, and realization is expected at an early stage based on progress in demonstration testing and the like as well as the status of providing existing services.

- Collision avoidance assistance by using hazard information (c-3)

Since lane change assistance is also expected in addition to c-1, verification, etc., of technology for lateral direction avoidance assistance by changing lanes is necessary, and that is expected to be realized after c-1.

- Driving assistance based on emergency vehicle information (e-1)

Service has already started to be provided by ITS Connect for some uses cases, and realization is expected at an early stage based on progress in demonstration testing and the like.

iii) Use cases where V2N communication is assumed

- Driving assistance by using traffic signal information (b-1-2)

Realization is expected at an early stage based on trends in SIP R&D and other factors.

- Lookahead information: Trajectory change (d-1, d-2, d-3, d-4, d-5)

Quick and extensive deployment is expected, and it is assumed that service will begin in 2025 as effects can be expected from starting early.

- Driving assistance based on emergency vehicle information (e-1)

Service has already started to be provided by ITS Connect for some uses cases, and realization is expected at an early stage based on progress in demonstration testing and the like at SIP as well as the status of providing existing services.

- Request for rescue (e-Call) (f-1)

Service has already started to be provided by HELPNET for some uses cases, and realization is expected at an early stage based on progress in demonstration testing and the like.

- Collection of information to optimize the traffic flow (f-2)

Some similar services have already started by OEM, and realization is expected at an early stage based on progress in demonstration testing and the like.

- Update and automatic generation of maps (f-3)

Realization is expected after other “f” use cases because of the need for technical verification for realization.

- Collection of information to optimize the traffic flow (f-4)

Some similar services have already started by OEM, and realization is expected at an early stage based on progress in demonstration testing and the like.

4.2.3 Use cases beneficial to automated driving support

(1) Selection of use cases that contribute to automated driving

Use cases related to cooperative driving automation selected based on the aforementioned assumptions are as follows.

(a) Use cases where V2I communication is assumed

- Mainline merging assistance (a-1-1, a-1-2)
- Cooperative merging assistance with vehicles on the mainline by roadside control (a-1-3)
- Driving assistance by using traffic signal information (b-1-1)
- Driving assistance based on intersection information (c-2-2)

(b) Use cases where V2V communication is assumed

- Lane change/merging assistance by moderation (a-1-4, a-2, a-3)
- Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly (c-1)
- Driving assistance based on intersection information (c-2-1)
- Collision avoidance assistance by using hazard information (c-3)
- Driving assistance based on emergency vehicle information (e-1)
- Platooning (g-1, g-2)

(c) Use cases where V2N communication is assumed

- Driving assistance by using traffic signal information (b-1-2)
- Lookahead information: Trajectory change (d-1, d-2, d-3, d-4, d-5)
- Driving assistance based on emergency vehicle information (e-1)
- Request for rescue (e-Call) (f-1)
- Collection of information to optimize the traffic flow (f-2)
- Update and automatic generation of maps (f-3)
- Collection of information to optimize the traffic flow (f-4)
- Operation and management of mobility service cars (h-1)

(2) Forecast adoption of automated driving

Similar to the forecast adoption of OBU described in section 4.2.2(2)(c), this study forecast the adoption of automated vehicle in the most recent period, 2025 to 2040. The following describes the assumptions made and results obtained in the study related to forecast of adoption.

(a) Single-year sales forecast for automated vehicles

In forecasting the adoption of automated vehicles, “2020 Future Prospects for the Automated Driving and AI Car Market” published by Fuji Chimera Research Institute was referenced.

Since the materials include forecasts of single-year sales of automated vehicles (Level 3 or higher) from 2020 to 2045, in this study, linear interpolation of these trends into a graph for each year was used as shown in Fig. 4.2.3-1.

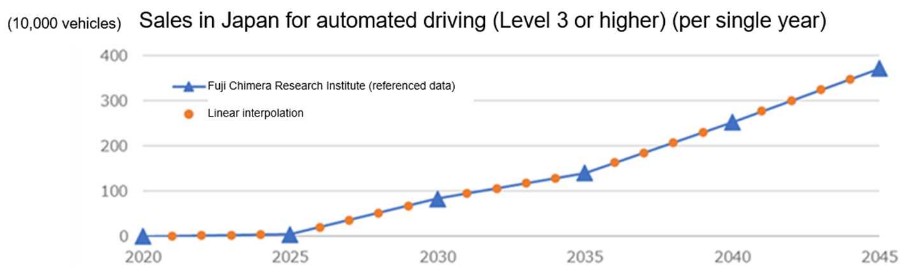


Fig. 4.2.3-1 Forecast for single-year sales of automated vehicles (Level 3 or higher)[31]

(b) Volume of automated vehicles adopted and forecast adoption rate

Adoption volume of ordinary and large vehicles in Japan between 2025 and 2040, calculated assuming that 95% of the single-year sales volume shown in Fig. 4.2.3-1 is for ordinary vehicles and the remaining 5% for ordinary vehicles, is shown in Fig. 4.2.3-2.

As mentioned in section 4.2.2(2)(c), the number of years between the purchase of a new vehicle and its replacement is assumed to be 12 years for autonomous vehicles, and the number of vehicles adopted is calculated as the sum of the single-year sales figures for the past 12 years.

[31]Source: Fuji Chimera Research Institute, “2020 Future Prospects for the Automated Driving and AI Car Market”

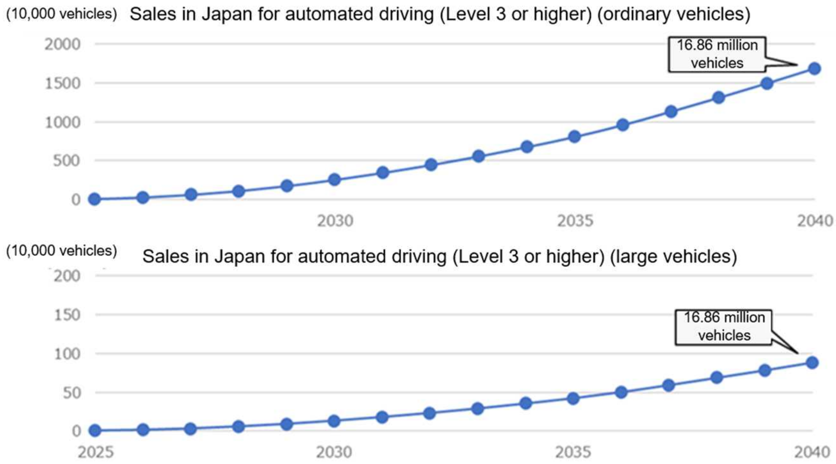
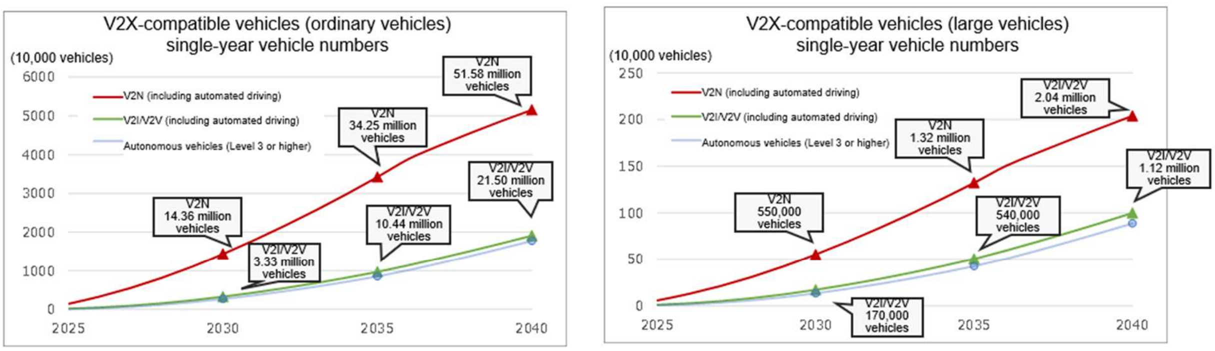


Fig. 4.2.3-2 Automated vehicles (Level 3 or higher) adoption volume forecast

The forecast for the number of V2X-supported vehicles is shown in Fig. 4.2.3-3, which combines the number of autonomous vehicles in section Fig. 4.2.3-2 and the number of vehicles adopting OBU in section 4.2.2(2)(c). The adoption rate of V2X-supported vehicles as a percentage of all ordinary and large vehicles in Japan from 2025 to 2040 is shown in Fig. 4.2.3-4.



Ordinary vehicles (including automated driving)		2025	2030	2035	2040
V2N	DCM	1.44 million	14.36 million	34.25 million	51.58 million
V2I/ V2V	ITS Connect	210,000	3.33 million	10.44 million	21.50 million
Remarks	V2X becomes a subject of assessment from 2030				

Ordinary vehicles (including automated driving)		2025	2030	2035	2040
V2N	DCM	60,000	550,000	1.32 million	2.04 million
V2I/ V2V	ITS Connect	10,000	170,000	540,000	1.12 million
Remarks	V2X becomes a subject of assessment from 2030				

Fig. 4.2.3-3 V2X-supported vehicle adoption volume forecast (reposted from Fig. 4.2.2-10)

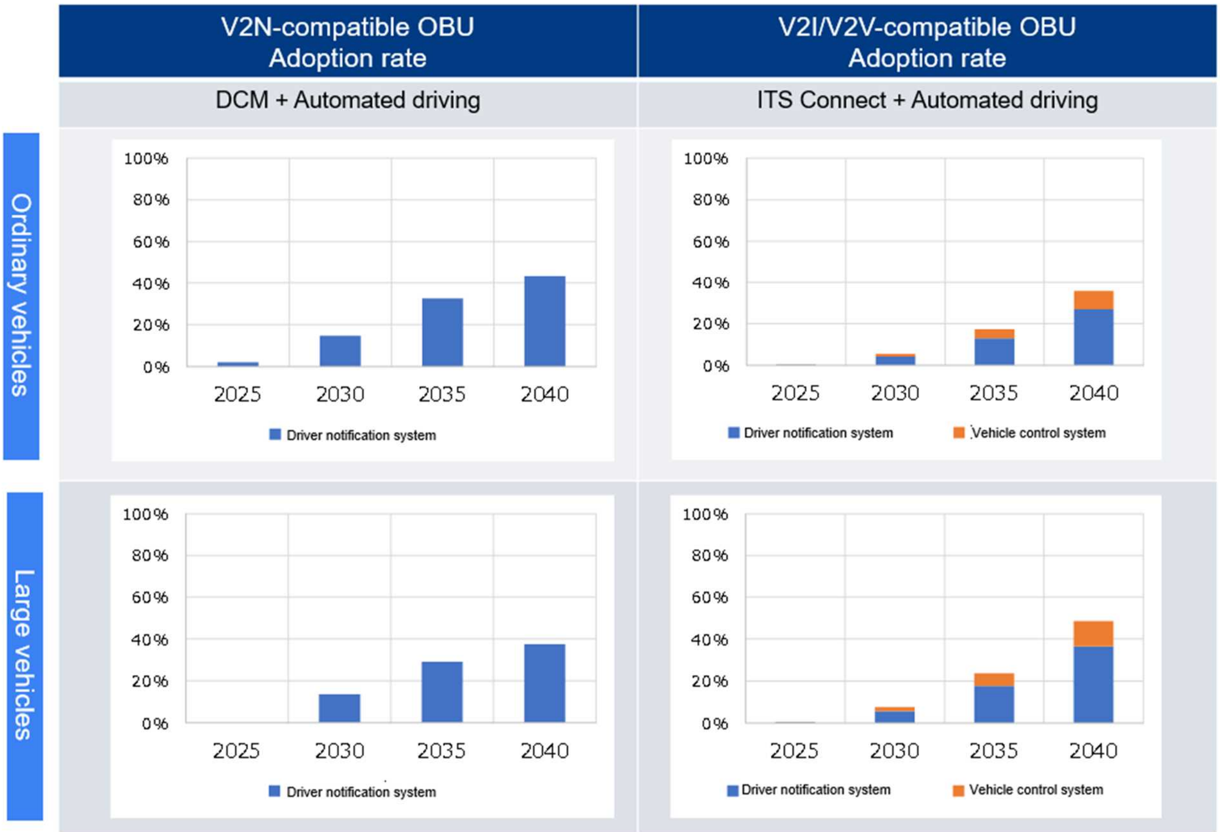


Fig. 4.2.3-4 V2N- and V2I/V2V-supported vehicle adoption rate forecast (reposted from Fig. 4.2.2-13)

(3) Concept of timing of use case start

The use cases being considered in SIP are use cases for social implementation of automated driving, but this does not mean that automated driving will not be put to practical use unless all of them are realized. In addition, some of the use cases do not require Level 3 or higher automated vehicles for them to be expected to be effective in reducing accidents.

For the selection of use cases necessary for cooperative driving automation, use cases considered to be the minimum necessary for practical application of automated driving were extracted from the descriptions in "Public-Private ITS Initiative/Roadmaps (2021)". The relationship between the relevant descriptions in "Public-Private ITS Initiative/Roadmaps (2021)" and the corresponding use cases is shown in Fig. 4.2.3-5.

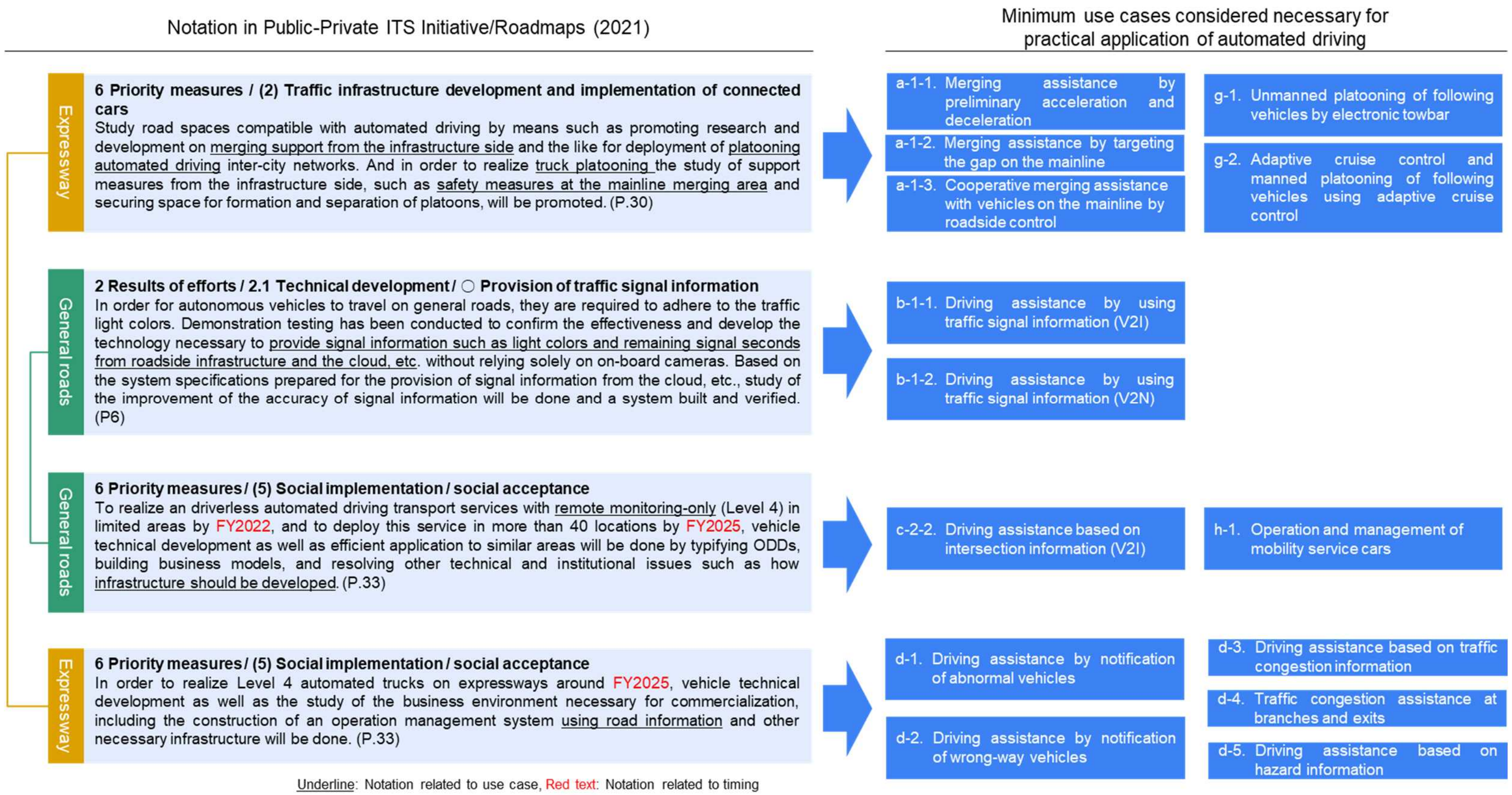


Fig. 4.2.3-5 Use cases extracted from Public-Private ITS Initiative/Roadmaps (2021)

While not mentioned in "Public-Private ITS Initiative/Roadmaps (2021)", merging assistance was extracted based on the assumption that it will continue to advance after 2030, the period covered by the Public-Private ITS Initiative/Roadmaps (2021) and that use cases that do not depend on infrastructure will also be realized. At the same time, it was assumed that the use cases shown in Fig. 4.2.3-6 would also be realized, since detecting the approach of an emergency vehicle is considered necessary for automated driving but difficult to do with autonomous sensors.

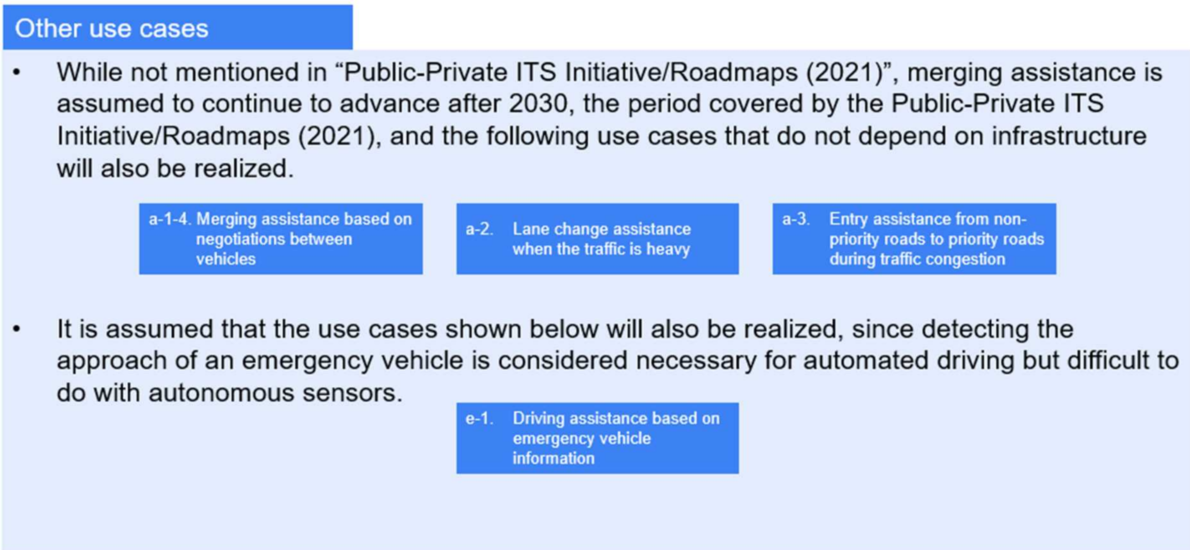


Fig. 4.2.3-6 Extraction of other use cases necessary for automated driving

Use cases that do not fall into the above are not limited to automated driving systems, but are assumed to be implemented as a safe driving support function for vehicles in which the driver takes the initiative in driving, leading to automated driving in the future.

The concept of when to start use cases related to cooperative driving automation that were studied based on these considerations is as follows.

(a) Use cases where V2I communication is assumed

- Mainline merging assistance (a-1-1, a-1-2)

Public-Private ITS Initiative/Roadmaps notes "realization of Level 4 automated driving of trucks on expressways around FY 2025", and realization of that is expected at an early stage in order to realize the service of mainline merging assistance toward the realization of the roadmap goals.

- Cooperative merging assistance with vehicles on the mainline by roadside control (a-1-3)

This is a use case that requires agreement to be reached between infrastructure and vehicle, and a certain adoption rate is necessary to realize the service. It is positioned by JAMA as a merging assistance Day 3 system, and is expected to be realized when the automated driving adoption rate reaches about 30%.

- Driving assistance by using traffic signal information (b-1-1)

  Public-Private ITS Initiative/Roadmaps notes “driverless automated driving transport services in limited areas may spread to 40 or more areas by the rough target of FY 2025”, and realization is expected at an early stage in order to achieve driverless automated driving transport services in limited areas.

- Driving assistance based on intersection information (c-2-2)

  Public-Private ITS Initiative/Roadmaps notes “driverless automated driving transport services in limited areas may spread to 40 or more areas by the rough target of FY 2025”, and realization is expected at an early stage in order to achieve driverless automated driving transport services in limited areas.

(b) Use cases where V2V communication is assumed

- Lane change/merging assistance by moderation (a-1-4, a-2, a-3)

  These are use cases where moderation and agreement formation are necessary, and a certain adoption rate is necessary to realize the service. They are positioned by JAMA as merging assistance Day 4 systems, and are expected to be realized when the automated driving adoption rate reaches about 50%.

- Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly (c-1)

  Public-Private ITS Initiative/Roadmaps notes “Goal for 2030: Achieve a safe and convenient digital transportation society that supports the affluent lifestyles of people, ahead of the rest of the world”, and realization is expected at about the same timing as realization of services as safe driving support.

- Driving assistance based on intersection information (c-2-1)

  Service has already started to be provided by ITS Connect for some uses cases, and realization is expected at an early stage based on progress in demonstration testing and the like as well as the status of providing existing services.

- Collision avoidance assistance by using hazard information (c-3)

  Since lane change assistance is also expected in addition to c-1, verification, etc., of technology for lateral direction avoidance assistance by changing lanes is necessary, and that is expected to be realized after c-1.

