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: Evaluation of 700 MHz band ITS

Report of Outcomes

May 2022

Kyocera 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

R&D Outcomes and Status

(1) R&D outcomes

The applicability of 20 cooperative driving automation use cases (below, “SIP-UC”) that include V2I and V2V (and excluding V2N) with 700 MHz Band Intelligent Transport Systems (below, "700 MHz band ITS") under the communication requirements presented by the Radio System Technology TG of the Advanced ITS Info-communication Systems Committee of the ITS Info-communications Forum (below, the "Radio System Technology TG") was evaluated through desk study and simulations and the outcomes were reported.

Desk studies confirmed the communication area and quality in environments not affected by V2I or V2V interference and confirmed evaluation of transmission time constraints. Specifically, in the confirmation of the communication area, a propagation loss model was used to find the receive power at the edge of the service area and confirm the communication area by comparing against the signal receive threshold. In the confirmation of transmission time constraints, transmission data volume was calculated taking into consideration current 700 MHz band ITS security and overhead, as based on application data size, within the communication requirements presented by the Radio System Technology TG. The study confirmed whether the transmission data volume can be transmitted within the transmission time constraints in the 100 ms cycle prescribed by the ARIB STD-T109 standard.

Additionally, a study was done on arrangement of wireless transmission slots so that there would be no interference when communication is received by the OBU caused by overlapping of transmission timing of 700 MHz band ITS V2I communication service RSUs and SIP-UC service RSUs.

For simulations, an SIP use case review model (below, “SIP-UC review model") was built, referring to “Study for the Advancement of 700 MHz Band Intelligent Transport Systems” [1], conducted in 2016. Within this model, study was done on the time when service would be provided for each use case in the nearby area and the study confirmed achievability under SIP-UC 700 MHz band ITS and the potential for coexisting with existing services.

Based on the simulation results, issues were identified, and future actions were devised for use cases where the communication requirements presented by the Radio System Technology TG were not achieved.

(2) Status

Within the study of communication methods to realize the SIP-UC, results of 700 MHz band ITS-related evaluations were presented, issues relating to the results were identified, future actions were devised, and the future outlook was presented. The results suggested that those SIP-UC that do not require interaction have the potential to be achieved under 700 MHz band ITS. In those use cases that do require interaction, an approach to achieving these using a new communication method or using both 700 MHz band ITS and a new communication method was presented as a solution.

The results of this study were input into the roadmap to be developed for the study of the cellular V2X system, which is being conducted separately from this R&D theme, and the purpose was achieved.

- **Research presentations and lectures, literature, patents, etc.**

(1) Research presentations and lectures

None

(2) Papers

None

(3) Patents, etc. (intellectual property)

None

(4) Awards received

None

(5) Efforts to disseminate results (press releases, etc.)

None

• Summary in English

Cooperative driving automation use cases in which V2X is expected to be utilized (below, "SIP-UC") were considered 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. In this research, based on the specific communication requirements and other specifications discussed for SIP-UC by the Radio System Technology TG of the Advanced ITS Info-communication Systems Committee of the ITS Info-communications Forum (below, the "Radio System Technology TG"), the feasibility of using 700 MHz Band Intelligent Transport Systems (below, "700 MHz band ITS") to support SIP-UC was evaluated through desk study and simulations. A summary is given below.

(1) Desk study

Based on the communication requirements presented by the Radio System Technology TG, this study evaluated the communication area, transmission time constraints, roadside unit installation constraints, and message sets.

- As a result of considering the allocation of wireless transmission slots (below, "slots") for roadside units, it became possible to allocate the 4 slots required for SIP-UC. Accordingly, it was confirmed that roadside-vehicle communication and inter-roadside communication can be established even if SIP-UC are added to existing ITS services.
- As a result of studying the possibility of adding SIP-UC message sets to the existing 700 MHz band ITS, it was confirmed that SIP-UC message sets can be added by utilizing the free field (optional area) of ITS Connect TD-001.
- A transmission cycle for emergencies in the g-1 use case (Unmanned platooning of following vehicles by electronic towbar) is specified as 20 ms, but since the T109 standard used in this evaluation specifies a communication cycle of 100 ms, the transmission requirement was not met.
- Some of the UCs that required interaction (a-1-3, a-1-4, a-2, a-3) did not meet the communication requirement for number of vehicles.

(2) Simulation

Based on the communication requirements presented by the Radio System Technology TG, a simulation-based evaluation was conducted to see if SIP-UC could be added to the existing 700 MHz band ITS.

- Roadside-to-vehicle communication met the requirements and was able to be added. (This was because in the desk study, the slots for roadside unit transmission time were able to be allocated to all roadside units within the range that affect each other in terms of distance without duplication, and the simulation was able to be successfully performed under those conditions)
- Vehicle-roadside communication, and some aspects of inter-vehicle communication, did not meet the requirements due to the impact of interference among onboard units (OBU). Regarding these, wireless communication delay required to satisfy the packet arrival rate and required communication distance requirements is shown.

- For the use cases where requirements were not met, as a basis for future consideration of realistic requirements when implementing these services, evaluation was also conducted to reflect changes in receiver sensitivity, availability of slots for inter-roadside communication, and vehicle density.

Based on the above results, issues were identified, and future actions devised for use cases where the communication requirements presented by the Radio System Technology TG were not met.

(3) Issues and future actions

- The issue is deeper examination of the service requirements of SIP-UC. As an action, for each use case, it is necessary to work with related organizations that have studied it to further specify service requirements based on circumstances at time of service, behavior of automated vehicles, etc., and to define practical and optimal communication requirements (communication distance, maximum acceptable delay of radio communication part, etc.) based on service requirements.
- For SIP-UC a-1-3, a-1-4, a-2, a-3 that require interaction, since the current 700 MHz band ITS specification is a broadcast protocol, supporting interaction is difficult. However, radio waves in the 700 MHz band, with their distant reach and ability to go around obstacles, are ideally used for basic exchanges for confirmation of positioning, and deeper discussion is needed on how to use 700 MHz band ITS. We have proposed two measures for the above SIP-UC. These will need to be considered in the future.

  Proposal 1: New communication method only

  A new communication method that includes recognition of surrounding conditions (position, speed information, etc.) will be used. In such cases, it is necessary to study bandwidth and transmission (propagation). In addition, relationships with existing safe driving support services need to be considered (in the case of coexistence, the impact of cost and installation is significant. Deployment and dissemination of vehicles and quality assurance are issues when transitioning to a new system).