- Driving assistance based on emergency vehicle information (e-1)

  Service has already started to be provided by ITS Connect for some uses cases, and realization is expected at an early stage based on progress in demonstration testing and the like.

- Platooning (g-1, g-2)

  Public-Private ITS Initiative/Roadmaps notes “realization of Level 4 automated driving of trucks on expressways around FY 2025”, and similar services are undergoing demonstration testing by SIP and other organizations. Since this is necessary for the commercialization of platooning, realization is expected at an early stage in order to achieve the roadmap goals.

(c) Use cases where V2N communication is assumed

- Driving assistance by using traffic signal information (b-1-2)

  Realization is expected at an early stage based on trends in SIP R&D and other factors.

- Lookahead information: Trajectory change (d-1, d-2, d-3, d-4, d-5)

  Quick and extensive deployment is expected, and it is assumed that service will begin in 2025 as effects can be expected from starting early.

- Driving assistance based on emergency vehicle information (e-1)

  Service has already started to be provided by ITS Connect for some uses cases, and realization is expected at an early stage based on progress in demonstration testing and the like at SIP as well as the status of providing existing services.

- Request for rescue (e-Call) (f-1)

  Service has already started to be provided by HELPNET for some uses cases, and realization is expected at an early stage based on progress in demonstration testing and the like.

- Collection of information to optimize the traffic flow (f-2)

  Some similar services have already started by OEM, and realization is expected at an early stage based on progress in demonstration testing and the like.

- Update and automatic generation of maps (f-3)

  Realization is expected after other “f” use cases because of the need for technical verification for realization.

- Collection of information to optimize the traffic flow (f-4)

  Some similar services have already started by OEM, and realization is expected at an early stage based on progress in demonstration testing and the like.

- Operation and management of mobility service cars (h-1)

  Similar services are undergoing demonstration testing by SIP and other organizations. Since this is necessary for the practical application of mobile service vehicles with remote monitoring as assumed in the Ministry of Economy, Trade and Industry’s “RoAD to the L4,” realization is expected at an early stage.

4.2.4 Survey of trends outside Japan

This section describes trends outside Japan related to cooperative driving automation, which were used as reference in the study of the roadmaps.

Trends in the study of communication technologies for practical application of V2X among the overseas case examples surveyed are shown in Table 4.2.4-1. The projects that are studying the development of V2X and conducting demonstrations are shown in Table 4.2.4-2 and Table 4.2.4-3, and the items following those provide an overview of each of these case studies.

Note that the research projects in Table 4.2.4-3 are not used as a reference for the roadmap study due to bias in participating members and direction of study. However, since a roadmap of the introduction and adoption period for each V2X use case has been published, the details of the study are described here as reference information.

Table 4.2.4-1 Trends in the study of communication technologies for practical application of V2X

Country/region	Organization implementing	Trend	Scheduled completion
International	3GPP	Formulation of 3GPP Release 18	Within 2023
International	IEEE	Formulation of IEEE 802.11bd	Within 2022
USA	Federal Communications Commission (FCC)	Transition from 5.9 GHz band DSRC to C-V2X	Within 2024
Europe	Euro NCAP	V2X becoming a subject of assessment	Within 2024
Europe	C2C CC	Study advancement of ITS-G5	Unknown*1

*1 Information is available that implementation may be done after IEEE 802.11bd is formulated, but actual start/end date is unknown.

Table 4.2.4-2 V2X research projects in countries other than Japan

Country/region	Organization implementing	Project name	Remarks
USA	Department of Transportation, Federal Highway Administration (FHWA)	CARMA	Development of communication protocols related to the realization of V2X use cases
Europe	European Commission (EC)	Study by ERTRAC and DG MOVE	Adoption plan and roadmap for V2X use cases studied
Europe	European Commission (EC) Consortium of European Companies	C-Roads	Demonstration of V2X use cases and development of communication infrastructure promoted
China	Chinese government	Smart Car Innovation and Development Strategy	V2X development and adoption in China promoted
China	China Society of Automotive Engineers (China-SAE)	Technology Roadmap 2.0 for Energy-Saving and New Energy Vehicles	A direction of adhering to a pure electric vehicle-led development strategy is shown, and “six major overall technological goals” are presented for 2035.

Table 4.2.4-3 V2X research projects in countries other than Japan (examples excluded from this study)

Country/region	Organization implementing	Project name	Reason for exclusion
International	5GAA	Study by 5GAA	Study assumed use of C-V2X.
Europe	Conference of European Directors of Roads (CEDR)	MANTRA	Study was conducted without automotive and in-vehicle equipment manufacturers.

(1) Trends in telecommunication technology studies outside Japan

The following is a summary of the case studies of communication technologies shown in Table 4.2.4-1 and the sources of the various information.

(a) International: 3GPP

The latest (as of February 2022) study schedule for the 3GPP standard, which is the communication protocol underlying C-V2X, is shown in Fig. 4.2.4-1. In recent news, 3GPP Release 18 is expected to be formulated by the end of 2024.

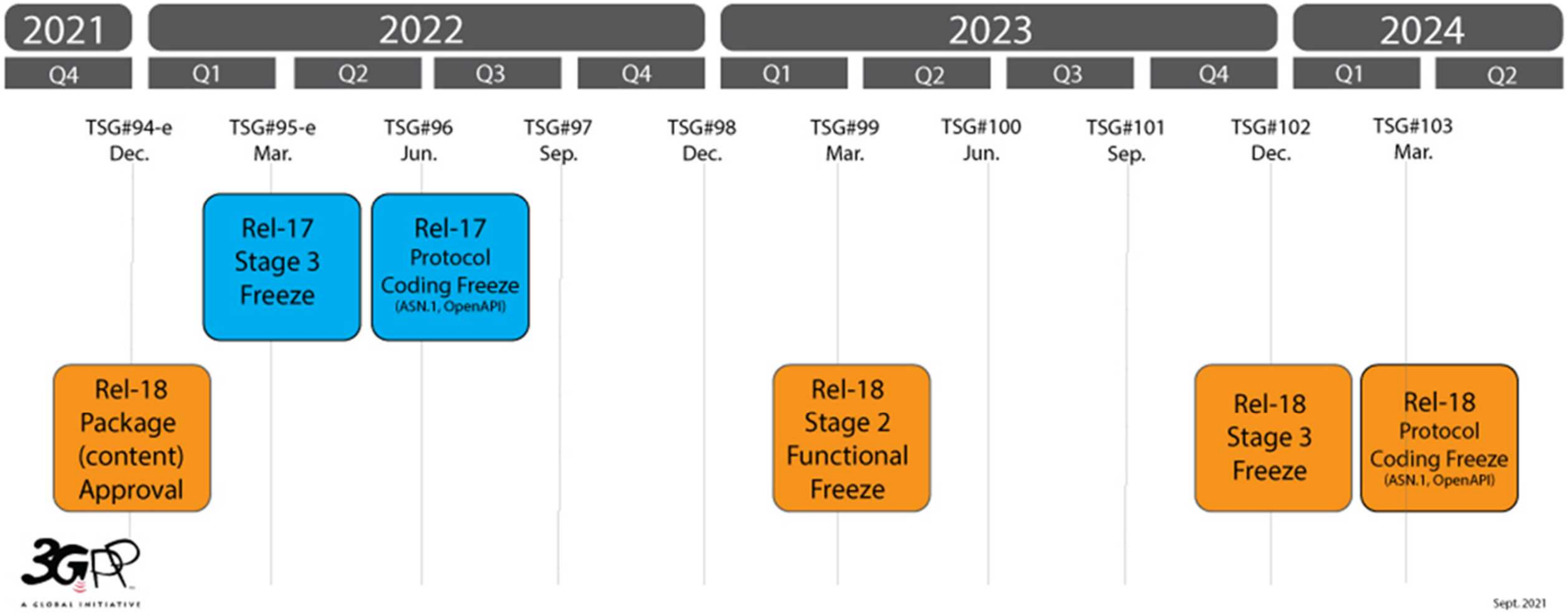


Fig. 4.2.4-1 Schedule for formulation of 3GPP Release 18[32]

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[32]Source: 3GPP "Release 18" https://www.3gpp.org/release18 (retrieved March 23, 2022)

(b) International: IEEE

Currently, standardization is underway for 802.11bd, which is compatible with IEEE 802.11p, the communication protocol for DSRC. The specific implementation schedule is as shown in Table 4.2.4-4, and final approval for standard development is scheduled for December 2022.

Table 4.2.4-4 IEEE 802.11bd formation schedule [33]

MILESTONE	TIME
PAR approved	Dec 2018
First TG meeting	Jan 2019
D0.1 spec draft	Nov 2019
D1.0 WG Letter Ballot	Oct 2020
D2.0 WG recirculation LB	Jul 2021
Form Sponsor Ballot Pool	Nov 2021
D3.0 LB recirculation	Dec 2021
D4.0 LB recirculation	Mar 2022
D4.0 LB unchanged recirculation	Mar 2022
Initial Sponsor Ballot (D4.0)	Mar 2022
Final 802.11 WG approval	Sep 2022
802 EC approval	Oct 2022
RevCom and SASB approval	Dec 2022

[33] Source: IEEE 802.11 Task Group Status of Project "IEEE P802.11bd"
https://www.ieee802.org/11/Reports/tgbd_update.htm (retrieved March 23, 2022)

(c) USA: FCC

The FCC allocated the 75 MHz portion of the 5.9 GHz band (5850 MHz to 5925 MHz) for ITS to DSRC in October 1999. However, nearly 20 years after that allocation, the FCC announced a proposed reallocation of the frequency in December 2019, citing the slow evolution of DSRC-based services and the lack of widespread market deployment outside of certain transportation-related businesses.

In the reallocation proposal, the lower 45 MHz (5850 MHz-5895 MHz) is shown to be allocated for Wi-Fi, the upper 30 MHz (5895 MHz-5925 MHz) for ITS, 10 MHz (5895 MHz-5905 MHz) for DSRC and 20 MHz (5905 MHz-5925 MHz) for C-V2X, or all of them allocated for C-V2X, and a call for public comment opened in February 2020.

On November 18, 2020, the FCC unanimously approved the proposed reallocation of the 5.9 GHz band. The proposed approval stipulates that the first half (45 MHz) will be allocated to Wi-Fi and other wireless stations that do not require licensing and registration, and the second half (30 MHz) will be allocated to C-V2X for ITS (see the red box in Fig. 4.2.4-2)

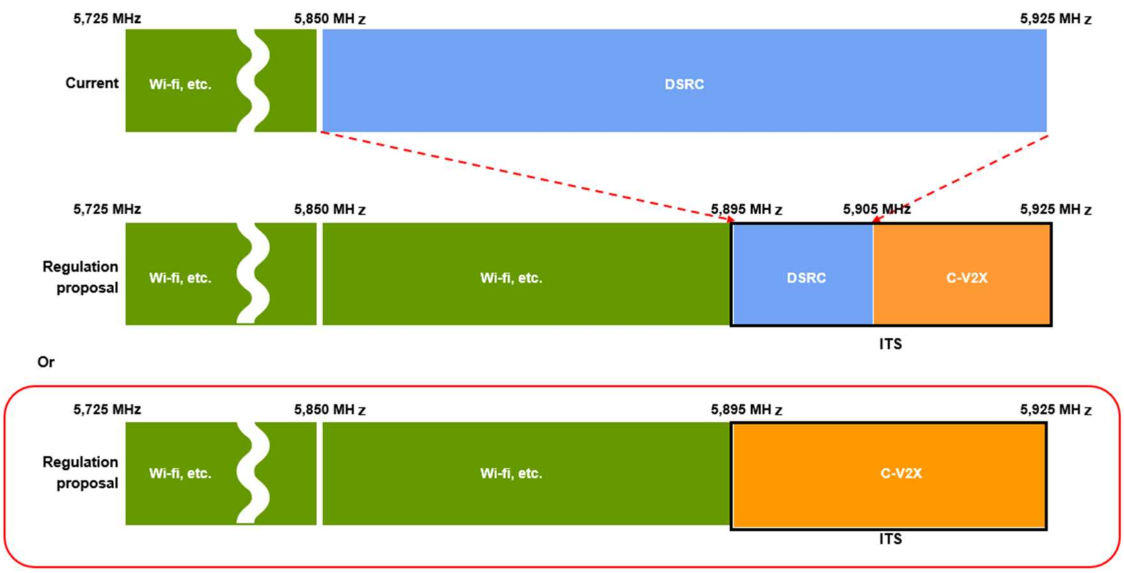

Fig. 4.2.4-2 FCC frequency reorganization proposal and decision[34]

The proposed approval was officially promulgated in the Federal Register on May 3, 2021[35], and the subsequent flow is based on this promulgation date. The future flow stipulated in the proposed approval is as follows.

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[34]Source: Prepared based on Federal Register "85 FR 6841" https://www.federalregister.gov/d/2020-02086 and FCC announcement (Nov. 18, 2020) https://docs.fcc.gov/public/attachments/FCC-20-164A1.pdf (retrieved March 18, 2022)

[35] Federal Register /Vol. 86, No. 83 /Monday, May 3, 2021 https://www.govinfo.gov/content/pkg/FR-2021-05-03/pdf/2021-08802.pdf (retrieved March 18, 2022)

(1) Move DSRC currently operating at the lower 45 MHz to the upper 30 MHz (by July 5, 2022).

(2) Transition from DSRC to C-V2X within one year after the public notice regarding technical problems associated with the switch from DSRC to C-V2X and problems related to radio interference for the lower 45 MHz (2022 to 2023).

(3) Operators using C-V2X must not cause interference with DSRC during the 24-month grace period between (1) and (2).

(4) DSRC operations will be completely ended and only C-V2X will be available for ITS use (after 2024).

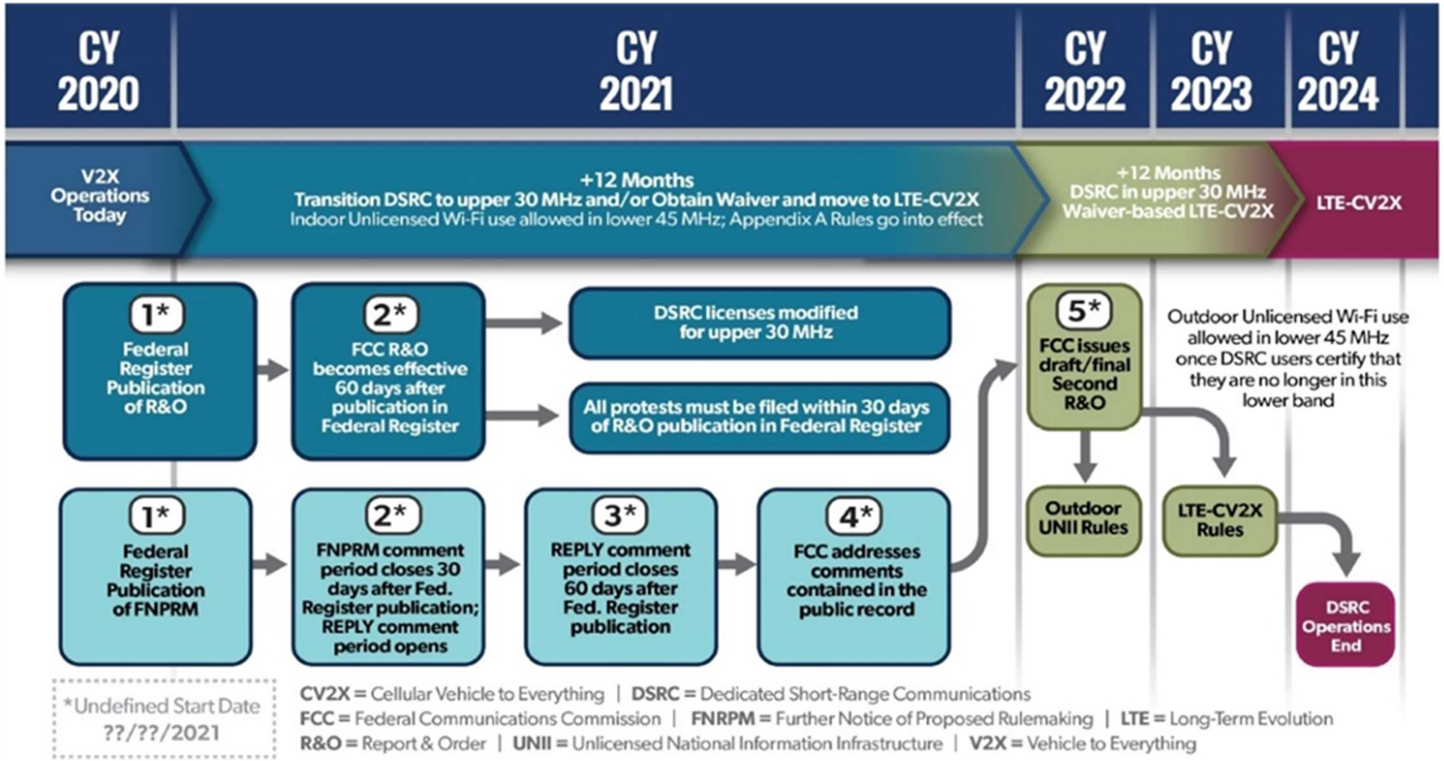

Fig. 4.2.4-3 Flow of future transition [36]

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[36]Source: Materials distributed by US Department of Transportation "5.9GHZ Safety Band Stakeholder Forum"(Dec. 16, 2020) https://www.transportation.gov/sites/dot.gov/files/2020-12/USDOT%205.9GHz%20Safety%20Band%20Stakeholder%20Meeting%20Slides%2018DEC2020%20v12.pdf

(d) Europe: Euro NCAP

According to public information from Euro NCAP, the European new vehicle safety assessment standard, the items shown in Fig. 4.2.4-4 are scheduled to be added as new targets for evaluation by 2025. As noted in the figure, safety standards for V2X-related technologies are expected to be established by 2024.

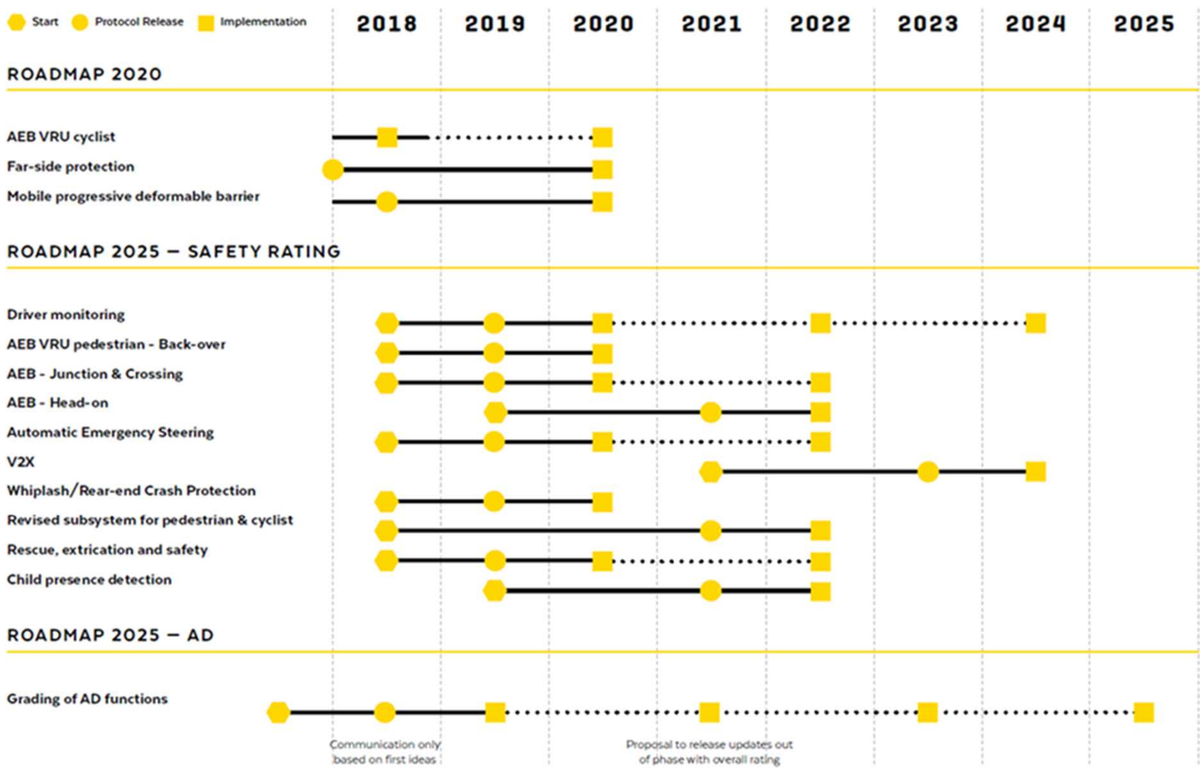


Fig. 4.2.4-4 Safety assessment standards expected to be added to Euro NCAP[37]

(e) Europe: C2C-CC

A report [38] that examined the future coexistence of ITS-G5 and LTE-V2X was published in 2021 at C2C-CC, a consortium formed by European automakers.

In this study, it is stated that the advancement of ITS-G5 will be an issue for consideration after the development of 802.11bd, which is compatible with IEEE 802.11p, and it is suggested that C2C-CC will be involved in this study.