  Proposal 2: 700 MHz band ITS + new communication method

  This proposal is for the concept of "Basic Message (BM) + Advanced Message," in which basic recognition of the surrounding situation (position, speed information, etc.) is performed by the 700 MHz band ITS, and the subsequent interactive sequence is performed by new communication methods.
- For practical application of the system, setting definitions for message set standardization, security requirements, etc., are issues. Future actions to address this issue include formulating guidelines and promoting standardization in consultation with related organizations.
- At present, there is no slot allocation rule for roadside units. Therefore, with the spread of roadside units in the future, creating rules (formulating guidelines) for efficient slot allocation remains an issue. Future actions to address this issue include promoting rulemaking in consultation with various relevant organizations.

- The g-1 use case (Unmanned platooning of following vehicles by electronic towbar) may be achieved using 700 MHz band ITS at normal states, but there is an issue with 20-ms cycle transmission during sudden braking (during emergencies). Future actions include changing the ARIB STD-T109 standard or changing requirements after deep examination of use case requirements.

The results of this study were input into the roadmap to be developed for the study of the cellular V2X system, which is being conducted separately from this R&D theme.

1. Introduction

1.1. Purpose of project

Great hopes have been pinned on the social transformation that automated driving may bring solutions to social issues like reducing traffic accidents and traffic congestion, securing means of mobility for people with transport limitations, improvement of the shortage of drivers for distribution and transportation services, and lowering costs, as well as opportunities to create new businesses. With this as the backdrop, in Cross-Ministerial Strategic Innovation Promotion Program (SIP) Phase 2 - Automated Driving (Expansion of Systems and Services), in order to overcome technological issues for the practical application of automated driving, development is being promoted, 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 studying the 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.

The purpose of this project is to verify the technical feasibility in terms of specific requirements for wireless communication technology in SIP Cooperative Driving Automation Use Cases (below, “SIP-UC”) that are expected to use V2X, which were created by the Task Force on V2X Communication for Cooperative Driving Automation (below, “the TF”) for studying cooperative driving automation communication systems.

1.2. Project overview

The project used desk study and simulations to conduct (a)–(d) below for the communication requirements (data volume, communication area, maximum acceptable delay of radio communication part, communication speed, packet arrival rate, etc. Below, the "communication requirements") required to popularize automated vehicles as examined by the Radio System Technology TG of the Advanced ITS Info-communication Systems Committee of the ITS Info-communications Forum (below, the "Radio System Technology TG").

(a) Evaluation of applicability with 700 MHz band ITS

Use desk study or simulation to evaluate applicability with narrow-area communication requirements with a 700 MHz band intelligent transportation system (below, “700 MHz band ITS”).

(b) Extraction and summary of technical issues

Extract and summarize technical issues to meet communication requirements for narrow-area communications that are not compatible based on the results of (a) above.

(c) Planning future actions for issues

Based on the issues found in (b), formulate measures to deal with the issues (measures to improve existing communications methods, etc.).

(d) Reporting to the TF and ITS Info-communications Forum and supporting preparation of reference materials

1) Report study status at meetings of the TF and ITS Info-communications Forum and at other meetings designated by the New Energy and Industrial Technology Development Organization (below, "NEDO"), the Cabinet Office, and Ministry of Internal Affairs and Communications, and appropriately reflect advice from each meeting in the conducting of the project. Participate as secretariat in these meetings as necessary. Meetings where status is to be reported shall be decided in consultation with concerned parties from NEDO, the Cabinet Office, Ministry of Internal Affairs and Communications, etc.

2) Support preparation of study reference materials for meetings of the TF (held once each month) and of the ITS Info-communications Forum (held multiple times each month). When preparing reference materials, take account of results of (a)–(c) and consultations with concerned parties, etc., from NEDO, the Cabinet Office, Ministry of Internal Affairs and Communications, the TF, and the ITS Info-communications Forum.

1.3. Research methods

The R&D organization is shown in Fig. 1-1. Kyocera met with the Radio System Technology TG of the ITS Info-communications Forum and with the 700MHz BAND ITS Implementation Committee once a month and at extraordinary meetings as appropriate. We reported at these meetings, consulted with the persons concerned there, and received support.

Kyocera pursued this R&D theme in partnership with NEC Corporation, which was commissioned to do a study on the cellular V2X method, which is being conducted separately from this theme.

Results and progress of this R&D were reported to the TF whenever needed.

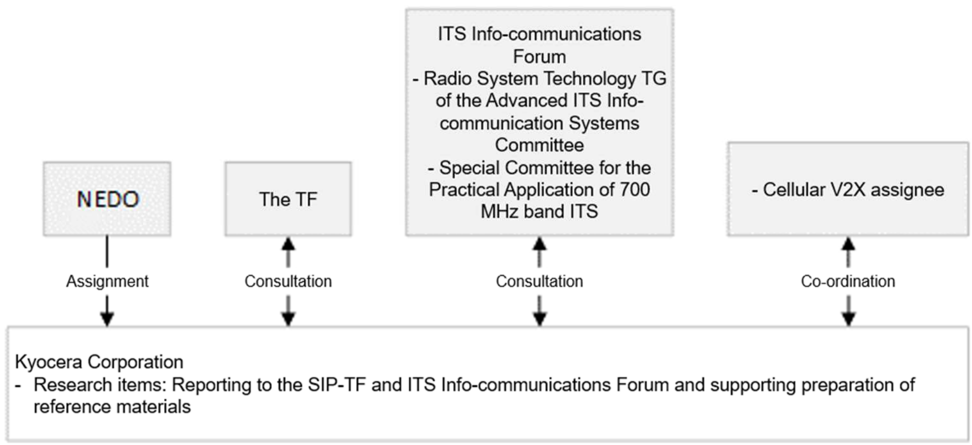


Fig. 1-1 Project organization

1.4. Overview of 700 MHz band ITS

700 MHz band ITS was instituted in December 2011 as a safe driving support system. It assists drivers in preventing accidents through V2V communication and V2I communication using frequencies in the 700 MHz band (755.5 MHz to 764.5 MHz). The 700 MHz band is characterized by good reach of radio waves even when obstructed by buildings, vehicles, and other objects, and it is expected to see a variety of uses. In V2I communications systems, RSUs provide nearby vehicles with information that is hard to detect with onboard sensors, such as traffic signal information, oncoming vehicle information, and pedestrian information. Examples of such systems include traffic signal information providing systems and right-turn collision prevention systems. In V2V communications systems, a vehicle provides information about itself (location, speed, direction, etc.) to nearby vehicles. Services are presently being offered that help prevent head-on and rear-end collisions and provide emergency vehicle information (see Table 1-1). In this R&D, V2I communications systems and V2V communications systems that are presently offered are referred to jointly as existing services.