[37] Source: Euro NCAP "Euro NCAP 2025 Roadmap" https://cdn.euroncap.com/media/30700/euroncap-roadmap-2025-v4.pdf (retrieved March 23, 2022)
[38] C2C CC "White paper on ITS-G5 and Sidelink LTE-V2X Co-Channel Coexistence Mitigation Methods" https://www.car-2-car.org/fileadmin/documents/General_Documents/C2CCC_WP_2091_Co-ChannelCoexistence_MitigationMethods_V1.0.pdf (retrieved March 23, 2022)

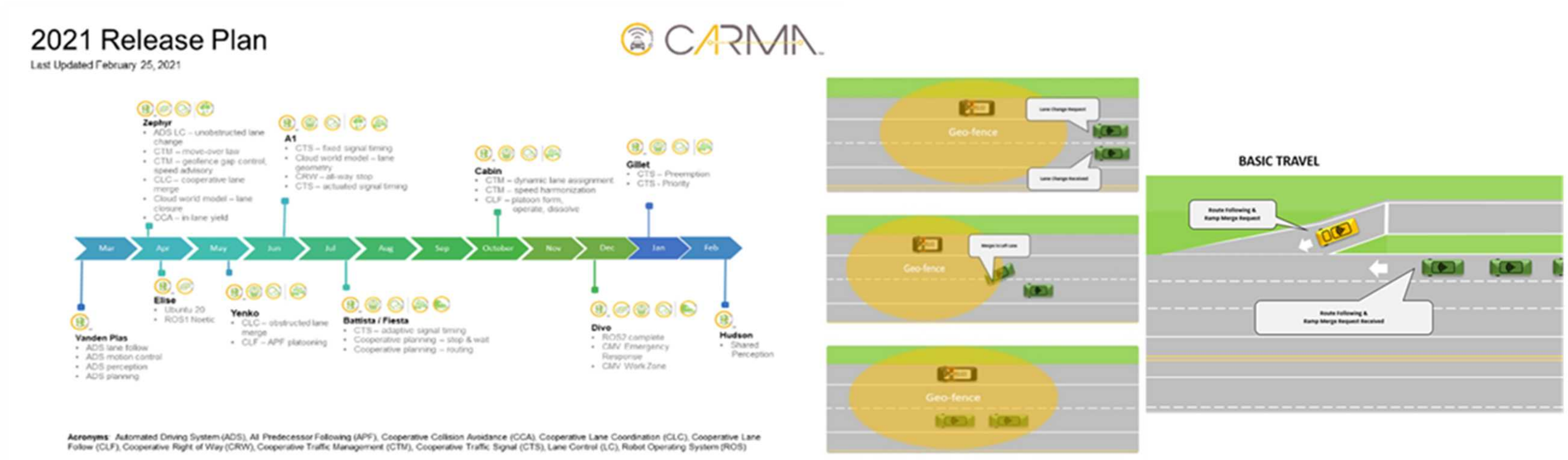
(2) Research projects outside Japan

The following is a summary of the case studies of research projects shown in Table 4.2.4-2 and Table 4.2.4-3 and the sources of the various information.

(a) USA: CARMA

CARMA (Cooperative Automation Research Mobility Applications) is a project led by the US Department of Transportation's Federal Highway Administration (FHWA), and extensive research and development of vehicle body control systems that should be equipped ton automated vehicles is done there. Members participating in the study are the Department of Transportation as well as private-sector OBU manufacturers and others.

The development plan within 2021 (*1 in Fig. 4.2.4-5) includes plans to develop communication control programs related to lane change and merging assistance, and the contents of studies on performance requirements, etc., for communication use cases that are expected to be developed in the future are also disclosed. (*2 and *3 in Fig. 4.2.4-5)



Automated driving system development plan for March 2021 to February 2022 *1

Cooperation in avoiding vehicles in accidents as a use case study example *2

Cooperation at merging as a use case study example *3

Fig. 4.2.4-5 2021 plan and use case examples studied (CARMA)[39]

[39] Source for *1 in figure: CARMA "CARMA Ecosystem Roadmap"
https://usdot-carma.atlassian.net/wiki/spaces/CRMECO/pages/1093435397/CARMA+Ecosystem+Roadmap (retrieved March 23, 2022)
Source for *2 in figure: CARMA "Traffic incident Management"
https://usdot-carma.atlassian.net/wiki/spaces/CRMPLT/pages/1324286032/Traffic+Incident+Management (retrieved March 23, 2022)
Source for *3 in figure: CARMA "Cooperative Basic Travel"
https://usdot-carma.atlassian.net/wiki/spaces/CRMPLT/pages/1327104033/Cooperative+Basic+Travel (retrieved March 23, 2022)

(b) Europe: Study by ERTRAC and DG MOVE

ERTRAC (the European Road Transport Research Advisory Council) is a survey and study group with the participation of the European Commission and European automobile and OBU manufacturers. ERTRAC is studying roadmaps for automated driving technologies related to general passenger cars, freight transport vehicles, and mobility service vehicles. The roadmaps disclosed in 2019 are shown in shown in Fig. 4.2.4-6 and Fig. 4.2.4-8.

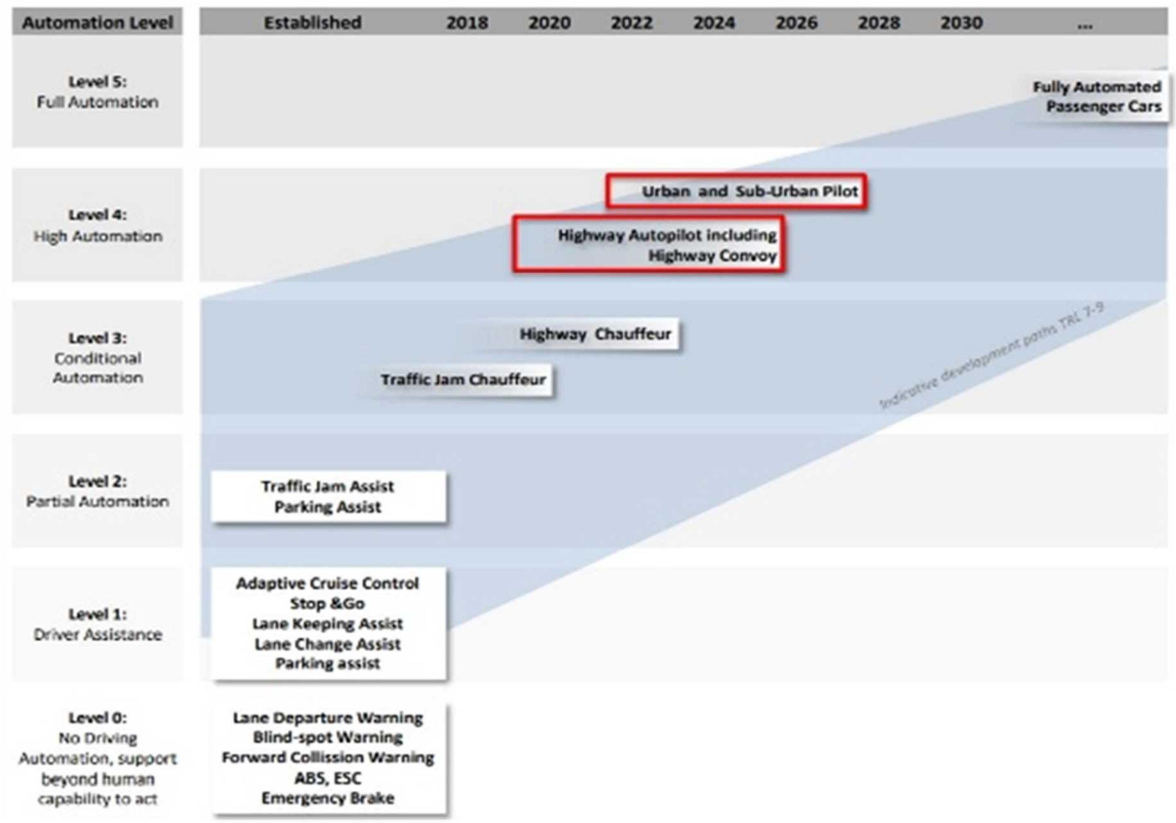


Fig. 4.2.4-6 Roadmaps for introducing automated driving use cases related to general passenger cars (ERTRAC)[40]

[40]Source: ERTRAC "Cooperative Basic Travel" https://www.ertrac.org/uploads/documentsearch/id57/ERTRAC-CAD-Roadmap-2019.pdf (retrieved March 23, 2022)

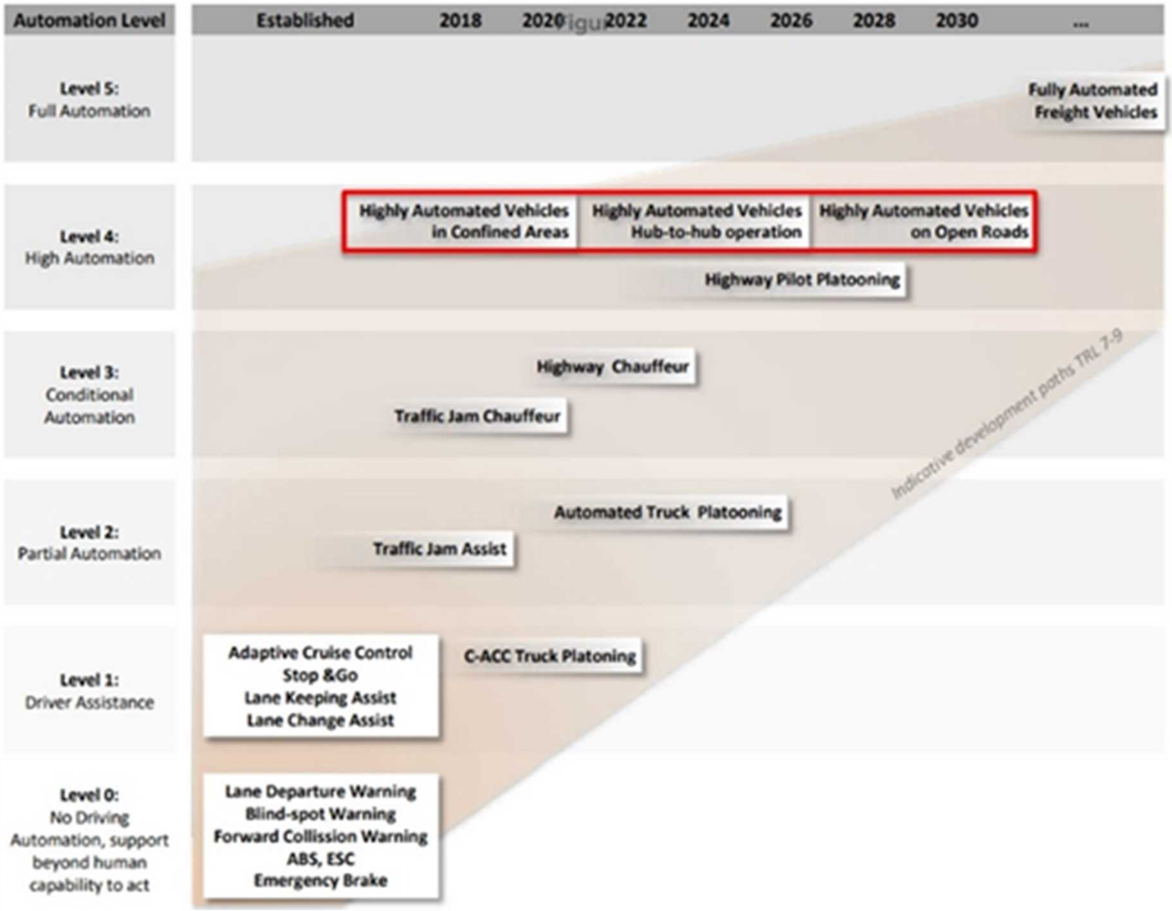


Fig. 4.2.4-7 Roadmaps for introducing automated driving use cases related to freight transport vehicles (ERTRAC)[41]

[41]Source: ERTRAC "Cooperative Basic Travel" https://www.ertrac.org/uploads/documentsearch/id57/ERTRAC-CAD-Roadmap-2019.pdf (retrieved March 23, 2022)

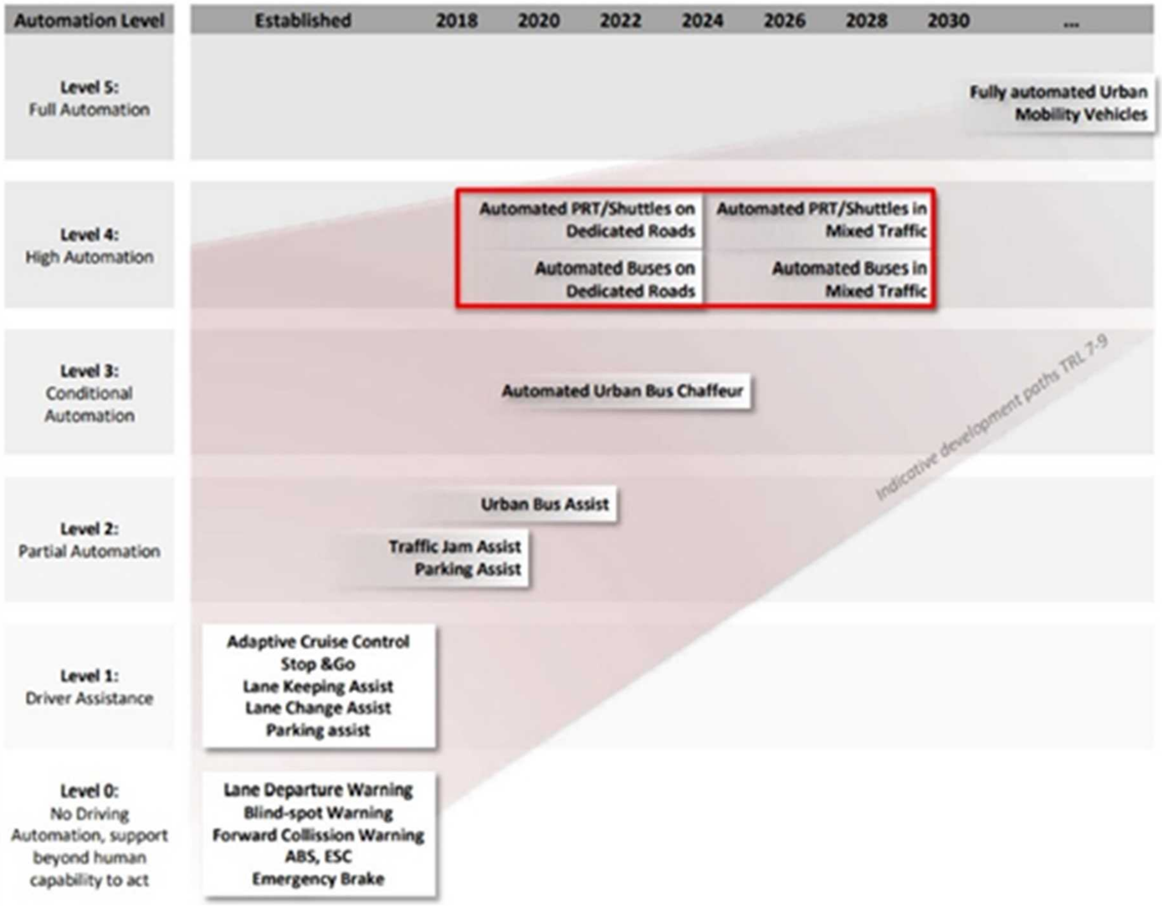


Fig. 4.2.4-8 Roadmaps for introducing automated driving use cases related to mobility service vehicles (ERTRAC)[42]

Additionally, the following describes the status of studies being conducted by DG MOVE separately from the ERTRAC efforts.

To start with, an outlook for C-ITS services published by DG MOVE 2018 is shown in Fig. 4.2.4-9. The developments in Day 2 to the first half of Day 3 (2020 to 2030) in this figure are mainly directed toward the realization of Level 4 automated driving, and they are consistent with the deployment plan presented by ERTRAC in the roadmaps above.

[42]Source: ERTRAC "Cooperative Basic Travel" https://www.ertrac.org/uploads/documentsearch/id57/ERTRAC-CAD-Roadmap-2019.pdf (retrieved March 23, 2022)

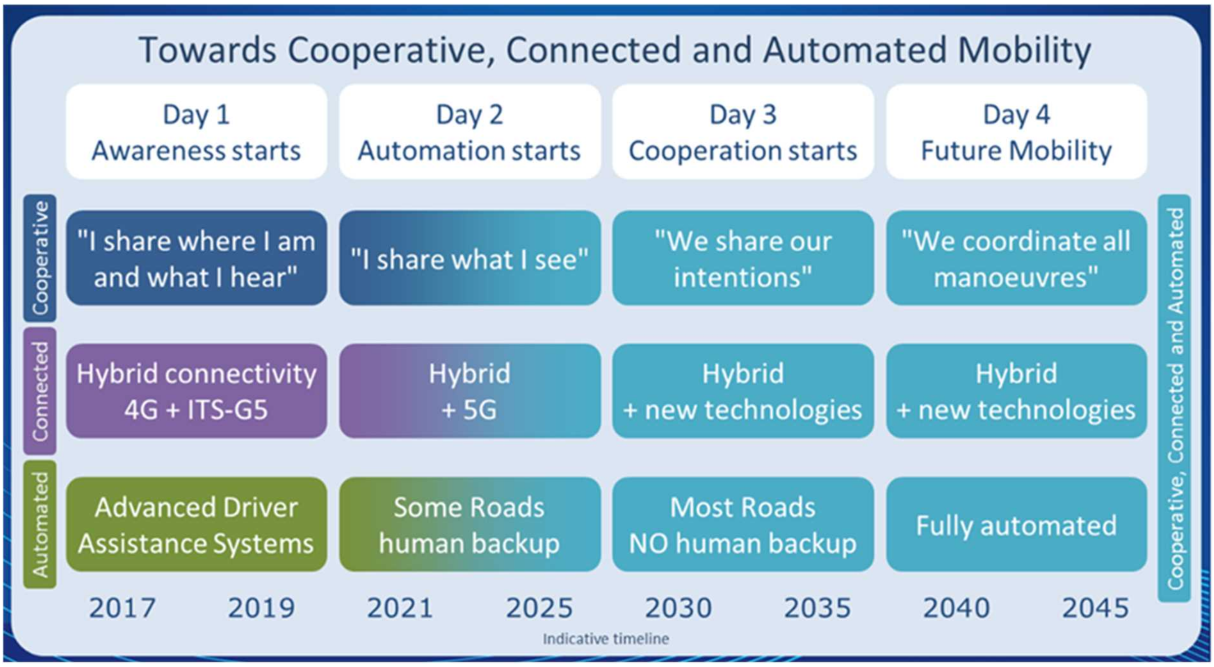


Fig. 4.2.4-9 Outlook for C-ITS services (DG MOVE)[43]

The use cases in this figure studied in Day 1 (2016 to 2020), which has already been completed, are shown in Table 4.2.4-5, and the use cases studied most recently are shown in Table 4.2.4-6.

[43]Source: DG MOVE “EU developments in Intelligent Transport Systems” https://www.interregeurope.eu/fileadmin/user_upload/tx_tevprojects/library/file_1521040514.pdf (retrieved March 23, 2022)

Table 4.2.4-5 Cooperative driving automation use cases studied in Day 1 (2016 to 2020)[44]

Studied use case	UC definition	Corresponding Japanese use case
Information sharing at low speeds/stops	A vehicle traveling at low speed or stopped notifies surrounding vehicles of its own information.	d-1
Road construction warning	Notifies driver of information on road construction through V2I communication.	d-5
Weather condition warning	Notifies driver of hazardous weather conditions that may impair driving.	-
Emergency vehicle approach notification	Notifies driver of approaching emergency vehicles.	e-1
Other hazard notification	Notifies driver of warning information identified by roadway administrators via V2I communication.	d-5
In-vehicle signage	Notifies driver of information on road signs via V2I communication. Units installed on the road provide information on speed limits and junctions ahead.	-
Speed limit notification	Notifies driver of speed limit information identified by the road administrator via V2I communication.	-
Priority signal request	Requests that a priority signal be sent to an emergency vehicle or the like when that vehicle passes.	-
Congestion ahead warning	Notifies the driver of congestion on the road ahead when that occurs.	d-3
Signal notification	Notifies the driver of information such as the time remaining for signal indication switching.	b-1-1
Probe information	Gathers information on the location and movements of surrounding vehicles.	-

Table 4.2.4-6 Cooperative driving automation use cases scheduled to be studied in Day 1.5 to 2 (2018 to 2030)[45]

Studied use case	UC definition	Corresponding Japanese use case
Route notification to avoid congestion	Notifies driver of appropriate routes based on road congestion.	f-2
Park and ride information	Notifies driver of information related to park and ride (transfer service between private cars and public transportation).	-
Protection of vulnerable road users	Detects the location of vulnerable road users and provides information to assist in collision avoidance.	-

(c) Europe: C-Roads

C-Roads is a project led by the European Commission and involving European governments and automakers. The demonstration tests shown in Table 4.2.4-7 are being conducted as activity achievement in the period 2016 to 2020. Based on the evaluation results of these demonstration tests, a roadmap study for the practical application of automated driving is scheduled to be conducted during 2022.

As a distinctive activity achievement, verification tests for traffic situation monitoring and collision avoidance assistance on expressways and intersections using RSUs have been conducted over a wide area of Europe, and the performance and technical requirements for OBU for each use case of cooperative driving automation are being studied at "SCOOP@F" in France.

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[44] Source: Prepared from EC materials (https://ec.europa.eu/transport/sites/default/files/com20160766_en.pdf) and related C-Roads materials (https://www.c-roads.eu/pilots/implemented-services.html)
[45] Source: Prepared from EC materials (https://ec.europa.eu/transport/sites/default/files/com20160766_en.pdf) and related C-Roads materials (https://www.c-roads.eu/pilots/implemented-services.html)

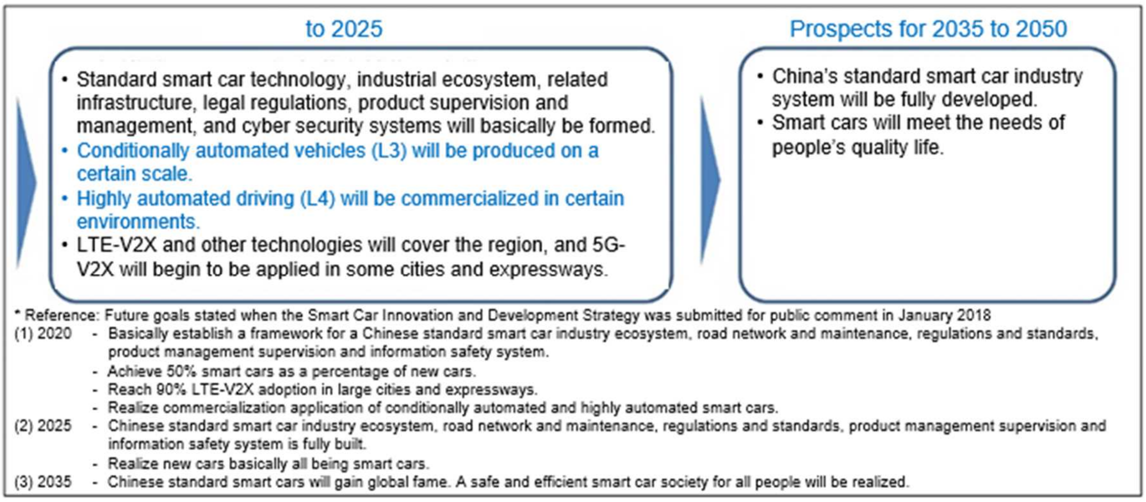
Table 4.2.4-7 Demonstration testing conducted in European countries in C-Roads[46]

Country	Demonstration testing / Use case	Status and plans for the future
France	• Lane change assistance in urban areas • Traffic congestion monitoring and distribution	• Management of RSUs installed for demonstration testing will be outsourced by the end of 2021.
Belgium	• Low-speed/stationary vehicle and vehicle ahead alert (traffic congestion) • Weather conditions, low visibility, temporary slippery road notifications • Hazardous area notification (accident zones, slippery roads, etc.)	• Demonstration testing is managed by the local traffic authority in Flanders, ITS Belgium, and other companies. • Test results will be evaluated by summer 2021
Finland	• Low-speed/stationary vehicle and vehicle ahead alert (traffic congestion) • Road construction warning • Weather conditions, low visibility, temporary slippery road notifications • Hazardous area notification (accident zones, approaching emergency vehicles, animals or people on the road, obstacles on the road, etc.)	• Finland's pilot program is part of the NordicWay2 project. - The NordicWay 2 project started on February 7, 2017 and ended on December 31, 2020 (progress delayed by COVID-19). - The followup NordicWay 3 project is under study.
Germany	• Low-speed/stationary vehicle and vehicle ahead alert (traffic congestion)	• Demonstration testing is run by a consortium of 18 German companies. • The use case will be tested in urban areas by 2023 as Day 1.5.
Italy	• Acceleration/deceleration and merging assistance on expressways • Platooning • Driving assistance by using traffic signal information • Driving assistance at intersections	• So far, demonstration tests of transport vehicles have been conducted mainly on expressways as Day 1. • Demonstration of V2I services based on traffic signal information is scheduled as Day 2 in the future.
UK	• Identification of accident situations on expressways • Low-speed/stationary vehicle and vehicle ahead alert (traffic congestion)	• Implemented mainly by the UK Department for Transport and Highways. • Determination on whether to continue the service will be made by the end of 2020 (results not yet announced).
Czech Republic	• Acceleration/deceleration, merging assistance, collision avoidance on expressways • Driving assistance at intersections • Traffic control for buses, trams and other mobility services	• Demonstration testing has been completed as of 2020 and work is currently in the evaluation phase. • Security requirements for V2X were defined in 2016, and demonstration testing uses communication technology in line with those security requirements.

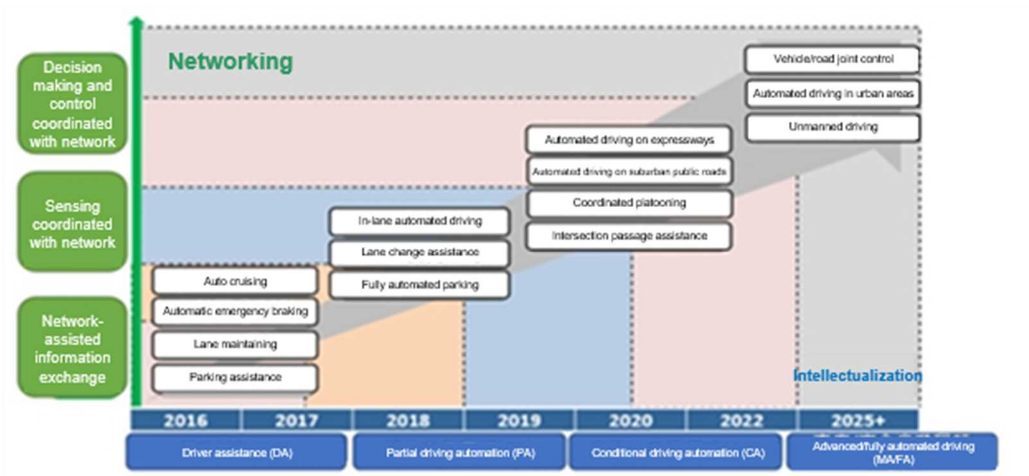
[46] Source: Prepared from C-Roads disclosed materials (https://www.c-roads.eu/fileadmin/user_upload/media/Dokumente/C-Roads_Brochure_2021_final.pdf)

(d) China: Smart Car Innovation and Development Strategy

The Smart Car Innovation Development Strategy is a research plan announced by the Chinese government in February 2020 and is a follow-up project to Made in China 2025, a research plan also announced by the Chinese government in 2015. Although the detailed status of the study is unknown, commercialization of Level 4 automated vehicles and development of areas where V2X can be used by 2025 are planned.



Future prospects of Smart Car Innovation and Development Strategy



* Reference: Made in China 2025 (announced in 2015) roadmap

Fig. 4.2.4-10 Roadmap for introduction and adoption of cooperative driving automation in China[47]

[47] Source: NEDO "About China's Policies Related to Automated Driving and Connected Cars (July 2020)" and "China's Policies Related to Automated Driving and Connected Cars"
https://www.nedo.go.jp/content/100922174.pdf (retrieved March 23, 2022)
https://www.nedo.go.jp/library/ZZAT09_100017.html (retrieved March 23, 2022)

(e) China: Energy-saving and New Energy Vehicle Technology Roadmap 2.0

On October 27, 2020, the "Energy-saving and New Energy Vehicle Technology Roadmap 2.0" was announced at the annual meeting and exhibition of the China Society of Automotive Engineers (China-SAE) held in Shanghai 48. Since this roadmap was prepared mainly by China-SAE under the guidance of the Ministry of Industry and Information Technology of the central government, it is believed to reflect the intentions of the government to a certain degree.

In this roadmap, a direction of adhering to a pure electric vehicle-led development strategy is shown, and "six major overall technological goals" are presented for 2035. Among them, with regard to intelligent connected vehicles (ICVs), the report presents the goal of "basically establishing a Chinese-style ICV technology system and putting products to practical use on a large scale"49. On that basis, the following numerical targets for ICV adoption achievement rates in 2025 and 2030 are presented.

In Table 4.2.4-8, "PA" refers to "partially automated driving" (equivalent to SAE Level 2), "CA" refers to "conditionally automated driving" (equivalent to SAE Level 3), and "HA" refers to "highly automated driving" (equivalent to SAE Level 4).

Table 4.2.4-8 ICV adoption targets in "Technology Roadmap 2.0 for Energy-Saving and New Energy Vehicles"[50]

	2025	2030
Ratio of ICV sales	• PA/CA level: 50% or more of total automobile sales • HA level automobile market introduction started	• PA/CA level: 70% or more of total automobile sales • HA level: More than 20% of total automobile sales
Equipping with C-V2X terminals	Percentage of new vehicles equipped with C-V2 terminals: 50%	Achievement of basic adoption of vehicles equipped with C-V2X terminals

(f) [Reference] International: Study by 5GAA

The 5GAA, comprised of telecommunications carriers and automakers from around the world, has published a C-V2X use case deployment plan as shown in Fig. 4.2.4-11. In this study, the information released by the 5GAA, which is based on the assumption that C-V2X will be widely adopted, is not used as a reference in roadmap formation.

[48]China Society of Automotive Engineers "Energy-saving and New Energy Vehicle Technology Roadmap 2.0" offi cial release (Oct. 27, 2020) http://www.sae-china.org/news/society/202010/3957.html (retrieved March 18, 2022)

[49]JETRO business brief "Automotive technology roadmap to 2035 announced, with new energy vehicles accountin g for more than 50% of sales." (Nov. 5, 2020) https://www.jetro.go.jp/biznews/2020/11/429bf4411a60db56.html (r etrieved March 18, 2022)

[50]Source: Prepared from Global × Automobile × Environmental Regulation.jp "China Society of Automotive Engineering released 'Technology Roadmap 2 for Energy-saving and New Energy Vehicles' -- aiming for 50% new NEVs and 50% HVs by 2035" (Dec. 1, 2020) https://ecocar-policy.jp/article/20201204/ (retrieved March 18, 2022)

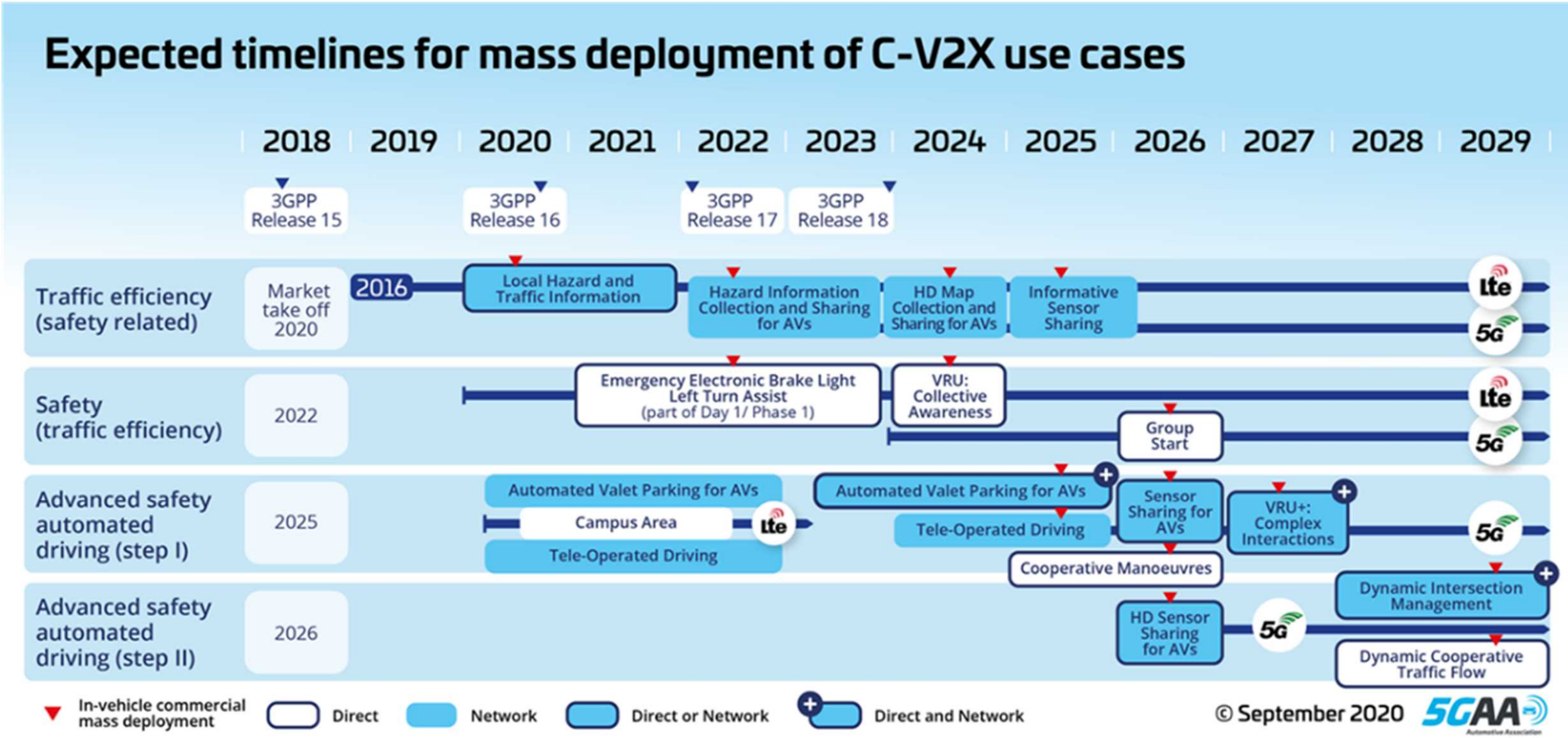


Fig. 4.2.4-11 C-V2X use case deployment roadmap released by 5GAA[51]

[51]Source: 5GAA “White Papers” https://5gaa.org/news/the-new-c-v2x-roadmap-for-automotive-connectivity (retrieved March 23, 2022)

(g) [Reference] Europe: MANTRA

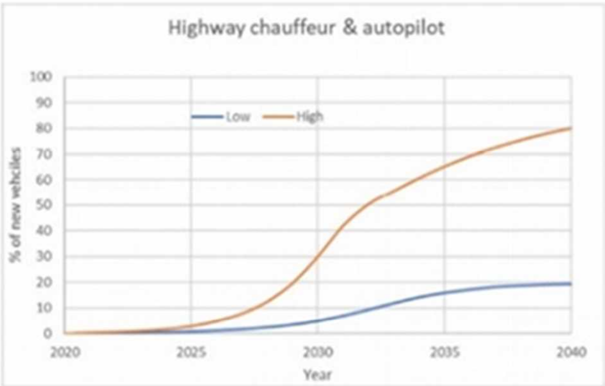
MANTRA (Making full use of Automation for National Transport and Road Authorities) is a research project by the Conference of European Directors of Roads (CEDR), and it forecasts the introduction and widespread deployment of automated driving technology as part of its activities.

In MANTRA, a forecast of the start of the adoption of automated driving use cases shown in Table 4.2.4-9 and a forecast of the adoption rate of automated vehicles shown in Fig. 4.2.4-12 is released. However, the results of these studies are CEDR's own estimates and are not validated by the participation of European automobile or OBU manufacturers in the project. Therefore, MANTRA was excluded from the global benchmark in this study.

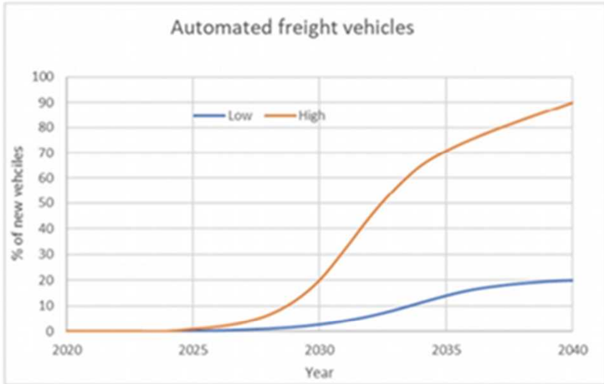
Table 4.2.4-9 Forecast start of the adoption of automated driving use cases (MANTRA)[52]

MANTRA Use case	High	Low
Highway chauffeur and autopilot	2021 2023	2021 2023
Automated freight vehicles	2025	2025
Robot taxis	2025	2032
Automated winter maintenance vehicles	2025	2030
Automated roadworks safety trailers	2023	2023

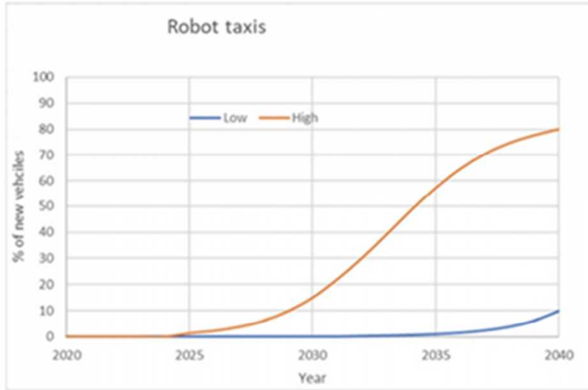
[52] Source: MANTRA "Vehicle fleet penetrations and ODD coverage of NRA-relevant automation functions up to 2040" https://www.mantra-research.eu/wp-content/uploads/2020/03/MANTRA_Deliverable_D2.1_1.0.pdf (retrieved March 23, 2022)



Adoption rate of autonomous vehicles on expressways



Adoption rate of automated freight transport vehicles



Adoption rate of driverless mobility service vehicles

Fig. 4.2.4-12 Forecast adoption rate of automated vehicles (MANTRA)[53]

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[53] Source: MANTRA "Vehicle fleet penetrations and ODD coverage of NRA-relevant automation functions up to 2040" https://www.mantra-research.eu/wp-content/uploads/2020/03/MANTRA_Deliverable_D2.1_1.0.pdf (retrieved March 23, 2022)

(3) Summary of roadmap study cases outside Japan

In the study cases listed above, three cases of ERTRAC and MANTRA in Europe and 5GAA have forecast the start of introduction of various use cases in cooperative driving automation and released roadmaps. An overview is shown in Fig. 4.2.4-13.

As mentioned above, the only case study referred to as a global benchmark in this study is ERTRAC in Europe, and the roadmaps of MANTRA in Europe and 5GAA are provided only as reference information.

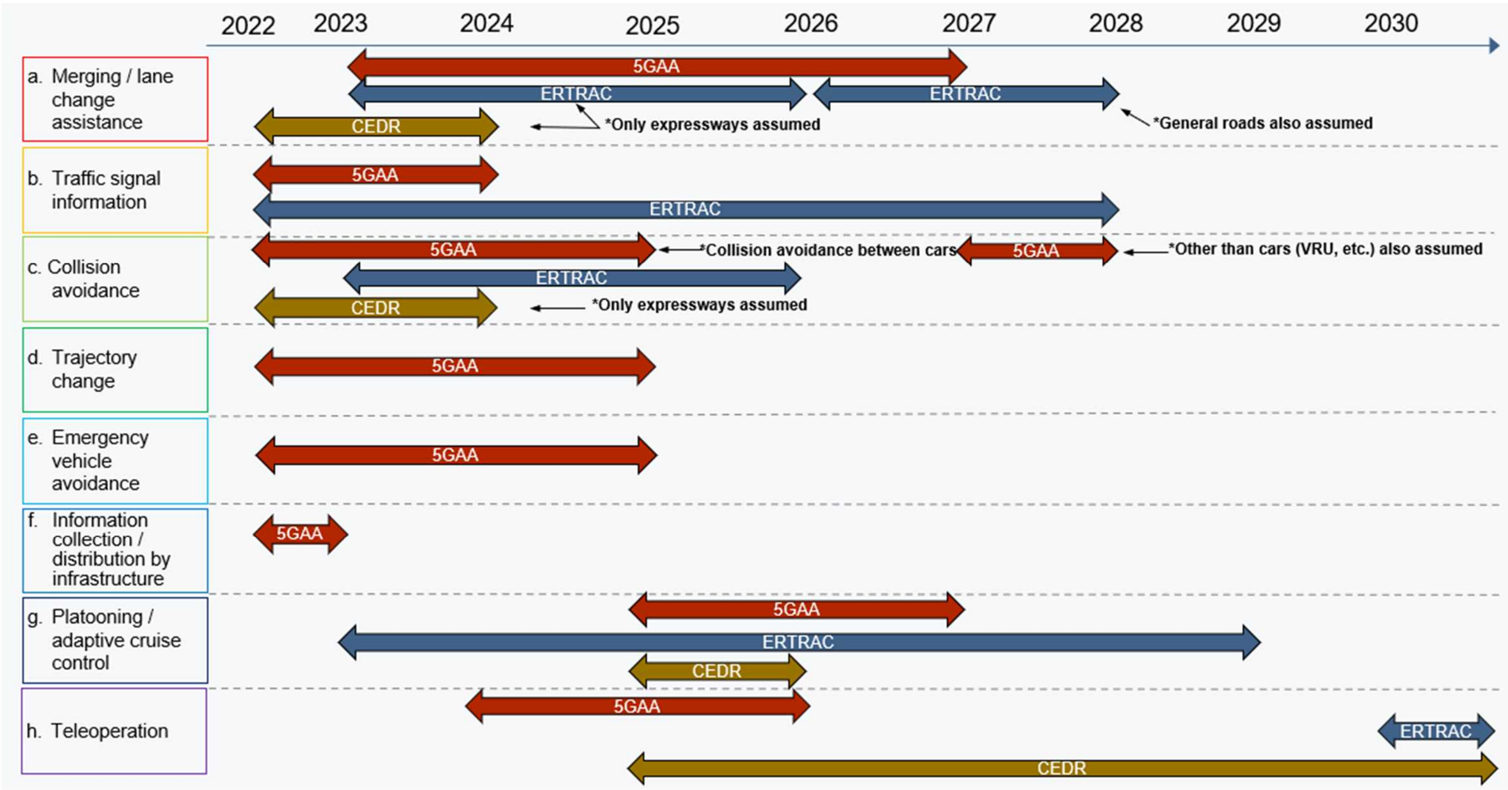


Fig. 4.2.4-13 V2X use case introduction timing shown by ERTRAC/MANTRA/5GAA

4.2.5 Use case deployment plans

Based on the studies up to the previous section, a time series of use case developments based on the projected adoption of OBU in 2.2 was studied.

The ultimate objective of this study is to create a roadmap for the social implementation of communication technologies necessary for realizing an automated driving society. In creating a roadmap, it is necessary to assume how much communication technology will be required at each point in time, so it is necessary to organize starting points for when the use cases will be deployed.

When considering a deployment plan, assumption of a starting point based on the assumptions of this study, development plans such as those for related infrastructure, and descriptions of roadmaps and the like from relevant ministries and agencies are required. In this study, the goals of the Public-Private ITS Initiative/Roadmaps, the existence of similar services, and examples of initiatives by various organizations were referenced, and discussions were held in the TF among academic experts, relevant government ministries and agencies, industry organizations (automobile, electronics, etc.), and other members to compile a use case deployment plan.

In studying the deployment plan, it was assumed that the roadmap would be created with a long-term perspective (to around 2050), given the condition that deployment of new communication technology is constrained by vehicle life cycle although communication technology continues to advance rapidly, and that the goals of the study, etc., listed below are on a timeline focused on up to around 2050.