The ARIB STD-T109 [2] standard was established by the Association of Radio Industries and Businesses as a standard governing 700 MHz band ITS. Communications specifications are listed in Table 1-2. A radio access method that shares V2V communications and V2I communications by time sharing in a single allocated transmission channel (frequency) is used as a communication method in the 700 MHz band ITS system. Transmission times for data transmitted by RSUs is allocated in advance by TDMA, while the remaining time is used by CSMA/CA in V2V communication. RSUs are time-synched to each other by GPS, etc., and the transmission timing of OBUs is based on the time transmitted by RSUs. The operator must make adjustments so that the time at which one RSU transmits does not overlap with the timing of transmissions from other RSUs. Additionally, it is possible to avoid interference between V2I and V2V by ensuring that the time at which RSUs transmit is transmitted by V2I transmissions and information is received from nearby OBUs even in OBUs that are outside the communication area for V2I communications.

In 2011, I2I communication was newly studied for the purpose of improving V2I services (for example, wide-area providing of information on traffic signals at nearby intersections and information on approaching emergency vehicles) and making traffic signal control systems more resilient. In March 2014, the ITS Info-communications Forum established “700MHz BAND INTELLIGENT TRANSPORT SYSTEMS - Experimental Guideline for Infrastructure-to-Infrastructure Communications ITS FORUM RC-012” [3]. Linking traffic signals with each other by I2I communication is expected to help build disaster-resilient infrastructure.

Table 1-1 Overview of 700 MHz band safe driving support system

	System overview	System characteristics
V2V communication	OBUs communicate with each other directly, obtain information about nearby vehicles (location, speed, etc.,), and provide safe driving support as necessary.	Can be used in non-specific places regardless of whether there is infrastructure.
V2I communication	Using communication between RSUs and OBUs, information from infrastructure (traffic signal information, regulation information, pedestrian information, etc.) is obtained and safe driving support is provided as necessary.	V2I communication can reliably provide information at the place where the RSU is located, which is expected to be useful in locations with many accidents.

*From “700 MHz band Safe Driving Support System” (https://www.soumu.go.jp/main_content/000281445.pdf)

Table 1-2 700 MHz band ITS communication specifications

	RSU	OBU
Frequency band	Over 755.5 MHz and up to 764.5 MHz	
Occupied bandwidth	9 MHz or less	
Antenna power	10 mW/MHz or less	
Modulation method	BPSK/OFDM, QPSK/OFDM, 16QAM/OFDM	
Error correction	Convolution FEC R = 1/2, 3/4	
Communication method	Broadcast	
Transmission cycle	100 ms	
Data transmission speed	3, 4, 5, 6, 9, 12, 18 Mbit/s	
Access method	TDMA	CSMA/CA
Security method	Electronic signature method + MAC method	MAC method
Transmission time	Total transmission time for any 100 ms period is 10.5 ms or less	Total transmission time for any 100 ms period is 0.66 ms or less, and the length of the transmission burst is 0.33 ms or less

Concerning security, in April 2011, the ITS Info-communications Forum established “Security Guideline for Driver Assistance Communications System ITS FORUM RC-009 Ver. 1.0” [4]. Subsequently, the Ministry of Internal Affairs and Communications established security measures, releasing “700 MHz band Safe Driving Support System Security Requirements”*1 in 2014 and “Security Guideline for Building 700 MHz Band Safe Driving Support Systems”*2 in 2015. Meanwhile, on the operating side, security information is managed and operated by an operations and management organization.

*1 https://www.soumu.go.jp/main_content/000297761.pdf

*2 https://www.soumu.go.jp/main_content/000367888.pdf

Reference works

[1] Report of the Terrestrial Radio Communications Committee, Information and Communications Technology Subcommittee, Information and Communication Council of MIC: Consultation No. 2029, dated July 28, 2009: “Technical Conditions for Advancing 700 MHz Band Intelligent Transport Systems,” in “Technical Conditions for ITS Radio Systems” https://www.soumu.go.jp/main_content/000477035.pdf

[2] ARIB STD-T109 Ver. 1.3, 700 MHz Band Intelligent Transport Systems Standard, ARIB, July 2017

[3] 700MHz BAND INTELLIGENT TRANSPORT SYSTEMS - Experimental Guideline for Infrastructure-to-Infrastructure Communications ITS FORUM RC-012 Ver. 1.1, ITS Info-communications Forum, March 31, 2014 https://itsforum.gr.jp/Public/J7Database/p59/ITS_FORUM_RC-012_v11.pdf

[4] Security Guideline for Driver Assistance Communications System ITS FORUM RC-009 Ver. 1.0, ITS Info-communications Forum, April 27, 2011 https://itsforum.gr.jp/Public/J7Database/p41/ITS_FORUM_RC009V1_0.pdf

[5] Study report on communication scenarios and requirements for "SIP Use Cases for Cooperative Driving Automation", ITS FORUM RC-017 Ver. 1.0, ITS Info-communications Forum, June 27, 2022

[6] IEEE802.11-2007 IEEE Standard for Information technology – Telecommunications and information exchange between systems – Local and metropolitan area networks – Specific requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications

[7] IEEE 802.11-14/0571r8 Appendix 3 – RBIR and AWGN PER Tables https://mentor.ieee.org/802.11/dcn/14/11-14-0571-08-00ax-evaluation-methodology.docx

[8] ITS Connect TD-001, Ver. 1.1, ITS Connect System V2V Communication Message Specification, November 2019

[9] Road Structure Ordinance, effective date November 25, 2020 https://elaws.e-gov.go.jp/document?lawid=345CO0000000320

[10] Security Guideline for Building 700 MHz Band Safe Driving Support Systems, Ver. 1.0, Ministry of Internal Affairs and Communications, July 9, 2015 https://www.soumu.go.jp/main_content/000367888.pdf

Note: the reference [5] is under translation process of as of the day of publication of this report hence the applied expression linked to communication requirement and message sets in this report might be different from the final edition of [5].

2. Evaluation method

2.1. Use cases evaluated

Under this R&D theme, of the 25 SIP-UC, 20 use cases where the communication format was V2I or V2V were evaluated. SIP-UC are listed in Table 2-1.

Table 2-1 List of SIP-UC

No.	Broad category	Middle category	Use case	Communication format
1	(1) Use cases in which information outside the detection range of on-board sensors must be obtained	a. Merging / lane change assistance	a-1-1. Merging assistance by preliminary acceleration and deceleration	V2I
2			a-1-2. Merging assistance by targeting the gap on the main lane	V2I
3		b. Traffic signal information	b-1-1. Driving assistance by using traffic signal information (V2I)	V2I
4			b-1-2. Driving assistance by using traffic signal information (V2N)	V2N
5		c. Lookahead information: Collision avoidance	c-1. Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly	V2V
6			c-2-1. Driving assistance based on intersection information (V2V)	V2V
7			c-2-2. Driving assistance based on intersection information (V2I)	V2I
8			c-3. Collision avoidance assistance by using hazard information	V2V
9		d. Lookahead information: Trajectory change	d-1. Driving assistance by notification of abnormal vehicles	V2I, V2N
10			d-2. Driving assistance by notification of wrong-way vehicles	V2I, V2N
11			d-3. Driving assistance based on traffic congestion information	V2I, V2N
12			d-4. Traffic congestion assistance at branches and exits	V2I, V2N
13			d-5. Driving assistance based on hazard information	V2I, V2N
14		e. Lookahead information: Emergency vehicle notification	e-1. Driving assistance based on emergency vehicle information	V2V, V2N
15	(2) Use cases in which information of one's own vehicle must be provided	f. Information collection / distribution by infrastructure	f-1. Request for rescue (e-Call)	V2N
16			f-2. Collection of information to optimize the traffic flow	V2I, V2N
17			f-3. Update and automatic generation of maps	V2N
18			f-4. Distribution of dynamic map information	V2N
19	(3) Use cases in which V2V and V2I interaction must be ensured	a. Merging / lane change assistance	a-1-3. Cooperative merging assistance with vehicles on the main lane by roadside control	V2I
20			a-1-4. Merging assistance based on negotiations between vehicles	V2V
21			a-2. Lane change assistance when the traffic is heavy	V2V
22			a-3. Entry assistance from non-priority roads to priority roads during traffic congestion	V2V
23		g. Platooning / adaptive cruise control	g-1. Unmanned platooning of following vehicles by electronic towbar	V2V
24			g-2. Adaptive cruise control and manned platooning of following vehicles using adaptive cruise control	V2V
25		h. Teleoperation	h-1. Operation and management of mobility service cars	V2N

2.2. Communication requirements

The communication requirements necessary to realize each SIP-UC are those requirements [5] studied by the Radio System Technology TG. Moreover, communication requirements used in this research are those presented as of July 2021, with details shown in Table 2-2 to Table 2-12.

Table 2-2 Definitions of terms used in communication requirements of the Radio System Technology TG

Item	Explanation
Classification by function	Name of the classification by function
Use case	Use case name
No.	Use case number
Message name	Message name, if specified.
V2V/V2I	Classification as V2V or V2I
Destination of the message	It describes the destination of the message. It can be 1) Roadside Infrastructure, 2) non-specific i.e. all nodes where the message is received including roadside infrastructure or vehicles, or 3) specific i.e. specific vehicles intended by the sender. This distinction may not be always same as the distinction in the radio access layer between broadcast or unicast in ITS FORUM RC-015. For instance, the radio access layer may use broadcast transmission but the message can be targeted to the specific vehicles by the identities of the target vehicles in application layer.
Target area (minimum range)	In the case of V2V, the same as the communication distance. In the case of V2I, the infrastructure area.
Number of transmitting vehicles per area	Number of transmitting vehicles per target area above in case of V2V or V2I
Required communication distance	The required communication distance in case of V2V or V2I, or the distance range in which information in messages is valid in case of V2V and V2I.
Maximum relative speed	The maximum relative speed between vehicles in case of V2V. The maximum vehicle speed in case of V2I.
Maximum data size	Maximum data size per message; includes 250 bytes of overhead.
Periodic or Aperiodic	Classification as Periodic or Aperiodic
Transmission periodicity	The update and transmission periodicity of information elements in case of periodic
PAR per message (Packet arrival rate)	The packet arrival rate of a message to be realized within the maximum acceptable delay of radio communication part
Maximum acceptable delay of radio communication part	The maximum delay which the system accepts for the radio access layer specified in ITS FORUM RC-015 to achieve the required reliability (including transmission waiting period, repetition/retransmission period, etc. at radio access layer). Messages that exceed the Maximum acceptable delay of radio communication part are considered not arrived regardless of the decoding result.

Table 2-3 Communication requirements presented by Radio System Technology TG (middle category: a. Merging / lane change assistance [1/4])

Classification by function	a. Merging / lane change assistance	
Use case	Merging assistance by preliminary acceleration and deceleration	Merging assistance by targeting the gap on the main lane
No.	a-1-1	a-1-2
Message name	Location information	Location information
V2V/V2I	V2I (I -> V)	V2I (I -> V)
Destination of the message	Non-specific vehicles	Non-specific vehicles
Target area (minimum range)	From 6 seconds before merging point to the halfway point between 6 seconds before merging point and merging point	From 6 seconds before merging starting point to merging starting point
Number of transmitting vehicles per area	1 vehicle	1 vehicle
Required communication distance*1	33.9 to 59.8 m (NILIM specification: 95 m)	66.7 to 116.7 m
Maximum relative speed	Merging lane: 20 to 70 km/h	Merging lane: 20 to 70 km/h
Maximum data size	1510 bytes (1260+250) Number of vehicles: 46	2752 bytes (2502+250) Number of vehicles: 92
Periodic or Aperiodic	Periodic	Periodic
Transmission periodicity	100 ms	100 ms
PAR per message	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)
Maximum acceptable delay of radio communication part	Not specified*	Not specified*

*Maximum acceptable delay of radio communication part from transmission periodicity anticipated to be 100 ms in order to judge applicability.