- Trends in Japan and other countries
  - Government
    "11th Fundamental Traffic Safety Program": Aim for 2,000 or fewer traffic accident fatalities by 2025
  - Unite Nations/SDGs
    Reduce by half the number of road traffic accident fatalities and injuries by 2030
  - EU
    "Vision Zero": Eliminate all traffic accident fatalities and serious injuries by 2050.
  - US DOT
    "National Highway Safety Strategy": Stipulates comprehensive actions to significantly reduce serious injuries and fatalities on roads

In preparing the deployment plan for the use cases, a custom timeline was set for the realization of the use cases based on the goals of the Public-Private ITS Initiative/Roadmaps, the availability of similar services, examples of efforts in various locations, etc. In addition, the basis for the assumption for the start timing was appended to each use case.

- Assumptions regarding the timing of use case start (text beginning with ▼) and assumptions regarding infrastructure, etc., (text beginning with ●) are appended.
- If the assumption is based on information such as the roadmap of the relevant ministries and agencies, it is in bold type, and if the assumption is based on the contractor's assumption, it is in thin type.
- Since there is no basis for assuming an end date, this study does not assume use case ending.

Use cases are basically listed in “Cooperative driving automation” but those that contribute to safe driving support are also listed in “Safe driving support”.

- UC in “Cooperative driving automation” is for Level 3 or higher automated vehicles.
- “Safe driving support” is for automated vehicles at Level 2 or lower or manually operated vehicles without automated driving functions.

(1) Use case deployment plans: V2I

The expected scenarios that will unfold for the use cases in which V2I is assumed to be the communication technology are shown in chronological order in Fig. 4.2.5-1.

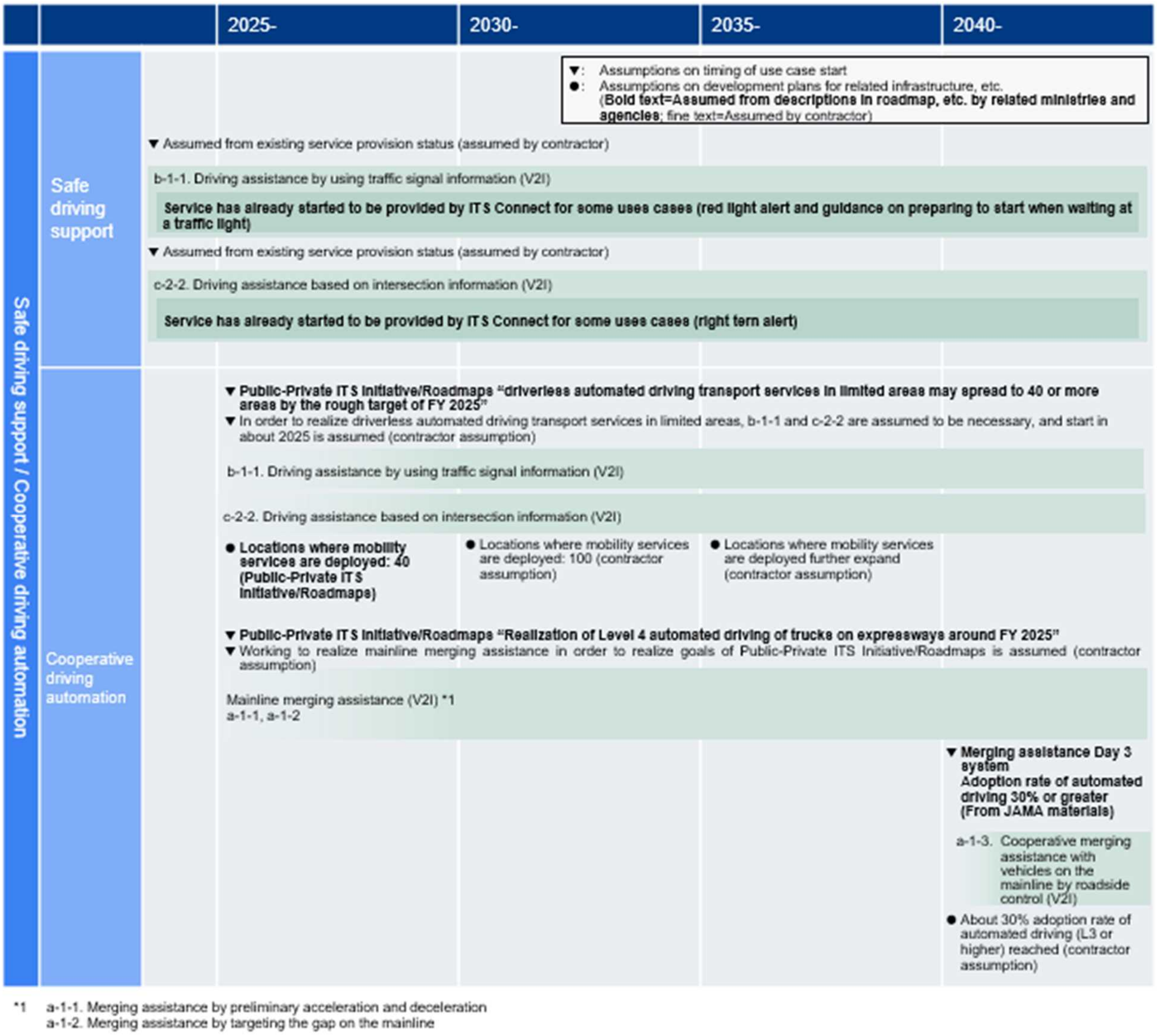
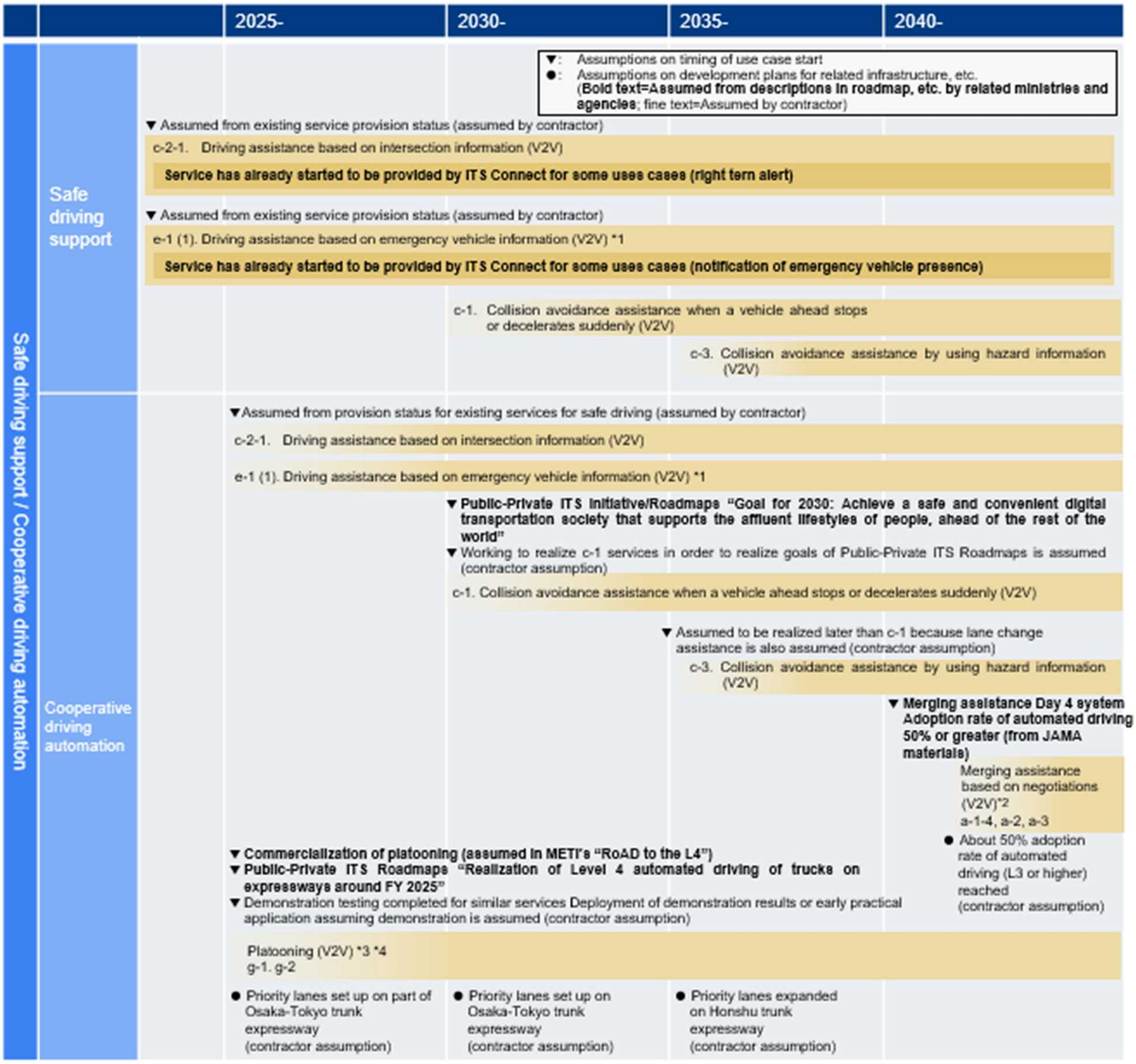


Fig. 4.2.5-1 Use case deployment scenarios (V2I)

(2) Use case deployment plans: V2V

The expected scenarios that will unfold for the use cases in which V2V is assumed to be the communication technology are shown in chronological order in Fig. 4.2.5-2.



*1 Transmission of emergency vehicle information assumed to be limited to "in emergency driving"

*2 a-1-4. Merging assistance based on negotiations between vehicles (V2V)
a-2. Lane change assistance when the traffic is heavy (V2V)
a-3. Entry assistance from non-priority roads to priority roads during traffic congestion (V2V)

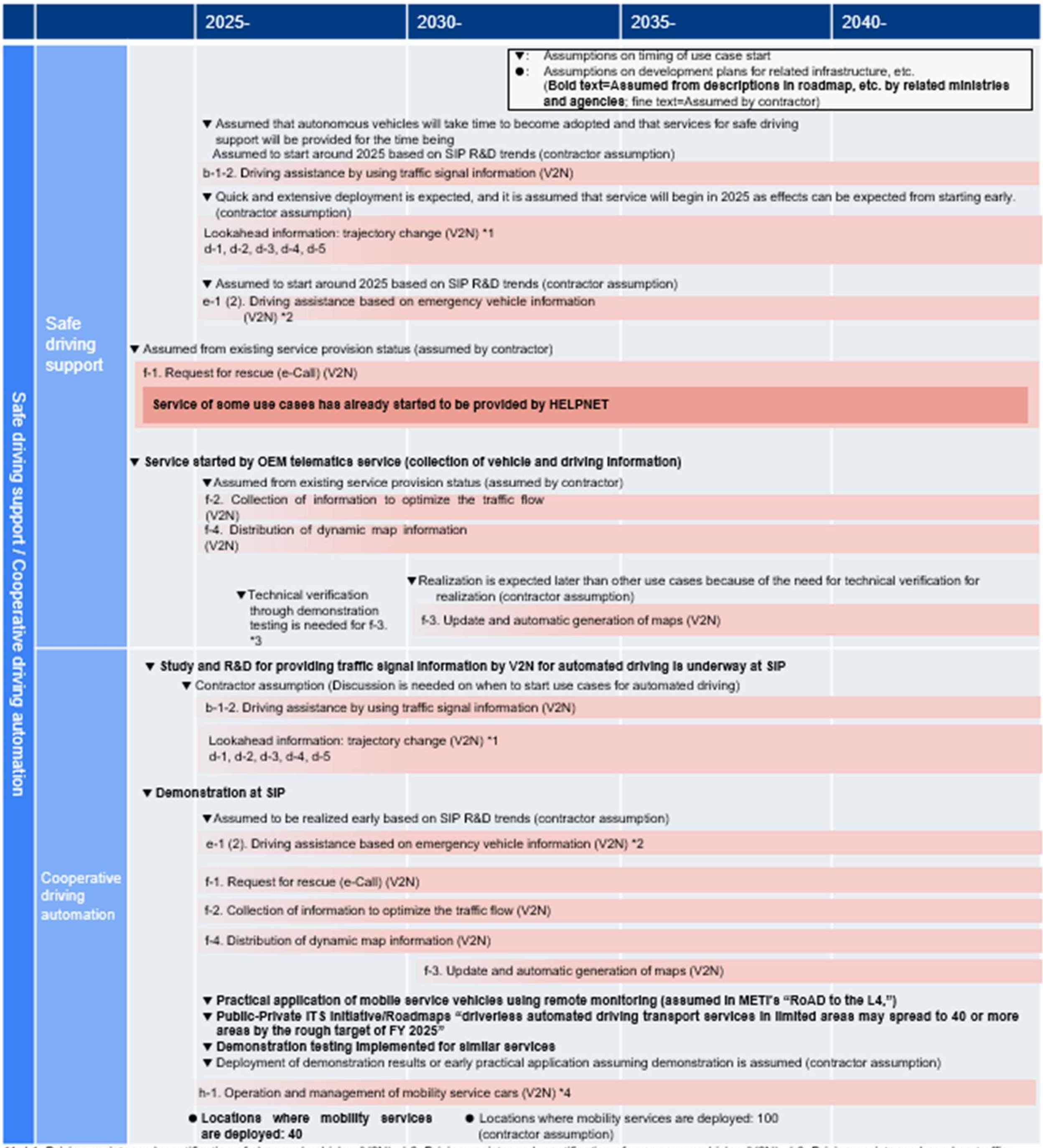
*3 g-1. Unmanned platooning of following vehicles by electronic towbar (V2V)
g-2. Adaptive cruise control and manned platooning of following vehicles using adaptive cruise control (V2V)

*4 For limited vehicles (automated driving trucks, etc.)

Fig. 4.2.5-2 Use case deployment scenarios (V2V)

(3) Use case deployment plans: V2N

The expected scenarios that will unfold for the use cases in which V2N is assumed to be the communication technology are shown in chronological order in Fig. 4.2.5-3.



*1 d-1. Driving assistance by notification of abnormal vehicles (V2N), d-2. Driving assistance by notification of wrong-way vehicles (V2N), d-3. Driving assistance based on traffic congestion information (V2N), d-4. Traffic congestion assistance at branches and exits (V2N), d-5. Driving assistance based on hazard information (V2N)
*2 Transmission of emergency vehicle information assumed to be limited to "in emergency driving"
*3 From results of interviews with related organizations during the study of communication requirements
*4 For limited vehicles (on-demand bus, etc.)

Fig. 4.2.5-3 Use case deployment scenarios (V2N)

4.3 Draft roadmap for communication requirements for cooperative driving automation

In formulating a roadmap for communication requirements for cooperative driving automation and for social implementation of communication technologies necessary for realizing an automated driving society, the following two items are implemented.

1) Conduct research on trends necessary for roadmap formulation, such as timing of realizing automated driving, adoption rate, and international communication technologies.
2) Based on the results of the verification in 1) and 3 as well as the findings from the “Study on communication protocols for achieving Use Cases for Cooperative Driving Automation Evaluation related to 700 MHz band ITS”, prepare a draft roadmap of specific communication requirements for wireless communication technology related to cooperative driving automation in Japan, according to the adoption rate of automated driving

In order to implement these two items, studies were performed under the following basic concepts.

- Categorize the use cases studied by the ITS Forum and study the timing of introduction based on trends in Japan and internationally, and organize the situation in which the categorized use cases are used in multiple ways over a time axis (from 2025 to 2040 in five-year increments).
- Based on the status of the adoption of automated vehicles and the deployment of radio communication devices related to cooperative driving automation, etc., compile communication requirements in order for the service to contribute to practical use, taking into consideration the situation where use cases are used in multiple ways in each time axis.

Based on these concepts of communication requirements, communication requirements related to cooperative driving automation are organized and a deployment plan for use cases is derived.

4.3.1 Accumulation of communication performance required to realize use cases

The communication requirements and communication performance compiled by the TF were listed along the timeline of the use case deployment studied in the previous section. The assumed communication technologies were also organized.

The proposed study of communication requirements for a. Merging / lane change assistance by the TF are shown in Table 4.3.1-1.

Table 4.3.1**-1 Study of communication requirements for merging/lane change assistance[54] (1/2)**

Classification by function	a. Merging / lane change assistance					
Use case	Merging assistance by preliminary acceleration and deceleration	Mainline gap aiming merging support	Mainline vehicle cooperative merging support by roadside control			
No.	a-1-1	a-1-2	a-1-3			
Message name	Location information	Location information	Location information	Control request	Agreement request Update request	Agreement response Update response
Communication format	V2I (I -> V)	V2I (I -> V)	V2I (I -> V)	V2I (V -> I)	V2I (I -> V)	V2I (V -> I)
Communication counterpart	Non-specified vehicles	Non-specified vehicles	Non-specified vehicles	Road infrastructure	Specified vehicles	Specified vehicles
Target area (minimum range)	From 6 seconds before merging starting point to the center between 6 seconds before merging starting point and merging starting point	From 6 seconds before merging starting point to merging starting point	From 6 seconds before merging starting point to merging starting point	Within control request range	Within control request range	Within control request range
Number of transmitting vehicles per area	1 vehicle	1 vehicle	1 vehicle	1 vehicle	1 vehicle (× control number)	48 vehicles (*5) (control number, when traffic is heavy)
Required communication distance (*1)	33.9 to 59.3 m (NILIM standard: 95 m)	67.8 to 118.6 m	Connecting route: 67.8 to 118.6 m Mainline: 112.5 to 270 m	67.8 to 118.6 m	Connecting route: 67.8 to 118.6 m Mainline: 112.5 to 270.0 m	Connecting route: 67.8 to 118.6 m Mainline: 112.5 to 270.0 m
Maximum relative speed	Connecting route: 20 to 70 km/h	Connecting route: 20 to 70 km/h	Connecting route: 20 to 70 km/h Mainline: 20 to 120 km/h	Connecting route: 20 to 70 km/h Mainline: 20 to 120 km/h	Connecting route: 20 to 70 km/h Mainline: 20 to 120 km/h	Connecting route: 20 to 70 km/h Mainline: 20 to 120 km/h
Maximum data size	1510 bytes (1260+250) Anticipated vehicles: 46	2752 bytes (2502+250) Anticipated vehicles: 92 (*2)	5236 bytes (4986+250) Anticipated vehicles: 184 (*3)	287 bytes (37+250)	369 bytes (119+250) (*4)	287 bytes (37+250)
Cyclic or acyclic	Cyclic	Cyclic	Cyclic	Acyclic	Acyclic	Acyclic
Transmission cycle	100 ms	100 ms	100 ms	Not specified (*6)		
PAR per packet	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)
Allowable delay of radio section	Not specified	Not specified	Not specified	Assume 100 ms as allowable delay of radio section	Assume 100 ms as allowable delay of radio section	Assume 100 ms as allowable delay of radio section

*1 Roadside infrastructure is installed at the merging starting point, and the difference in elevation is ignored. It is expected that roadside infrastructure antennas will be installed at some distance from the merging starting point, but this has not been taken into account. In practice, it is necessary to calculate the required communication distance, including the location of the roadside infrastructure antenna and the difference in elevation.
*2 Cases where information is provided for two lanes (mainline). If mainline is three lanes (anticipated vehicles: 138), 3744+250=3994 bytes. If mainline is six lanes (anticipated vehicles: 276), 7470+250=7720 bytes.
*3 Cases where information is provided for three lanes (mainline) and one lane (connecting route). If connecting route is two lanes and mainline is six lanes (anticipated vehicles: 368), 9954+250=10204 bytes.
*4 In the control response message, the information element of the scheduled time to start action (2 bytes) is added, for 121+250=371 bytes.
*5 Cases where vehicle density is estimated at 12 vehicles/lane for three lanes (mainline) and one lane (connecting route). With six lanes (mainline) and two lanes (connecting route), the number of transmitting vehicles is 96 vehicles.
* 6 See explanations in sections 2.5.1.4 and 2.5.1.6 of the source materials regarding transmission cycle of use case a-1-3.

[54]Source: Radio System Technology TG of the Advanced ITS Info-communication Systems Committee of the ITS Info-communications Forum, Study report on communication scenarios and requirements for "SIP Use Cases for Cooperative Driving Automation" (RC-017)

Table 4.3.1-1 **Study of communication requirements for merging / lane change assistance (2/2)**

Classification by function	a. Merging / lane change assistance					
Use case	Merging assistance based on negotiations between vehicles		Lane change assistance when the traffic is heavy		Entry assistance from non-priority roads to priority roads during traffic congestion	
No.	a-1-4		a-2		a-3	
Message name	Agreement request Update request	Agreement response Update response	Agreement request Update request	Agreement response Update response	Agreement request Update request	Agreement response Update response
Communication format	V2V	V2V	V2V	V2V	V2V	V2V
Communication counterpart	Non-specified vehicles (agreement request) Specified vehicles (update request)	Specified vehicles (requesting vehicles)	Non-specified vehicles (agreement request) Specified vehicles (update request)	Specified vehicles (requesting vehicles)	Non-specified vehicles (agreement request) Specified vehicles (update request)	Specified vehicles (requesting vehicles)
Target area (minimum range)	Within agreement request range	Within agreement request range	Within lane change request range	Within lane change request range	Within intersection request range	Within intersection request range
Number of transmitting vehicles per area	When temporarily stopping: 1 vehicle (*7) When starting to merge: 1 vehicle (*7)	When temporarily stopping: 27 vehicles (*7) When starting to merge: 36 vehicles (*7)	73 vehicles	48 vehicles	2 vehicles	68 vehicles
Required communication distance	255 m	255 m	Agreement request: 255 m Update request: 38.9 m	Agreement response: 255 m Update response: 38.9 m	111.1 m	111.1 m
Maximum relative speed	20 to 70 km/h	20 to 70 km/h	Agreement request: 0 to 120 km/h Update request: 0 to 20 km/h	Agreement response: 0 to 120 km/h Update response: 0 to 20 km/h	0 to 60 km/h	0 to 60 km/h
Maximum data size	291 bytes (41+250)	287 bytes (37+250)	291 bytes (41+250)	287 bytes (37+250)	291 bytes (41+250) (*9)	287 bytes (37+250)
Cyclic or acyclic	Acyclic	Acyclic	Acyclic	Acyclic	Acyclic	Acyclic
Transmission cycle	Not specified (*8)		Not specified (*8)		Not specified (*8)	
PAR per packet	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)
Allowable delay of radio section	Assume 100 ms as allowable delay of radio section	Assume 100 ms as allowable delay of radio section	Assume 100 ms as allowable delay of radio section	Assume 100 ms as allowable delay of radio section	Assume 100 ms as allowable delay of radio section	Assume 100 ms as allowable delay of radio section

*7 Number of vehicles assuming temporary stop scenario of merging lane length 190 m @ 70 km/h and merging start time scenario of merging lane length 255 m @ 100 km/h
*8 See explanations in sections 2.5.1.4 and 2.5.2.5 of the source materials regarding transmission cycle of use cases a-1-4., a-2., and a-3.
*9 If intersection information is not available from the dynamic map, 10 bytes should be added.