Table 2-4 Communication requirements presented by Radio System Technology TG (middle category: a. Merging / lane change assistance [2/4])

Classification by function	a. Merging / lane change assistance			
Use case	Cooperative merging assistance with vehicles on the main lane by roadside control			
No.	a-1-3			
Message name	Location information	Control request	Mediation request Update request	Mediation response Update response
V2V/V2I	V2I (I -> V)	V2I (V -> I)	V2I (I -> V)	V2I (V -> I)
Destination of the message	Non-specific vehicles	Roadside infrastructure	Specific vehicles	Specific vehicles
Target area (minimum range)	From 6 seconds before merging point to merging 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 (×number of controlled vehicles)	48 vehicles (number of controlled vehicles, when traffic is heavy)
Required communication distance	Merging lane: 66.7 to 116.7 m Main lane: 111.1 to 266.7 m	66.7 to 116.7 m	Connecting route: 66.7 to 116.7 m Main lane: 111.1 to 266.7 m	Connecting route: 66.7 to 116.7 m Main lane: 111.1 to 266.7 m
Maximum relative speed	Merging lane: 20 to 70 km/h Main lane: 20 to 120 km/h	Merging lane: 20 to 70 km/h Main lane: 20 to 120 km/h	Merging lane: 20 to 70 km/h Main lane: 20 to 120 km/h	Merging lane: 20 to 70 km/h Main lane: 20 to 120 km/h
Maximum data size	5236 bytes (4986+250) Number of vehicles: 184	287 bytes (37+250)	273 bytes (23+250)	287 bytes (37+250)
Periodic or Aperiodic	Periodic	Aperiodic	Aperiodic	Aperiodic
Transmission periodicity	100 ms	Indefinite		
PAR per message	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)
Maximum acceptable delay of radio communication part	Not specified	100 ms	100 ms	100 ms

Table 2-5 Communication requirements presented by Radio System Technology TG (middle category: a. Merging / lane change assistance [3/4])

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	
No.	a-1-4		a-2	
Message name	Mediation request Update request	Mediation response Update response	Mediation request Update request	Mediation response Update response
V2V/V2I	V2V	V2V	V2V	V2V
Destination of the message	Non-specific vehicles (mediation request) Specific vehicles (update request)	Specific vehicles (requesting vehicles)	Non-Specific vehicles (mediation request) Specific vehicles (update request)	Specific vehicles (requesting vehicles)
Target area (minimum range)	Within mediation request range	Within mediation request range	Within lane change request range	Within lane change request range
Number of transmitting vehicles per area	When temporarily stopping: 1 vehicle When starting to merge: 1 vehicle	When temporarily stopping: 27 vehicles When starting to merge: 36 vehicles	73 vehicles	48 vehicles
Required communication distance	255 m	255 m	Mediation request: 255 m Update request: 38.9 m	Mediation response: 255 m Update response: 38.9 m
Maximum relative speed	20 to 70 km/h	20 to 70 km/h	Mediation request: 0 to 120 km/h Update request: 0 to 20 km/h	Mediation response: 0 to 120 km/h Update response: 0 to 20 km/h
Maximum data size	291 bytes (41+250)	287 bytes (37+250)	291 bytes (41+250)	287 bytes (37+250)
Periodic or Aperiodic	Aperiodic	Aperiodic	Aperiodic	Aperiodic
Transmission periodicity	Indefinite	Indefinite	Indefinite	Indefinite
PAR per message	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)
Maximum acceptable delay of radio communication part	100 ms	100 ms	100 ms	100 ms

Table 2-6 Communication requirements presented by Radio System Technology TG (middle category: a. Merging / lane change assistance [4/4])

Classification by function	a. Merging / lane change assistance	
Use case	Entry assistance from non-priority roads to priority roads during traffic congestion	
No.	a-3	
Message name	Mediation request Update request	Mediation response Update response
V2V/V2It	V2V	V2V
Destination of the message	Non-Specific vehicles (mediation request) Specific vehicles (update request)	Specific vehicles (requesting vehicles)
Target area (minimum range)	Within intersection request range	Within intersection request range
Number of transmitting vehicles per area	2 vehicles	68 vehicles
Required communication distance	111.1 m	111.1 m
Maximum relative speed	0 to 60 km/h	0 to 60 km/h
Maximum data size	291 bytes (41+250)	287 bytes (37+250)
Periodic or Aperiodic	Aperiodic	Aperiodic
Transmission periodicity	Indefinite	Indefinite
PAR per message	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)
Maximum acceptable delay of radio communication part	100 ms	100 ms

Table 2-7 Communication requirements presented by Radio System Technology TG (middle category: b. Traffic signal communication)

Classification by function	b. Traffic signal information
Use case	Driving assistance by using traffic signal information (V2I)
No.	b-1-1
Message name	-
V2V/V2I	V2I
Destination of the message	Non-Specific vehicles
Target area (minimum range)	206.3 m (provisional)
Number of transmitting vehicles per area	RSU installation model (see https://www.soumu.go.jp/main_content/000455914.pdf Part 4.2)
Required communication distance	Large vehicles: about 206.3 m (provisional)
Maximum relative speed	70 km/h
Maximum data size	About 1 Kbyte / intersection
Periodic or Aperiodic	Periodic
Transmission periodicity	100 ms
PAR per message	At least 99% in 5 m evaluation section (same as 700 MHz band system)
Maximum acceptable delay of radio communication part	Delay not specified. Fluctuation within +/-300 ms (https://www.sip-adus.go.jp/rd/rddata/rd03/205.pdf)

Table 2-8 Communication requirements presented by Radio System Technology TG (middle category: c. Lookahead information: collision avoidance)

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	-	-	-	-
V2V/V2I	V2V	V2V	V2I (I => V)	V2V
Destination of the message	See c-3	Non-Specific vehicles	Non-Specific vehicles	
Target area (minimum range)	See c-3	(Communication area in which right-turning vehicle needs distributed information) - Upstream side: upstream from point 30 m upstream from right-turning vehicle's stop line - Downstream side: the point at which right turn is complete (oncoming vehicle range in which right-turning vehicle needs information) - Upstream side: the location upstream from the intersection equivalent to the amount of time during which oncoming lane can be crossed when starting the right turn at a safe rate of acceleration from the right-turn waiting point in the intersection. - 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 location is upstream from the stop line of the lane in which the oncoming vehicle moving straight through the intersection is traveling, then use the stop line as the location	(Communication area in which right-turning vehicle needs distributed information) See c-2-1	- Direct V2V communication: 250 m upstream from point where phenomenon occurs - If relay: 1 km upstream from point where phenomenon occurs
Number of transmitting vehicles per area	See c-3	6 lanes in each direction: 348 vehicles 3 lanes in each direction: 125 vehicles	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	See c-3	6 lanes in each direction: 190 m 3 lanes in each direction: 135 m	6 lanes in each direction: 75.2 m 3 lanes in each direction: 52.4 m	- Direct V2V communication: 250 m upstream from point where phenomenon occurs - If relay: 1 km upstream from point where phenomenon occurs
Maximum relative speed	See c-3	Up to 70 km/h	Up to 70 km/h	Up to 120 km/h
Maximum data size	See c-3	282 bytes (32+250)	6 lanes in each direction: 1534 bytes (1284+250) 3 lanes in each direction: 1150 bytes (900+250))	312 bytes (62+250)
Periodic or Aperiodic	See c-3	Cyclic	Cyclic	Cyclic
Transmission periodicity	See c-3	100 ms	100 ms	100 ms
PAR per message	See c-3	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)
Maximum acceptable delay of radio communication part	See c-3	100 ms is anticipated	100 ms is anticipated	- 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