The proposed study of communication requirements for b. Traffic signal information by the TF are shown in Table 4.3.1-2.

Table 4.3.1**-2 Study of communication requirements for traffic signal information**[55]

Classification by function	b. Traffic signal information	
Use case	Driving assistance by using traffic signal information (V2I)	Driving assistance by using traffic signal information (V2N)
No.	b-1-1	b-1-2
Message name		
Communication format	V2I	V2N
Communication counterpart	Non-specified vehicles	Same as to the left
Target area (minimum range)	Passenger vehicles: Approx. 138.5 m (provisional) Large vehicles: Approx. 206.3 m (provisional) (yellow 4 sec. 60 km/h)	Same as to the left for around intersections Service area is range covered by cellular
Number of transmitting vehicles per area	See RSU installation model (https://www.soumu.go.jp/main_content/000455914.pdf section 4.2)	Same as to the left
Required communication distance	Passenger vehicles: Approx. 138.5 m (provisional) Large vehicles: Approx. 206.3 m (provisional) (yellow 4 sec. 60 km/h) Note, 700 MHz band system request value is 240 m	Same as to the left
Maximum relative speed	70 km/h	Same as to the left
Maximum data size	About 1K byte / intersection	About value in 700 MHz band system*3
Cyclic or acyclic	Cyclic	Under consideration
Transmission cycle	100 ms	
PAR per packet	At least 99% in 5 m evaluation section (*1) (same as 700 MHz band system)	Under consideration
Allowable delay of radio section	Delay not specified. Fluctuation within ±300 ms (https://www.sip-adus.go.jp/rd/rddata/rd03/205.pdf)	Consideration needed throughout system-wide delay

*1: 70 km/h is approx. 20 m/s. 250 ms required in 5 m evaluation section. Two 100 ms cycle transmissions occur within 250 ms. Cumulative packet arrival rate 99% should be satisfied with at least 90% packet arrival per packet, derived from 1-(0.1*0.1) = 0.99. Thus, 90% packet arrival rate at 100 ms allowable delay of radio section.

The proposed study of communication requirements for c. Lookahead information: Collision avoidance by the TF are shown in Table 4.3.1-3 and the proposed study of communication requirements for d. Lookahead information: Trajectory change is shown in Table 4.3.1-4.

[55]Source: Radio System Technology TG of the Advanced ITS Info-communication Systems Committee of the ITS Info-communications Forum, Study report on communication scenarios and requirements for “SIP Use Cases for Cooperative Driving Automation” (RC-017)

Table 4.3.1-3 Study of communication requirements for lookahead information: Collision avoidance[56]

Classification by function	c. Lookahead information: Collision avoidance				
Use case	Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly	Driving assistance based on intersection information	Driving assistance based on intersection information		Collision avoidance assistance by using hazard information / Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly
No.	c-1	c-2-1	c-2-2		c-3
Message name	Merged with c-3	-	Not considered	-	-
Communication format	Merged with c-3	V2V	V2I (V=>I)	V2I (I => V)	V2V
Communication counterpart	Merged with c-3	Non-specified vehicles	Not considered	Non-specified vehicles	Non-specified vehicles
Target area (minimum range)	Merged with c-3	(Communication area in which right-turning vehicle needs distributed information) - Upstream side: upstream from location right-turning vehicle turns on turn signal (point 30 m upstream stop line) - Downstream side: the point at which right turn is complete (oncoming vehicle range in which right-turning vehicle needs information) *Target lanes are all straight ahead lanes - Upstream side: Oncoming vehicle in a location to initiate a right turn at safe acceleration from the right-turn waiting point within the intersection and finish crossing the oncoming lane in a situation where waiting to turn right at the right-turn waiting point within the intersection, with the intersection center or right-turn waiting point as the base point. If the right-turn waiting point exceeds the center of the intersection, the right-turn waiting point shall be the base point, and if there are multiple right-turn waiting points, the point closer to the oncoming lane shall be used.) - Downstream side: The location not within line of sight (i.e., there is a blind spot) when looking from right-turning vehicle to oncoming vehicles moving straight through the intersection. If this position is upstream from the stop line of the lane in which the oncoming vehicles moving straight is traveling, it shall be the stop line position.	Not considered	(Communication area in which right-turning vehicle needs distributed information) Same as c-2-1	- Direct V2V communication: 250 m upstream from point where event occurs - If relay: 1 km upstream from point where event occurs

[56] Source: Radio System Technology TG of the Advanced ITS Info-communication Systems Committee of the ITS Info-communications Forum, Study report on communication scenarios and requirements for “SIP Use Cases for Cooperative Driving Automation” (RC-017)

Classification by function	c. Lookahead information: Collision avoidance				
Use case	Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly	Driving assistance based on intersection information	Driving assistance based on intersection information		Collision avoidance assistance by using hazard information / Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly
No.	c-1	c-2-1	c-2-2		c-3
Number of transmitting vehicles per area	Merged with c-3	(Number of lanes in one direction: 6; oncoming vehicle speed: 70 km/h) 348 vehicles (Number of lanes in one direction: 3; oncoming vehicle speed: 70 km/h) 125 vehicles	Not considered	N/A	(Vehicle speed: 120 km/h; intervehicle distance: 2 s) 79 vehicles (Vehicle speed: 60 km/h; intervehicle distance: 1 s) 277 vehicles (Total vehicles for 6 lanes in 1 km section from point where emergency action occurs
Required communication distance	Merged with c-3	(Number of lanes in one direction: 6; oncoming vehicle speed: 70 km/h) 190 vehicles (Number of lanes in one direction: 3; oncoming vehicle speed: 70 km/h) 135 m	Not considered	Dependent on road infrastructure antenna location. The following if roadside infrastructure antenna installed at side of intersection and antenna height 6 m: (No. of lanes on one side: 6) 75.2 m (No. of lanes on one side: 3) 52.4 m	- Direct V2V communication: 250 m upstream from point where event occurs - If relay: 1 km upstream from point where event occurs
Maximum relative speed	Merged with c-3	Up to 70 km/h	Not considered	Up to 70 km/h	Up to 120 km/h
Maximum data size	Merged with c-3	282 bytes	Not considered	(No. of lanes on one side: 6) 1534 bytes (No. of lanes on one side: 3) 1150 bytes (*1)	312 bytes
Cyclic or acyclic	Merged with c-3	Cyclic	Not considered	Cyclic	Cyclic
Transmission cycle	Merged with c-3	100 ms	Not considered	100 ms	100 ms
PAR per packet	Merged with c-3	PAR ≥ 99% (provisional value in WG2. Value scrutinized as needed.)	Not considered	PAR ≥ 99% (provisional value in WG2. Value scrutinized as needed.)	PAR ≥ 99% in direct V2V communication (provisional value in WG2. Value scrutinized as needed.)

Classification by function	c. Lookahead information: Collision avoidance				
Use case	Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly	Driving assistance based on intersection information	Driving assistance based on intersection information		Collision avoidance assistance by using hazard information / Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly
No.	c-1	c-2-1	c-2-2		c-3
Allowable delay of radio section	Merged with c-3	Assume [100] ms as allowable delay of radio section (provisional value in WG2. Value scrutinized as needed.)	Not considered	Assume [100] ms as allowable delay of radio section (provisional value in WG2. Value scrutinized as needed.)	- Up to 255 m upstream from place where emergency avoidance action occurs: within [100] ms - Points upstream from the above: up to 1 km upstream, relax to as much as 30 s based on distance (provisional value in WG2. Value scrutinized as needed.)

*1: Message size when traffic signal information, intersection identification information, and vehicle detection information are sent together in a single message. If each piece of information is sent in a separate message, the security overhead is taken into account for each piece of information.

Table 4.3.1-4 Study of communication requirements for lookahead information: Trajectory change[57]

Classification by function	d. Lookahead information: Trajectory change			
Use case	Traffic congestion assistance at branches and exits		Driving assistance based on hazard information	
No.	d-4		d-5	
Message name				
Communication format	V2I	V2N	V2I	V2N
Communication counterpart	Non-specified vehicles present in areas where hazard information can be effectively used	Non-specified vehicles present in areas where hazard information can be effectively used	Non-specified vehicles present in areas where hazard information can be effectively used	Non-specified vehicles present in areas where hazard information can be effectively used
Target area (minimum range)	Minimum 66.6 m and up	Event occurrence point to 1 km (provisional) and one branch or exit previous upstream to 1 km upstream	Minimum 66.6 m and up	Event occurrence point to 1 km (provisional)
Number of transmitting vehicles per area	Uplink: Number of abnormal vehicles (ordinarily 1 vehicle) Downlink: Broadcast	Uplink: Number of abnormal vehicles (ordinarily 1 vehicle) Downlink: 570 (unicast assumed)	Downlink: Broadcast	Downlink: 285 (unicast assumed)
Required communication distance	Minimum 66.6 m and up	From 255 m to 1 km upstream from the event occurrence point (provisional) As service provision range	Minimum 66.6 m and up	From 255 m to 1 km upstream from the event occurrence point (provisional) As service provision range
Maximum relative speed	20 km/h to 120 km/h	20 km/h to 120 km/h	20 km/h to 120 km/h	20 km/h to 120 km/h
Maximum data size	715 Bytes (465+250)	715 Bytes (465+250)	715 Bytes (465+250)	715 Bytes (465+250)
Cyclic or acyclic	Cyclic	Cyclic	Cyclic	Cyclic
Transmission cycle	Minimum 1 second	Minimum 7.65 sec.	Minimum 1 second	Minimum 7.65 sec.
PAR per packet	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)
Allowable delay of radio section	Not specified	Not specified	Not specified	Not specified

[57]Source: Radio System Technology TG of the Advanced ITS Info-communication Systems Committee of the ITS Info-communications Forum, Study report on communication scenarios and requirements for "SIP Use Cases for Cooperative Driving Automation" (RC-017)

The proposed study of communication requirements for e. Lookahead information: Emergency vehicle notification by the TF are shown in Table 4.3.1-5 and the proposed study of communication requirements for f. Information collection / distribution by infrastructure is shown in Table 4.3.1-6.

Table 4.3.1-5 Proposed study of communication requirements for lookahead information: Emergency vehicle notification[58]

Classification by function	e. Lookahead information: Emergency vehicle notification	
Use case	Driving assistance based on emergency vehicle information	
No.	e-1	
Message name		
Communication format	V2V	V2N
Communication counterpart	Non-specified vehicles present in areas where emergency vehicle information can be effectively used	Non-specified vehicles present in areas where emergency vehicle information can be effectively used
Target area (minimum range)	150 m semicircle	General road: Semicircle with radius of 700 m Expressway: Semicircle with radius of 1000 m
Number of transmitting vehicles per area	Downlink: Broadcast	Uplink: Number of emergency vehicles (ordinarily 1) Downlink: 285 (provisional, unicast assumed)
Required communication distance	Minimum 150 m	General road: Semicircle with radius of 700 m Expressway: Semicircle with radius of 1000 m
Maximum relative speed	20 km/h to 120 km/h	20 km/h to 120 km/h
Maximum data size	302 Byte (52+250)	1035 Bytes (785+250)
Cyclic or acyclic	Cyclic	Cyclic
Transmission cycle	100 ms	Minimum 7.65 sec.
PAR per packet	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)
Allowable delay of radio section	V2V: 100 ms or less	Not specified

[58]Source: Radio System Technology TG of the Advanced ITS Info-communication Systems Committee of the ITS Info-communications Forum, Study report on communication scenarios and requirements for “SIP Use Cases for Cooperative Driving Automation” (RC-017)

Table 4.3.1-6 Study of communication requirements for information collection/distribution by infrastructure[59]

Classification by function	f. Information collection / distribution by infrastructure			
Use case	Request for rescue (e-Call)	Collection of information to optimize the traffic flow	Update and automatic generation of maps	Distribution of dynamic map information
No.	f-1	f-2	f-3	f-4
Message name				
Communication format	V2N	V2I/V2N	V2N	V2N
Communication counterpart	Non-specified vehicles	Non-specified vehicles	Non-specified vehicles	Non-specified vehicles
Target area (minimum range)	Communication area of public network by telecommunication carrier	V2I：Circle with a radius of 171.8 m (*1) V2N: Communication area of public network by telecommunication carrier	Communication area of public network by telecommunication carrier	Communication area of public network by telecommunication carrier
Number of transmitting vehicles per area	Not specified	V2I: 389 vehicles (maximum case) (*1) V2N: Not specified	Not specified	Not specified
Required communication distance	-	V2I: Minimum 33.3 m * Travel distance in 1 second when driving at 120 km/h	-	-
Maximum relative speed	20 km/h to 120 km/h	20 km/h to 120 km/h	20 km/h to 120 km/h	20 km/h to 120 km/h
Maximum data size (*2)	Uplink：675 Bytes (425+250) Downlink: Not specified *Voice always communicated during communication for both Uplink and Downlink in addition to the above	Uplink：279 Bytes (29+250) Downlink: Not specified	Uplink: 20.5M Bytes (including image data (up to 5 images)) Downlink: Not specified	Uplink: Not specified Downlink: 67 Mbps (maximum case)
Cyclic or acyclic	Acyclic	Cyclic	Acyclic	Acyclic
Transmission cycle *3	-	V2I: Minimum 1 second V2N: Minimum 1 minute	-	-
PAR per packet (*4)	-	V2I: PAR ≥ 99% (provisional)	-	-
Allowable delay of radio section	Not specified	Not specified	Not specified	Not specified

*1: Assumes communication area: 171.8 m (360°), maximum three lanes in one direction, two-way intersection, vehicle speed 20 km/h, vehicle interval 1 s, average vehicle length 5 m. Transmitting vehicles per area: 171.8×3×2×4÷(5.6×1+5) ＝ 389 vehicles)

*2: Indicates data size at application layer.

*3: Indicates transmission cycle at application layer.

*4: Indicates PAR at radio layer.

[59]Source: Radio System Technology TG of the Advanced ITS Info-communication Systems Committee of the ITS Info-communications Forum, Study report on communication scenarios and requirements for “SIP Use Cases for Cooperative Driving Automation” (RC-017)

The proposed study of communication requirements for g. Platooning / adaptive cruise control by the TF is shown in Table 4.3.1-7 and the proposed study of communication requirements for h. Remote control is shown in Table 4.3.1-8.

Table 4.3.1-7 Study of communication requirements for platooning and adaptive cruise control[60]

Classification by function	g. Platooning / adaptive cruise control		
Use case	Unmanned platooning of following vehicles by electronic towbar (Non-rich content)	Unmanned platooning of following vehicles by electronic towbar (Rich content)	Adaptive cruise control and manned platooning of following vehicles using adaptive cruise control
No.	g-1	g-1	g-2
Message name			
Communication format	V2V	V2V	V2V
Communication counterpart	Specified vehicles (use one-to-N to achieve one-to-one)	Specified vehicles (use one-to-N to achieve one-to-one)	Non-specified vehicles
Target area (minimum range)	Relative distance about 60 m	Relative distance about 60 m	141 m
Number of transmitting vehicles per area	3 vehicles	3 vehicles	Calculated with 4 vehicles
Required communication distance	Relative distance about 60 m	Relative distance about 60 m	141 m
Maximum relative speed	Large vehicles 80 km/h	Large vehicles 80 km/h	Passenger vehicles 100 km/h; large vehicles 80 km/h
Maximum data size	Up to same as 700 MHz band system	(*1)	Up to same as 700 MHz band system
Cyclic or acyclic	Cyclic	(*1)	Cyclic
Transmission cycle	100 ms, in emergencies 20 ms	(*1)	100 ms
PAR per packet	Ordinarily 98%/100 ms, in emergencies 99.99%/100 ms	(*1)	95% packet accumulation rate in 10 m of travel (same as 700 MHz band system)
Allowable delay of radio section	100 ms (intervehicle distance 10 m; speed 80 km/h)	(*1)	100 ms or less

*1: Full high-definition real-time communication is needed and United Nations Economic Commission for Europe Regulation 46 electronic mirror regulations can be used as a reference for delay and communication quality in the camera-to-display section. However, the delay for encoding and decoding images will differ depending on what image encoding method is used, resulting in different transmission bandwidth and communication delay required for the radio section. It is necessary to specify the communication delay in the radio section, taking into account implementation of the delay in the camera and display as well. From these, specific content and size cannot be specified in this document.

[60]Source: Radio System Technology TG of the Advanced ITS Info-communication Systems Committee of the ITS Info-communications Forum, Study report on communication scenarios and requirements for “SIP Use Cases for Cooperative Driving Automation” (RC-017)

Table 4.3.1-8 Study of communication requirements for remote control[61]

Classification by function	h. Remote control	
Use case	Operation and management of mobility service cars (Instructions for remote control outside ODD conditions)	Operation and management of mobility service cars (Instructions for travel route under ODD conditions)
No.	h-1a	h-1b
Message name		
Communication format	V2N	V2N
Communication counterpart	Non-specified vehicles	Non-specified vehicles
Target area (minimum range)	Communication area of public network by telecommunication carrier	Communication area of public network by telecommunication carrier
Number of transmitting vehicles per area	Not specified	Not specified
Required communication distance	-	-
Maximum relative speed	T.B.D.	T.B.D.
Maximum data size (*1)	Uplink: Video information around vehicle, remote control request Downlink: Remote control data (when remote control is implemented)	Uplink: Video information around vehicle, route instruction request Downlink: Travel route (when travel route instruction is implemented)
Cyclic or acyclic	Acyclic	Acyclic
Transmission cycle (*2)	-	-
PAR per packet (*3)	T.B.D.	T.B.D.
Allowable delay of radio section	T.B.D.	T.B.D.

*1: Indicates data size at application layer.
*2: Indicates transmission cycle at application layer.
*3: Indicates PAR at radio layer.

[61]Source: Radio System Technology TG of the Advanced ITS Info-communication Systems Committee of the ITS Info-communications Forum, Study report on communication scenarios and requirements for “SIP Use Cases for Cooperative Driving Automation” (RC-017)

(1) Communication characteristics and requirements demanded for use case deployment: V2I

The communication characteristics and requirements demanded for deployment of use cases in which V2I is assumed to be the communication technology are shown in Fig. 4.3.1-1.

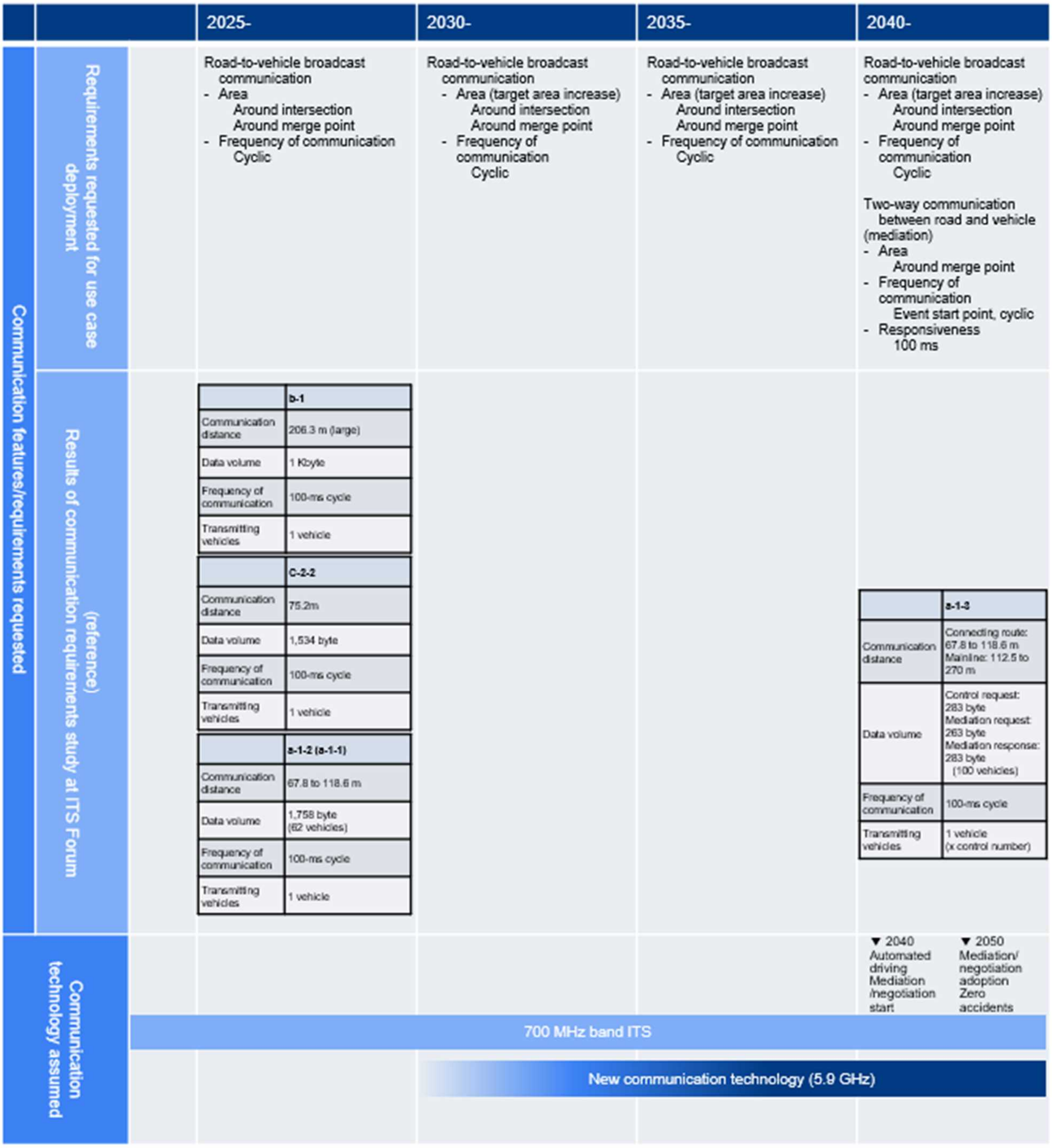


Fig. 4.3.1-1 Communication characteristics and requirements demanded for deployment of use cases (V2I)

(2) Communication characteristics and requirements demanded for use case deployment: V2V

The communication characteristics and requirements demanded for deployment of use cases in which V2V is assumed to be the communication technology are shown in Fig. 4.3.1-2.