Table 2-9 Communication requirements presented by Radio System Technology TG (middle category: d. Lookahead information: trajectory change)

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	-	-	-	-	-
V2V/V2I	V2I	V2I	V2I	V2I	V2I
Destination of the message	Non-Specific vehicles present in areas where hazard information can be effectively used	Non-Specific vehicles present in areas where hazard information can be effectively used	Non-Specific vehicles present in areas where hazard information can be effectively used	Non-Specific vehicles present in areas where hazard information can be effectively used	Non-Specific 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 (usually 1 vehicle) Downlink: Broadcast	Uplink: Number of abnormal vehicles (usually 1 vehicle) Downlink: Broadcast	Uplink: Number of abnormal vehicles (usually 1 vehicle) Downlink: Broadcast	Uplink: Number of abnormal vehicles (usually 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)
Periodic or Aperiodic	Periodic	Periodic	Periodic	Periodic	Periodic
Transmission periodicity	Minimum 1 second	Minimum 1 second	Minimum 1 second	Minimum 1 second	Minimum 1 second
PAR per message	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)	PAR ≥ 99% (provisional)
Maximum acceptable delay of radio communication part	Not specified*	Not specified*	Not specified*	Not specified*	Not specified*

*Maximum acceptable delay of radio communication part from transmission periodicity anticipated to be 1 s in order to judge applicability.

Table 2-10 Communication requirements presented by Radio System Technology TG (middle category: e. Lookahead information: emergency vehicle avoidance)

Classification by function	e. Lookahead information: Emergency vehicle avoidance
Use case	Driving assistance based on emergency vehicle information
No.	e-1
Message name	-
V2V/V2I	V2V
Destination of the message	Non-Specific vehicles present in areas where emergency vehicle information can be effectively used
Target area (minimum range)	150 m semicircle
Number of transmitting vehicles per area	Broadcast
Required communication distance	Minimum 150 m
Maximum relative speed	20 km/h to 120 km/h
Maximum data size	290 bytes (40+250)
Periodic or Aperiodic	Periodic
Transmission periodicity	100 ms
PAR per message	PAR ≥ 99% (provisional)
Maximum acceptable delay of radio communication part	100 ms or less

Table 2-11 Communication requirements presented by Radio System Technology TG (middle category: f. Information collection / distribution by infrastructure)

Classification by function	f. Information collection / distribution by infrastructure
Use case	Collection of information to optimize the traffic flow
No.	f-2
Message name	-
V2V/V2I	V2I
Destination of the message	Non-Specific vehicles
Target area (minimum range)	Circle with a radius of 151 m
Number of transmitting vehicles per area	389 vehicles (maximum case)
Required communication distance	Minimum 33.3 m and up *Travel distance in 1 second when driving at 120 km/h
Maximum relative speed	20 km/h to 120 km/h
Maximum data size	Uplink: 279 Bytes (29+250) Downlink: Not specified
Periodic or Aperiodic	Periodic
Transmission periodicity	V2I: Minimum 1 second
PAR per message	V2I: PAR ≥ 99% (provisional)
Maximum acceptable delay of radio communication part	Not specified*

*Maximum acceptable delay of radio communication part from transmission periodicity anticipated to be 1 s in order to judge applicability.

Table 2-12 Communication requirements presented by Radio System Technology TG (middle category: g. Platooning / adaptive cruise control)

Classification by function	g. Platooning / adaptive cruise control	
Use case	Unmanned platooning of following vehicles by electronic towbar (Non-rich content)	Adaptive cruise control and manned platooning of following vehicles using adaptive cruise control
No.	g-1	g-2
Message name	-	-
V2V/V2I	V2V	V2V
Destination of the message	Specific vehicles (use 1:N to achieve 1:1)	Non-Specific vehicles
Target area (minimum range)	Relative distance about 60 m	141 m
Number of transmitting vehicles per area	3 vehicles	Calculated with 4 vehicles
Required communication distance	Relative distance about 60 m	141 m
Maximum relative speed	Large vehicles 80 km/h	Passenger cars 100 km/h; large vehicles 80 km/h
Maximum data size	Up to same as 700 MHz band system	Up to same as 700 MHz band system
Periodic or Aperiodic	Periodic	Periodic
Transmission periodicity	100 ms, in emergencies 20 ms	100 ms
PAR per message	Ordinarily 98%/100 ms, in emergencies 99.99%/100 ms	95% packet accumulation rate in 10 m of travel (same as 700 MHz band system)
Maximum acceptable delay of radio communication part	100 ms (intervehicle distance 10 m; speed 80 km/h)	100 ms or less

3. Desk study

3.1. Method of examining

The following viewpoints guided the desk study.

- From the link budget viewpoint, whether the communication distance requirement can be achieved.

  Before conducting simulations, a link budget is found by desktop calculation, and it is checked whether the receive power at the required communication distance is insufficient relative to the minimum receiver sensitivity at PAR 99%. The link budget is found by calculating propagation loss for links overall, factoring in all gain and loss factors in the route between the transmitter end and receiver end.

- From the data size viewpoint, whether the delay requirements can be met.

  Under ARIB STD-T109 [2], the time during which transmission is possible in a 100 ms period must be within 10.5 ms for RSUs and 0.33 ms for OBUs. Check whether the application data size and maximum acceptable delay of radio communication part requirements as presented by the Radio System Technology TG can be met relative to this rule.

Desk study also confirms the following two points for doing the simulations described in Part 4.

- Whether wireless transmission slots (below, “slots”) can be allocated that will allow both existing services and SIP-UC to be established.

  There are 16 RSU slots in 100 ms, as indicated in Fig. 3-1. Appropriate slots need to be allocated from these so that RSUs do not interfere with each other. Study allocation of RSU slots in SIP-UC based on the slot allocation in the “Study for the Advancement of 700 MHz Band Intelligent Transport Systems” [1] (below, “existing model simulation”) conducted in 2016.