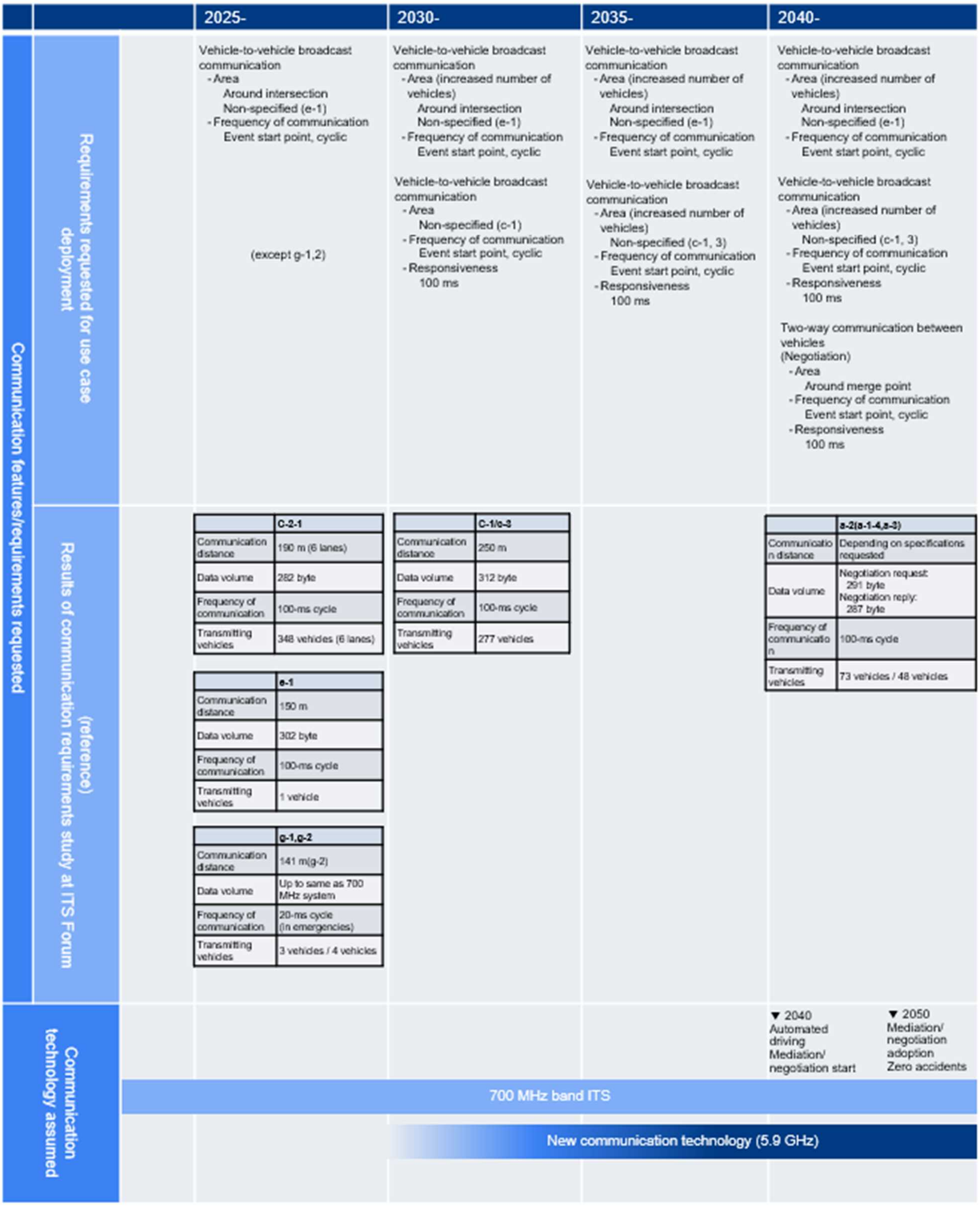


Fig. 4.3.1-2 Communication characteristics and requirements demanded for deployment of use cases (V2V)

(3) Communication characteristics and requirements demanded for use case deployment: V2N

The communication characteristics and requirements demanded for deployment of use cases in which V2N is assumed to be the communication technology are shown in Fig. 4.3.1-3.

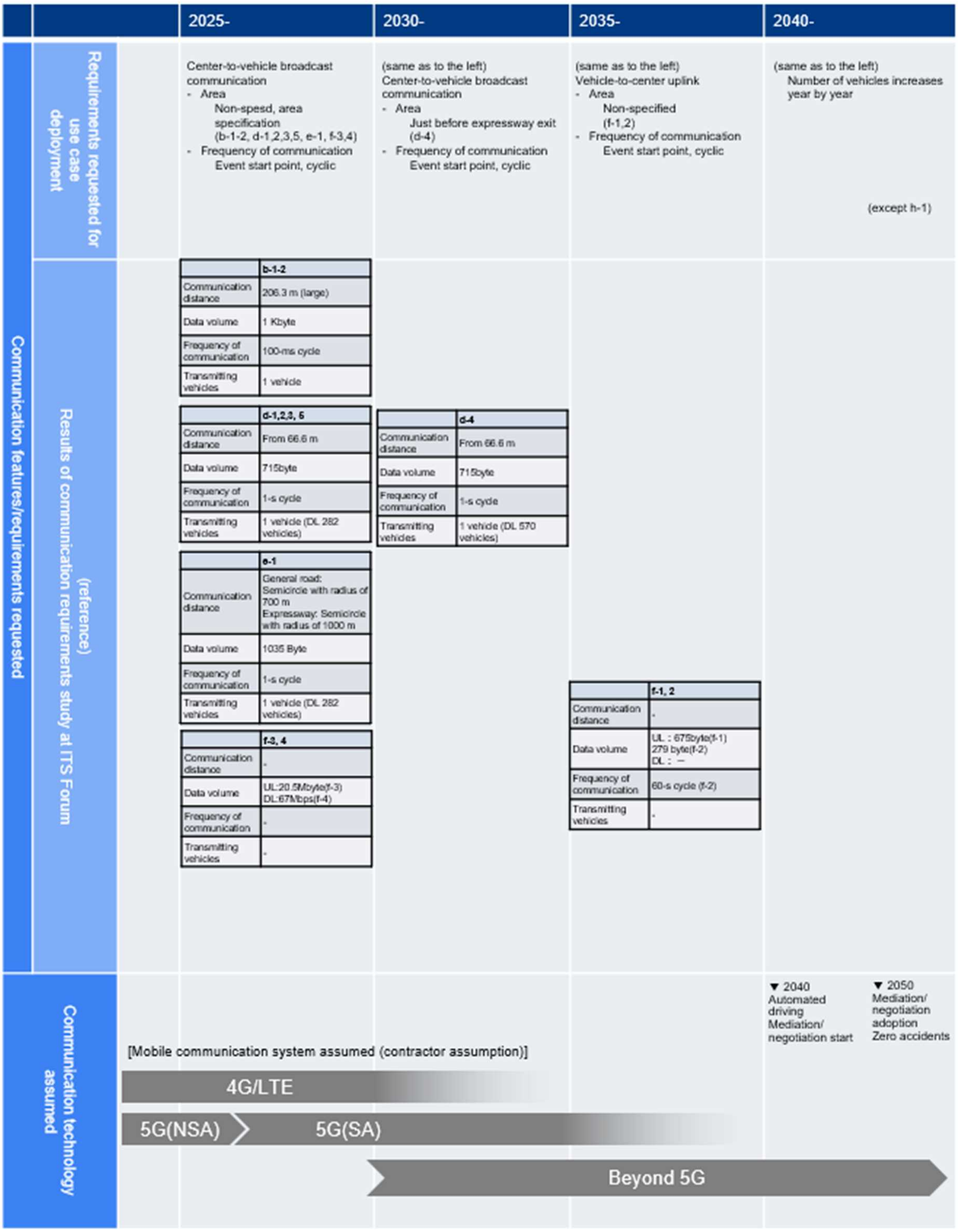


Fig. 4.3.1-3 Communication characteristics and requirements demanded for deployment of use cases (V2N)

4.3.2 Issues in realizing communication requirements

As shown in 4.3.1, the communication requirements for the 25 SIP cooperative driving automation use cases were studied by the ITS Forum.

In this project, for the V2V/I use cases out of the 25, the communication requirements studied by the ITS Forum were referenced, and compatibility of 700 MHz band ITS and 5.9 GHz band C-V2X (V2V/I), respectively, to the communication requirements of the use cases was verified and evaluated. Issues that need to be addressed to realize communication requirements were organized based on the results of this verification.

(1) Evaluation of 700 MHz band ITS

The following has been confirmed from the simulation results based on the communication requirements presented by the Radio System Technology TG.

- All I2V communication use cases (a-1-1, a-1-2, b-1-1, c-2-2, d-5) met communication requirements (delay: within 100 ms, PAR: 99% or less).
- In V2I communication and V2V communication,
    - d-1 to d-4, and f-2 met communication requirements (delay: within 1 sec, PAR: 99% or less).
    - For other use cases, communication requirements (delay: within 100 ms, PAR: 99% or less) were not met due to interference. However, for use cases that only send and receive basic messages (BM), the communication requirements can be met by revising the conditions.
- The communication requirements were not met for the negotiation part in negotiation use cases (a-1-4, a-2, a-3) and the agreement part in the agreement use case (a-1-3).
  ⇒ Introducing new communication technologies needs to be considered.
- Regarding the impact on existing services, communication requirements being met had been confirmed.
- Since the allowable communication delay (within 20 ms) in an emergency has not been reached, g-1 cannot be handled (from desktop study).

It has also been confirmed that the minimum requirements of communication technologies to realize service must be discussed (quality, distance, delay).

From the results above, the following were derived as 700 MHz band ITS issues.

- I2V communication can be realized with 700 MHz band ITS.
- V2I/V2V communication can be realized with 700 MHz band ITS by revising some conditions.
  (Based on more detailed communication requirements, a feasible range for 700 MHz band ITS needs to be continued to be studied.)
- Negotiation and agreement have not met communication requirements in the 700 MHz band ITS.

(2) Evaluation of narrow-area communication (5.9 GHz band C-V2X (V2I/V))

Simulation results at 10 MHz communication bandwidth confirm the following.

- In order to realize a single use case, communication in various requirements is mixed, and mutual influence occurs (from verification results related to a-1-3).
- In order to realize multiple use cases in the same place, communication in various requirements is mixed, and mutual influence occurs.
  (from verification around intersections where c-1, c-2-2, etc., occur)

And in actual operation, the wireless communication environment (shadowing, multipath, etc.) and the traveling vehicle environment (number of vehicles, interval) cannot be uniquely identified or limited. When communication occurs in an environment different from that expected, communication may be congested. As a result, communication delay and communication failure are thought to possibly occur.

From the results above, the following were derived as narrow-area communication (5.9 GHz band C-V2X (V2I/V)) issues.

- Securing communication bandwidth corresponding to the communication traffic, and division of communication channels according to the communication content
- Communication congestion control at a higher level according to the wireless communication environment and the traveling vehicle environment

4.3.3Study of communication conditions roadmap (draft)

Based on the studies up to this point, a communication method roadmap (draft) will be formulated. The SIP aims to realize a society in which all people can lead a high quality of life by contributing to solving social issues such as reducing traffic accidents, reducing traffic congestion, ensuring mobility for people with travel constraints, and improving and reducing the cost of driver shortage in logistics and transportation services through the practical application and expansion of automated driving. The 25 SIP use cases are for the realization of cooperative driving automation, but for use cases that contribute to safe driving, it is considered appropriate to use them not only for automated driving, but also as a safe driving support function for manual driving, which is also the purpose of the SIP.

Therefore, use cases that contribute to safe driving support were organized incorporated into both "Safe driving support" and "Cooperative driving automation."

The status of selection of the 25 SIP use cases for safe driving support and cooperative driving automation is shown in Table 4.3.3-1.

Table 4.3.3-1 Status of selection of safe driving support and cooperative driving automation use cases

Classification by function	Use case	Safe driving support	Cooperative driving automation
a. Merging / lane change assistance	a-1-1. Merging assistance by preliminary acceleration and deceleration (V2I)		✓
	a-1-2. Merging assistance by targeting the gap on the mainline (V2I)		✓
	a-1-3. Cooperative merging assistance with vehicles on the mainline by roadside control (V2I)		✓
	a-1-4. Merging assistance based on negotiations between vehicles (V2V)		✓
	a-2. Lane change assistance when the traffic is heavy (V2V)		✓
	a-3. Entry assistance from non-priority roads to priority roads during traffic congestion (V2V)		✓
b. Traffic signal information	b-1-1. Driving assistance by using traffic signal information (V2I)	✓	✓
	b-1-2. Driving assistance by using traffic signal information (V2N)	✓	✓
c. Lookahead information: collision avoidance	c-1. Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly (V2V)	✓	✓
	c-2-1. Driving assistance based on intersection information (V2V)	✓	✓
	c-2-2. Driving assistance based on intersection information (V2I)	✓	✓
	c-3. Collision avoidance assistance by using hazard information (V2V)	✓	✓
d. Lookahead information: trajectory change	d-1. Driving assistance by notification of abnormal vehicles (V2N)	✓	✓
	d-2. Driving assistance by notification of wrong-way vehicles (V2N)	✓	✓
	d-3. Driving assistance based on traffic congestion information (V2N)	✓	✓
	d-4. Traffic congestion assistance at branches and exits (V2N)	✓	✓
	d-5. Driving assistance based on hazard information	✓	✓
e. Lookahead information: emergency vehicle notification	e-1 (1). Driving assistance based on emergency vehicle information (V2V)	✓	✓
	e-1 (2). Driving assistance based on emergency vehicle information (V2N)	✓	✓
f. Information collection / distribution by infrastructure	f-1. Request for rescue (e-Call) (V2N)	✓	✓
	f-2. Collection of information to optimize the traffic flow (V2N)	✓	✓
	f-3. Update and automatic generation of maps (V2N)	✓	✓
	f-4. Distribution of dynamic map information (V2N)	✓	✓
g. Platooning / adaptive cruise control	g-1. Unmanned platooning of following vehicles by electronic towbar (V2V)		✓
	g-2 Adaptive cruise control and manned platooning of following vehicles using adaptive cruise control (V2V)		✓
h. Teleoperation	h-1. Operation and management of mobility service cars (V2N)		✓

In order to realize all 25 SIP cooperative driving automation use cases, new communication media will be needed. The start time of use cases that cannot be realized without the allocation of new communication media is assumed to be around 2040 based on previous studies, and it is assumed that new communication technologies will need to be in place from around 2030 (when automated driving will begin to be adopted) in order to be installed in 30% of cooperative driving automated vehicles in 2040, calculated backward from there.

Until new communication media is in place, it is necessary to wait for the adoption of OBU with safe driving support functions, etc., while utilizing existing ITS radio (700 MHz band), etc., and to solve issues that need to be resolved before the practical use of new communication media begins.

To realize this use case deployment plan, the following two major items are considered necessary to be implemented.

1) Approach to the practical application of the use cases

- Various issues (points) have been pointed out in the ITS Forum and TF in practical application of V2I/V/N use cases.
- It is necessary to clarify the direction of various issues (points) by such related parties through study and discussion among related parties.

2) Approach to the practical application of the new communication technologies

- It is assumed that agreement and negotiation use cases will start from 2040, when the adoption of automated vehicles is in full swing.
- With the current 10 MHz bandwidth, it will be difficult to realize agreement and negotiation use cases.
- On the other hand, the 5.9GHz band is the mainstream internationally, so new communication technology needs to be put into practical use.

Regarding 1) above, the following issues should be studied and discussed among the parties concerned to clarify the direction: formulation of security and privacy measures, formulation of a policy for sharing OBU, formulation of a policy on generational changes in communication technologies, establishment of a business model, assurance of communication quality, and clarification of the division of responsibilities. Regarding 2), study of frequency utilization, standardization and specification, and equipment development and practical application are considered necessary for the practical application of new communication technologies.

A summary of the concept of implementation items for the realization of the use case development plan is shown in Fig. 4.3.3-1.

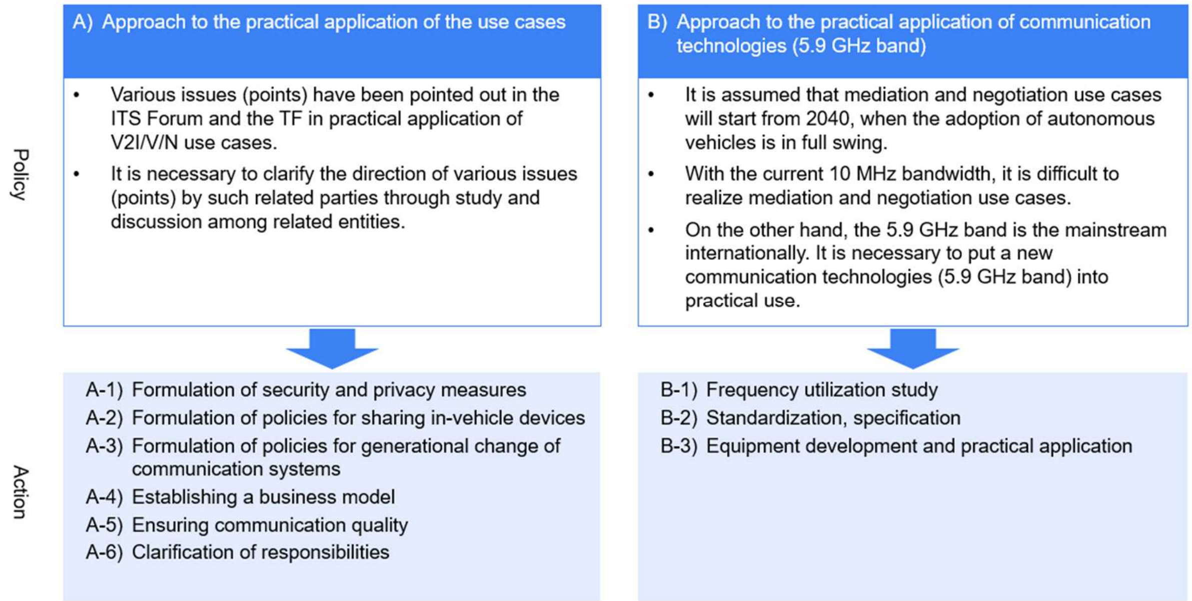


Fig. 4.3.3-1 Concept of implementation items for the realization of the use case development plan

(1) Approach to the practical application of the use cases

Items in issues brought up by the ITS Forum and TF that should be implemented for use cases in general are shown in Table 4.3.3-2.

Table 4.3.3-2 Items that should be implemented for practical application of all use cases[62]

Action	Overview of action
A-1) Formulation of security and privacy measures	• Security measures must be taken appropriately throughout the entire service, such as confirming the authenticity of information, authentication, countermeasures against tampering, and preventing the misuse of vehicle location information. • Privacy issues, such as the location of vehicles for information collection and distribution control, need to be addressed while making consistent with relevant laws and regulations.
A-2) Formulation of policies for sharing in-vehicle devices	• When multiple use cases run on OBU in V2V, V2I, and V2N (shared use), it is necessary to create rules for service introduction and service startup per each use case. • In addition, in consideration of the surrounding environment and circumstances, the user interface for what information to present to users, or the order of priority regarding what communication to send with priority, must also be studied and the necessary policies established.
A-3) Formulation of policies for generational change of communication systems	• The lifecycle of the communication technology and the lifecycle of the vehicle do not mesh, and measures to ensure service continuity are needed when the communication technology undergoes a generational change. • In preparation for new services that will start after the vehicle is manufactured, the vehicle should be equipped with functions for future services in advance, or be able to support new services later through OTA or vehicle maintenance, etc.
A-4) Establishing a business model	• Who will bear the communication costs between the vehicle and the infrastructure from what perspective needs to be sorted out. • When there are multiple stakeholders, it is necessary to develop a business model that takes into account not only communication costs but also construction and maintenance costs for information acquisition, collection, and distribution servers, etc. Issues include acceptability and profit model, especially when information senders and beneficiaries do not coincide.
A-5) Ensuring communication quality	• Particularly in the case of V2N, mechanisms to ensure real-time performance and reliability requested by the service and measures to deal with the existence of differences in area coverage are necessary.
A-6) Clarification of responsibilities	• When information is obtained via V2V, V2I, or V2N, it is necessary to clarify the concept regarding the respective role areas and responsibilities • When information passes through multiple entities before it is transmitted to the vehicle, it is necessary to clarify the concept regarding the division of responsibilities and responsibility boundary points of each in case of anomalies such as equipment failure or network failure.

Source: Additions were made by the contractor with reference to Survey Report on Advanced ITS and Automated Driving Using Cellular Communications Technologies (ITS Info-communications Forum Cellular System TG, ITS Info-communications Forum, January 2021)

[62]Source: Survey Report on Advanced ITS and Automated
Driving Using Cellular Communications Technologies
Supplementary materials: Issue Survey Report on Advanced ITS and Automated Driving Using Cellular Communications Technologies (ITS Forum May 2022)

(2) Approach to the practical application of the new communication technologies

After 2040, when the adoption of automated vehicles will be in full swing, it will be difficult to realize use cases for negotiation and agreement in both V2V and V2I with the current 10 MHz communication bandwidth, and practical application new communication technologies will be required. Internationally, the 5.9 GHz band is the mainstream, and it is considered necessary to put the 5.9 GHz band to practical use as a new communication technology in Japan.

A list of items to be implemented in the practical application of new communication technologies, based on the expected use cases, international trends, and the process of practical application of wireless systems, is shown in Table 4.3.3-3.

Table 4.3.3-3 Approach to practical application of new communication technologies

Action	Overview of action
B-1) Frequency utilization study	• Study of communication technology necessary to realize mediation and negotiation use cases envisioned after 2040, when the adoption of autonomous vehicles will be in full swing • Study and verification of frequency channel allocation according to communication content and traffic, and communication congestion control at a higher level
B-2) Standardization, specification	• Study and formulation of communication protocols and message format standards based on the demonstration results of each use case, study and formulation of common specifications across applications such as OBU and RSU, and establishment of a connectivity verification scheme for OBU • Study and formulation of communication protocols and message formats for the above, and application-specific specifications (service details, service levels, system configuration, etc.) • Publication of the formulated standards and specifications and their release to the necessary entities
B-3) Equipment development and practical application	• Development of base stations and radio stations based on the standards and specifications • Verification of operation through trials, acquisition of knowledge through test operations toward actual service operation, and modification as necessary • Sales of products for actual deployment and maintenance of base stations, etc. • Full-scale operation of services after confirmation through test operations

The basic concept of the roadmap is based on the assumption that new communication technologies for V2I/V2V will be required around 2040 to realize all 25 use cases of cooperative driving automation, based on the studies to this point.

In order to be installed in 30% of cooperative driving automated vehicles in 2040, new communication technologies must be in place from around 2030 (when automated driving will begin to be adopted). For use cases that start early, it is expected that existing ITS radio (700 MHz band) will be utilized. Moreover, it will be necessary to discuss and clarify direction for the following issues: Security and privacy measures, policy on sharing OBU, Policy on generational change of equipment, business model, ensuring communication quality, division of responsibilities.

Based on this concept, the implementation items for the realization of the use case deployment plan were detailed, and a roadmap for cooperative driving automation communication technologies was created. The roadmap for communication technologies is shown in Fig. 4.3.3-2.

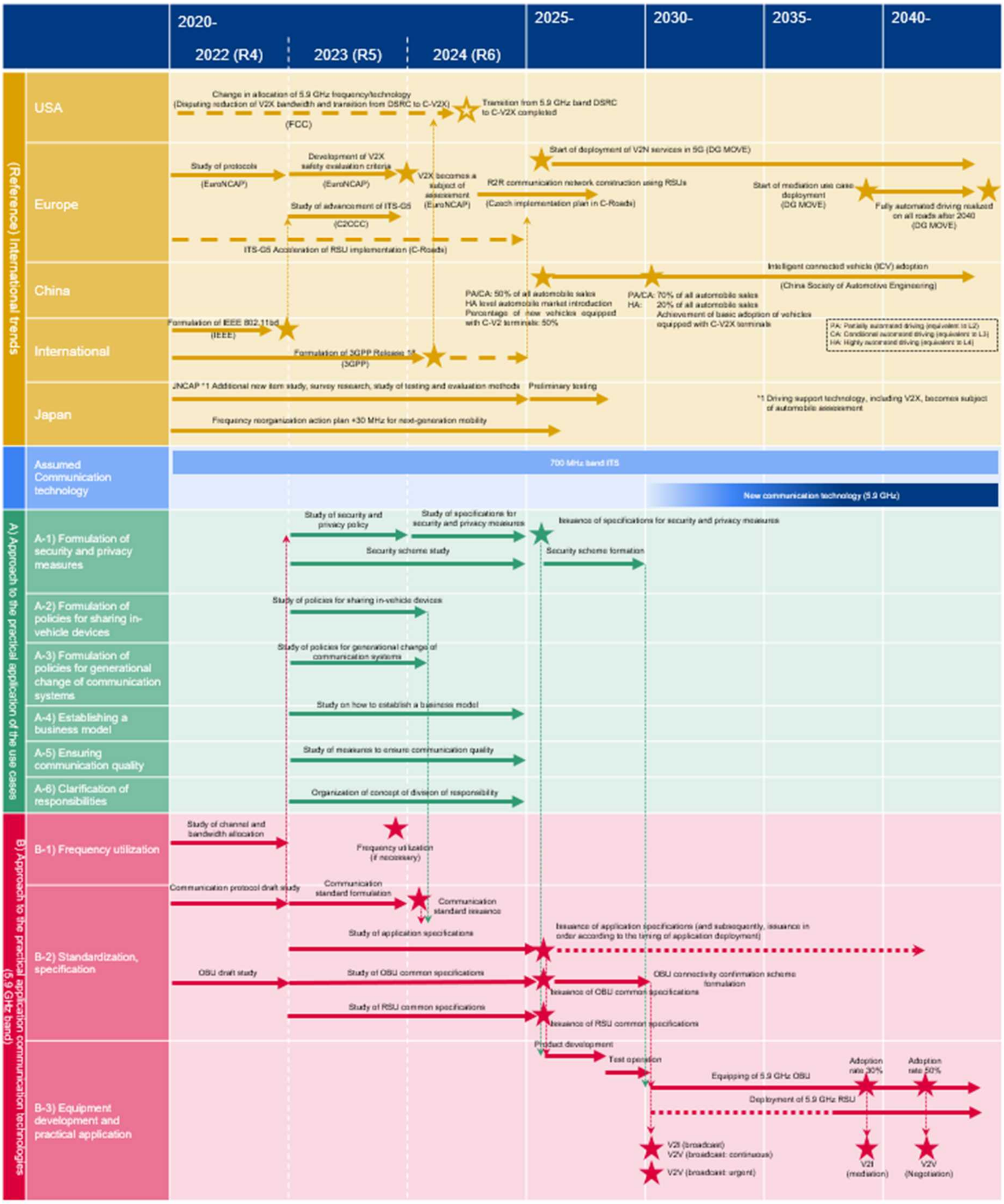


Fig. 4.3.3-2 Roadmap for cooperative driving automation communication technologies (draft)

5. Summary

This project, for use cases of cooperative driving automation expected to use V2X created at the study by the SIP Phase 2 Task Force on V2X Communication for Cooperative Driving Automation, formulated a roadmap for the social implementation of communication technologies necessary for realizing an automated driving society, taking into account the examination, verification, and demonstration of technical feasibility of communication, such as specific requirements for radiocommunication technology.

This roadmap was compiled through discussions among members including academic experts, relevant government ministries and agencies, industry associations (automobile industry, electronics industry), and others in the TF, and is based on current technological development and practical application trends in telecommunications from October 2021 to March 2022. It is assumed that each use case will be deployed sequentially according to the roadmap to achieve cooperative driving automation.

As of March 2022, 700 MHz band ITS is currently in practical use as a communication technology. However, results of verification show it will be difficult for current communication technology to meet all communication requirements, at least for agreement and negotiation, while continued studies are needed based on more detailed communication requirements for some use cases. For this reason, new communication technology (5.9 GHz) must be utilized to realize cooperative driving automation.

As shown in Fig. 4.3.3-2, the practical application period of use cases requiring agreement and negotiation is expected to be around 2040. In order to have a certain amount of OBU in place by then, assuming that the practical application period of the new communication method will be around 2030, study of frequency utilization, standardization and specification, and equipment development and practical application are considered necessary.

And to put use cases into practical application, it is necessary to discuss and clarify direction on the following diverse related issues: security and privacy measures related to communication technologies and service provided, policy on sharing OBU, policy on generational change of equipment, business model, ensuring communication quality, division of responsibilities.

In the future, we hope that efforts to realize cooperative driving automation will be promoted by sharing and examining the roles of stakeholders, including not only in telecommunications but also vehicles and infrastructure, starting with this roadmap and use cases, and deepening discussions and collaboration across industries.

And it is desirable that related entities continue to review this roadmap, taking into account future social trends, technological progress, and the progress of implementation items in the roadmap.

6. TF ITS Forum activities record

In proceeding with this commissioned research, we attended the TF and ITS Forum, reported on the contents of the study, and received opinions from the TF and ITS Forum members, which were reflected in the commissioned research.

6.1 Report to TF

The following is a summary of the results of participation in the TF and the contents of the report.

6.1.1 Results of participation

Meetings held during the period and participated in are as follows.

Table 6.1.1-1 Results of participation in TF

No.	Date held	Meeting
1	April 8, 2021	13th Task Force on V2X Communication for Cooperative Driving Automation
2	May 13, 2021	14th Task Force on V2X Communication for Cooperative Driving Automation
3	June 3, 2021	15th Task Force on V2X Communication for Cooperative Driving Automation
4	July 1, 2021	16th Task Force on V2X Communication for Cooperative Driving Automation
5	August 5, 2021	17th Task Force on V2X Communication for Cooperative Driving Automation
6	September 2, 2021	18th Task Force on V2X Communication for Cooperative Driving Automation
7	October 7, 2021	19th Task Force on V2X Communication for Cooperative Driving Automation
8	November 4, 2021	20th Task Force on V2X Communication for Cooperative Driving Automation
9	December 2, 2021	21st Task Force on V2X Communication for Cooperative Driving Automation
10	January 6, 2022	22nd Task Force on V2X Communication for Cooperative Driving Automation
11	February 3, 2022	23rd Task Force on V2X Communication for Cooperative Driving Automation
12	March 3, 2022	24th Task Force on V2X Communication for Cooperative Driving Automation

6.1.2 Report contents, comments/suggestions, and status of response

Main report contents, comments/suggestions, and status of responses for each time participated are as follows.

Table 6.1.2-1 Report contents, comments/suggestions (1/3)

Times participated	Report contents	Related comments / suggestions	Response
13	Explanation on progress	• How is communication with the management server controlled? • Is broadcast possible? • What is the division of roles between V2N and V2I?	• It is assumed that a management server will be defined for each service. • We are aware that this is not done by current carriers, but we are including it in the study in anticipation of future possibilities. • After a thorough investigation of use cases, this will be studied taking into account communication frequency and response.
14	Explanation on use cases	• One major point is whether or not signal information can be determined in front, including the delay. • Is 32-bit sufficient for vehicle ID? Is it assumed that distribution can be done to automakers around the world?	• Study, including for communication requirements, is underway. • How vehicle IDs should be defined will be discussed after organizing the vehicle information collection path and the overall data exchanged.
15	Explanation on use case h-1	• Instead of lumping all together as “automated driving,” wouldn’t it be better to proceed with studies on a function-by-function basis or to discuss upon clarifying which areas should be discussed?	• In order to avoid ending up with only the results being noted and the preconditions differing, we will keep in mind that we can proceed with the discussion at future TF meetings upon showing the conditions of review in turn and clearly indicating the items to be confirmed.
16	Explanation of the status of the study of communication requirements and the policy for studying the roadmap	• Since reallocation of wireless resources is expected to occur frequently on the town, the impact of this reallocation needs to be verified. • The roadmap should cover both automated driving and driving support the same as in use cases. Having a timeline that includes cost and reliability perspectives is desirable.	• This will be taken into account when studying verification conditions. • Comments will be taken into consideration.
17	Explanation on status of studying communication requirements	• Can the narrow-area dedicated frequency band be used for wide-area as well, or does another frequency band need to be secured?	• They are separated by narrow-area and wide-area. For wide-area, it is assumed that the existing public network will be used, but if there is a limit to the amount of communication delay reduction, it is assumed that desktop studies will be conducted, including those on dedicated frequency bands.

Table 6.1.2-1 Report contents, comments/suggestions (2/3)

Times participated	Report contents	Related comments / suggestions	Response
18	Explanation of the status of studying communication technologies and studying the roadmap	• Since the number of years a car is in use is longer than the span of cellular generational change, V2N should be designed to guarantee service provision for a certain long period of time (e.g., 10 years after the cessation of service announcement).	• This is a very important point of discussion, and it will be studied in the future.
19	Explanation on status of studying communication technologies	• The verification conditions are not thought to be sufficient for the a-1-3 sequence.	• The concept of sequence in verification will be reorganized.
20	Explanation of the status of studying communication technologies and studying the roadmap	• In studying the roadmap, it is necessary to consider mechanisms to ensure continuity of services even if the lifecycle is different, network failures, privacy measures, etc.	• The conditions and issues will be sorted out in organizing the roadmap.
21	Explanation of the status of studying communication technologies and studying the roadmap	• What do you think about dealing with attenuation due to shielding? • The roadmap should clearly state the assumed points to consider (standardization, network reliability, generational change, etc.).	• Additional verification will be conducted as needed after reviewing the demonstration results. • In future studies, this will be considered as a necessary point to consider for realizing the service.
22	Explanation of the status of studying communication technologies and studying the roadmap	• Instead of fixed congestion control, congestion control combined with priority control based on vehicle status must be studied.	• We recognize the need to make decisions based on the wireless environment, vehicle driving environment, vehicle situations, and other factors, and we believe that this will be an important theme for future study.
23	Explanation of the status of studying communication technologies and studying the roadmap	• How would you summarize the formation of complex radio environment created by reflections from surrounding vehicles and structures?	• We are considering a direction of identifying the radio environment for each situation and performing congestion control accordingly.
24	Explanation of the results of studying communication technologies and the roadmap	• Care should be taken to inform about the roadmap in a factually neutral manner so that those who see it will not have misunderstandings.	• Expressions will be modified to avoid misunderstandings.

6.2 Report to ITS Forum

The following is a summary of the results of participation in the ITS Forum and the contents of the report.

6.2.1 Results of participation

Meetings held during the period and participated in are as follows.

Table 6.2.1-1 Results of participation in Cellular System TG

No.	Date held	Meeting
1	August 27, 2021	28th Cellular System TG
2	September 29, 2021	29th Cellular System TG
3	October 28, 2021	30th Cellular System TG
4	November 26, 2021	31st Cellular System TG
5	December 24, 2021	32nd Cellular System TG
6	January 26, 2022	33rd Cellular System TG
7	February 10, 2022	34th Cellular System TG
8	February 21, 2022	35th Cellular System TG

Table 6.2.1-2 Results of participation in Radio System Technology TG

No.	Date held	Meeting
1	April 15, 2021	147th Radio System Technology TG
2	May 20, 2021	148th Radio System Technology TG
3	June 21, 2021	149th Radio System Technology TG
4	July 21, 2021	150th Radio System Technology TG
5	August 19, 2021	151st Radio System Technology TG
6	September 21, 2021	152nd Radio System Technology TG
7	October 19, 2021	153rd Radio System Technology TG
8	November 16, 2021	154th Radio System Technology TG
9	December 21, 2021	155th Radio System Technology TG
10	January 18, 2022	156th Radio System Technology TG
11	February 15, 2022	157th Radio System Technology TG

6.2.2 Report contents, suggestions, status of reflection

Main report contents, comments/suggestions, and status of responses for each time participated are as follows.

Table 6.2.2-1 Report contents, comments/suggestions (Cellular System TG) (1/2)

Times participated	Report contents	Related comments / suggestions	Response
28	Explanation of wide-area and narrow-area communication technologies as communication technologies to realize cooperative driving automation use cases	• (Wide-area communication) A survey should be done to determine whether it should be a multi-operator or single-operator. • (Narrow-area communication) Is LTE-V2X being studied for V2V/V2I?	• Will study. • Will the model to be LTE.
29	Explanation of wide-area and narrow-area communication technology demonstration testing for communication technology to realize cooperative driving automation use cases	• (Wide-area communication) Remote is a future issue as a timeline. What are issues for the near future? • (Narrow-area communication) Retransmission greatly affects delay, so it should be made clear. • (Demonstration testing) Definition of interference should be confirmed. The location and height of the interfering vehicle is important.	• As a result of organizing use cases using V2N, remote control remained as a use case that requires more communication performance. • Simulation conditions will be confirmed. • Simulation of multiple vehicles and creation of simulated source of interference will be studied.
30	Explanation of communication technologies to realize cooperative driving automation use cases	• Will issues be narrowed down to V2N? Will V2V and V2I be studied separately?	• Although limited to V2N in the materials, V2V and V2I will be included and organized in studying the roadmap.
31	Explanation of test results of communication technologies to realize cooperative driving automation use cases	• Evaluation results need to be separated (simulator constraints or PC5 design).	• Summary will be made in a manner where there are no misunderstandings.
32	Explanation of verification results of communication technologies to realize cooperative driving automation use cases and roadmap	• The contents that should be implemented (HARQ, reception diversity, etc.) and the improvement techniques that would normally be applied are not applied. In the summary or discussion, adding a statement such as "It is assumed that improvement will be achieved if the improvement function is included" should be considered.	• Considerations and conditions will be clearly stated in the report to avoid any misunderstanding.
33	Explanation of test results of communication technologies to realize cooperative driving automation use cases	• A notation that use cases and precondition handled are quite different for C-V2X and 700M should be added.	• Ideas behind C-V2X and 700M are quite different and there are areas that are not aligned, but the report will include their details and history.

Table 6.2.2-1 Report contents, comments/suggestions (Cellular System TG) (2/2)

Times participated	Report contents	Related comments / suggestions	Response
34	Explanation of issues in communication technologies to realize cooperative driving automation use cases	• It is recognized that the wording of the issues presented today is for reporting at the TF. How is it expected to be described in the report?	• We will consider how deep to delve into the issues at the stage of compiling the report.
35	None	• A major issue is which entity will lead the resolution of issues. Since investments will be needed to perform the service, discussions will need to take place in the organization that will make the decision.	• Determining which party will take the initiative is recognized as an issue.

Table 6.2.2-2 Report contents, comments/suggestions (Radio System Technology TG) (1/3)

Times participated	Report contents	Related comments / suggestions	Response
147	Explanation of proposed communication scenarios for use cases	• In the materials, there is mention of completion (of the study of communication requirements), but what is considered completion?	• It means that the first version has been completed in the study within the Radio System Technology TG. It is not final requirements and does not mean 100% complete.
148	Explanation of the contents of the report to the TF and the points raised	• Regarding the points made about the concept of communication delay, is it correct that the delay of the entire system will be studied and assumptions made? • The 700 MHz operator has been selected. How will the output be integrated?	• There is a need to clarify the areas studied, including assumptions. • Once the communication requirements have been determined, they are scheduled to be shared with the 700 MHz BAND ITS Implementation committee and collaboration done.
149	Explanation report contents to the TF	• The capacity when multiple cases are combined has not been studied. How do you envision proceeding in the future?	• First, the results of the study of individual use cases will be disseminated to the TG members, and then the communication performance in multiple cases will be studied.
150	Explanation on status of studies	• In the evaluation of narrow-area communication, packet arrival rate and communication distance are related to frequency bands, but what are the assumed frequency bands? • For V2N, will frequency bands and coverage remain as something to be considered in the future rather than in this R&D? Or will frequencies and coverage be excluded from study targets?	• 5.9 GHz band. 700 MHz band too will be considered. • As for V2N, we will be working on the issues or organizing future proposed countermeasures. In the future, V2N may replace narrow-area communication services, which will bring about issues in terms of coverage and the like. Recognition is that they will be discussed in a different venue.

Table 6.2.2-2 Report contents, comments/suggestions (Radio System Technology TG) (2/3)

Times participated	Report contents	Related comments / suggestions	Response
151	Explanation of the status of wide-area and narrow-area communication (CV2X) compatibility evaluation/issues and study of countermeasures, and of the status of narrow-area communication study	None	None
152	Explanation of the status of wide-area communication (V2N) compatibility evaluation/issues and study of countermeasures, and of the status of narrow-area communication (V2I/V2V) study	• What models are used for LoS and NLoS in the simulation?	• Change is only by the propagation model. For PC5, NR is also considered based on LTE.
153	Explanation of the interim report of the verification and the demonstration	• In the verification, are all vehicles set to transmit data at the same time? It is hard to imagine that being real.	• We are doing so assuming worst-case conditions, but will study again.
154	Explanation of the interim report of the verification and the demonstration	• Are the forecasts made by the TF?	• Adoption rates for automated vehicles are taken from general sources. Existing trends are taken into consideration for OBU. Discussion in the TF is forthcoming.
155	Explanation of verification and of interim report on demonstration and roadmap	• Will the evaluation be done in terms of communication traffic and bandwidth? • If the demonstration enabled diversity and the evaluation was with verification invalid, this should be clearly stated.	• Based on the results of verification to date, we plan to study the communication capacity on the desk. • It will be clearly stated upon confirmation.
156	Explanation of the results of demonstration testing and of the proposed final summary	• Regarding the assignment of communication channels, it is stated that communication channels are assigned according to the content of communication. Does this mean that frequencies should be prepared?	• The proposal is that communication channels should be separated and how to separate them needs to be considered. Consideration is needed on how to use frequencies differently from the existing 700 MHz band, including the 5.9 GHz band envisioned by the Ministry of Internal Affairs and Communications.

Table 6.2.2-2 Report contents, comments/suggestions (Radio System Technology TG) (3/3)

Times participated	Report contents	Related comments / suggestions	Response
157	Explanation of the status of roadmap formulation	• It is stated that existing ITS radio will be used until new communication is in place. If a-1-2 is implemented using existing radio, won't a-1-3, a variant of a-1-2, also use existing radio? • There are I2V, V2I, and negotiation, but some use cases use uplink/downlink. Should they be considered part of negotiation?	• Discussion is needed on how much to use existing 700M-ITS and how to use new communications such as the 5.9 GHz band, and how to divide the roles. This has not yet been decided at this time and is an issue for further study. • We believe that reorganization is necessary. The terms negotiation and agreement need to be well defined. We believe that it is also necessary to organize the contents of communication such as I2V and V2I.