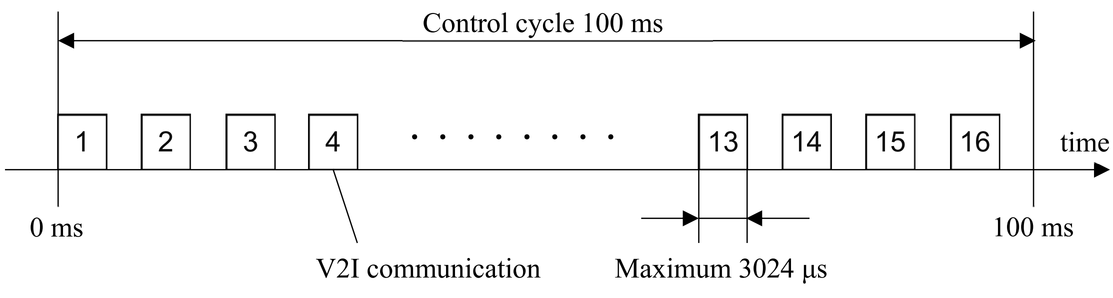


Fig. 3-1 Arrangement of V2I communication periods

- Message format of messages sent by RSUs/OBUs

  Study message sets, because it is necessary to decide RSU and OBU transmission messages when simulating the coexistence of existing services and SIP-UC. When studying message sets, confirm whether SIP-UC messages sent by RSU are compatible with 700 MHz band ITS V2I communication service standards for current services and whether SIP-UC OBU messages are compatible with 700 MHz band ITS V2V communication service standards. Additionally, study whether they are compatible under the same standards when existing services and multiple SIP-UC are in service at the same time.

The above is laid out in Table 3-1.

Table 3-1 Content evaluated in desk study

	Viewpoint	Item evaluated
1	From the link budget viewpoint, whether the communication distance requirement can be achieved	Evaluation of communication area & communication quality
2	From the data size viewpoint, whether the delay requirements can be met	Evaluation of transmission time constraints (transmission packet length)
3	Whether slots can be allocated that will allow both existing services and SIP-UC to be established	Evaluation of RSU installation constraints (slot allocation)
4	Message format of messages sent by RSUs/OBUs	Message sets

Table 3-2 lists the judgment criteria for the following three evaluations that require judgment in desk study.

- Evaluation of communication area & communication quality
- Evaluation of transmission time constraints (transmission packet length)
- Evaluation of RSU installation constraints (slot allocation)

Table 3-2 Judgment criteria in desk study

	Item evaluated	Evaluation method	Judgment criteria
1	Communication area & communication quality	Confirm communication quality at the edge of the communication area (assuming no interference)	Receive power where the desirable wave receive power at the edge of the communication area ≥ receive success rate 99%
2	Evaluation of transmission time constraints (transmission packet length)	Check wireless usage time based on transmission data size required to transmit messages and number of transmitting vehicles	Wireless usage time required for message transmission ≤ allowed slot usage time in ARIB STD-T109 (RSU: 10.5 ms, OBU: 0.33 ms)
3	Evaluation of RSU installation constraints (slot allocation)	Confirm separation distance between RSUs	Separation distance where DU ratio*1 at edge of communication area ≥ the DU ratio threshold*2

*1 Receive power ratio between desirable waves and undesirable waves (below, “DU ratio”)

*2 For DU ratio threshold, see required DU ratio in Table 3-3

3.1.1. Evaluation of communication area & communication quality

The evaluation of communication area & communication quality uses the formula below to find the receive power at the edge of the service area in each use case and judges whether it is compatible, based on whether or not that value equals or exceeds the signal receive threshold. The signal receive threshold refers to the receive power where the packet arrival rate as indicated by the communication requirements presented by the Radio System Technology TG is 99%. An illustration of how evaluation is done is given in Fig. 3-2.

Receive power = transmission power (*1) – (propagation loss + fading loss + shadowing loss)

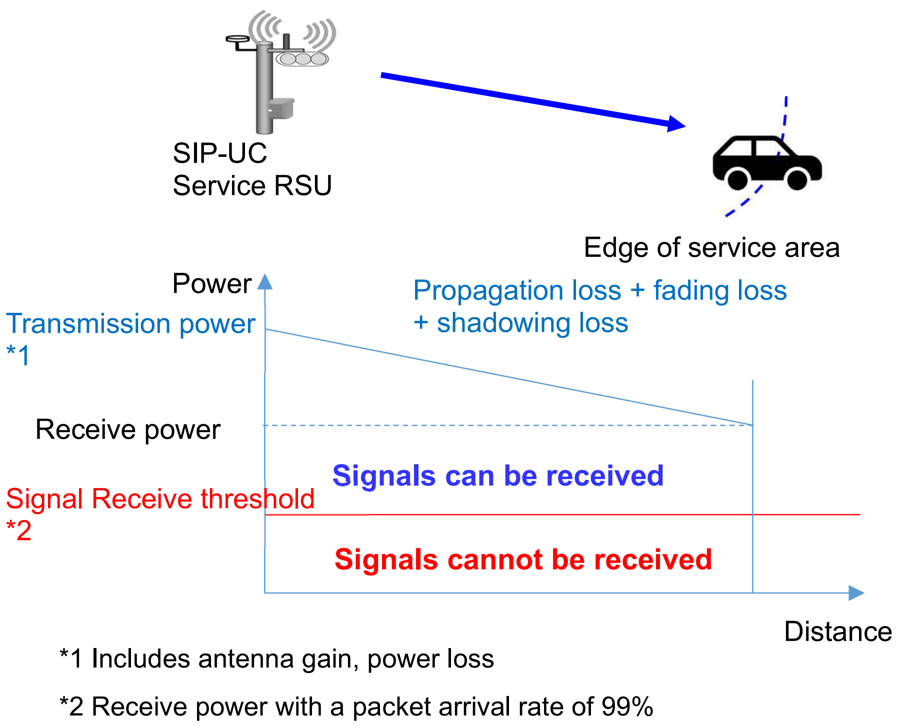


Fig. 3-2 Illustration of evaluation of communication area & communication quality

Propagation loss is calculated using the “700 MHz ITS V2I and I2I model” used in existing model simulations [1] and using the “Ito-Taga model.” Existing model simulation conditions, which have a track record and were derived from actual observations in the past, are used for other parameters also (see Table 3-3).

The signal receive threshold used is the minimum receiver sensitivity that was calculated based on PAR per packet as specified in the communication requirements presented by the Radio System Technology TG. The receiver sensitivity listed in Reference [6], which is an IEEE 802.11 related document, was used as reference, but because a value equivalent to PAR 90% is specified, the power ratio necessary to increase

PAR from 90% to 99% as per Reference [7]'s SNR-PER curve (Fig. 3-3) was found and the calculated values -75.9 dBm at 16QAM1/2 and -81 dBm at QPSK1/2, as in Table 3-4, were used.

Table 3-3 Desk study parameters

	RSU	OBU
Frequency	760 MHz	
Transmission power	19.2 dBm	
Modulation method	16QAM1/2	QPSK1/2
Data volume	Depends on conditions established separately	
Transmission cycle	V2I: 100 ms; I2I: 200 ms	100 ms
Antenna height	General roads: 6 m	General roads: 1.5 m
Antenna gain	0 dBi	0 dBi
Power loss	0 dB	3 dB
Signal receive threshold	-75.9 dBm (16QAM1/2, -81 dBm (QPSK1/2)	
Required DU ratio	14 dB (16QAM1/2), 9 dB (QPSK1/2)	
Propagation loss model	700 MHz ITS V2I and I2I model	Ito-Taga model
Fading	V2I: 4.4 dB	V2V: 6.4 dB
Shadowing	N/A	4.0 dB

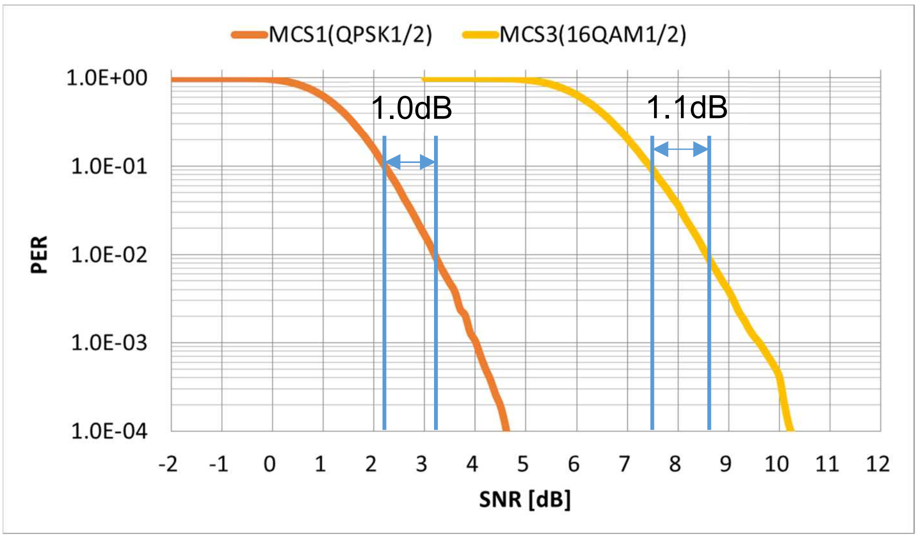


Fig. 3-3 SNR-PER curve (from Reference [7])

Table 3-4 Signal receive threshold used in desk study

(receiver sensitivity for each modulation method)

	16QAM1/2	QPSK1/2	Remarks
Receiver sensitivity (@PER10%)	-77 dBm	-82 dBm	Packet arrival rate (PAR) 90% equivalent *1
	↓ 1.1 dB	↓ 1.0 dB	Convert PER10% => PER1%*2
Receiver sensitivity (@PER1%)	-75.9 dBm	-81 dBm	Packet arrival rate (PAR) 99% equivalent

*1 From "Receiver performance requirements" in Reference [6]

*2 From Fig. 3-3 SNR-PER curve

3.1.2. Evaluation of transmission time constraints (transmission packet length)

The evaluation of transmission time constraints confirms whether the transmission packet length is of a size that can be transmitted in the maximum acceptable delay of radio communication part as presented by the Radio System Technology TG.

Under ARIB STD-T109, the time during which transmission is possible in a 100 ms period is decided and values are specified as below for RSUs and OBUs.

<Transmission time constraints in ARIB STD-T109 standard>

- RSUs: within 10.5 ms per 100 ms
- OBUs: within 0.33 ms per 100 ms

Find the transmission packet length from the transmission data size factoring in application data size and overhead (including security), then calculate transmission time. Here, if there are multiple vehicles covered by transmission, transmission time multiplied by number of vehicles N is used as the overall transmission time. Confirm whether the calculated transmission time is within the above transmission time constraints. Judge applicability, based on whether the calculated transmission time is within the maximum acceptable delay of radio communication part of communication requirements. Moreover, the data size listed in the communication requirements includes a uniform 250 bytes of overhead, but because this exceeds the time when transmission is possible as specified in ARIB STD-T109 in the case of OBUs, this evaluation used the security that is already part of existing services in ITS Connect and the overhead of the ARIB STD-T109 standard (see Table 3-5).

The total for transmission packets 1 through N is:

- RSUs: within 10.5 ms / 100 ms
- OBUs: within 0.33 ms / 100 ms

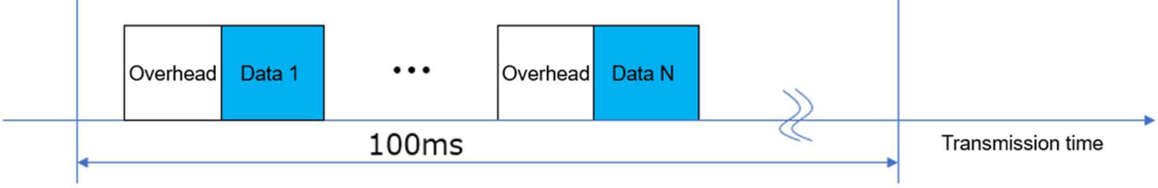


Fig. 3-4 Illustration of transmission packets

The specific procedure for calculating transmission time is shown below.

(i) Overhead is added to application data size to find the PLCP (Physical Layer Convergence Protocol) data size (layer 1 total message length).
PLCP data = application data size + overhead ((a)+(b)+(c) in Table 3-5)

(ii) Using Table 3-7, find the number of OFDM symbols from PLCP data size.
Also, the PLCP header's RATE – Tail (24 bits = SIGNAL portion) follows each modulation method starting with BPSK 1/2 and SERVICE

(iii) From ARIB STD-T109 [2] (IEEE802.11-2007 [6]), find the transmission time based on 1 OFDM symbol = 8 μs and finally add the PLCP preamble (32 μs) portion.

Table 3-5 Calculating transmission data size

		RSU	OBU
(a)	Security header size [bytes]	Lead packet: 273+28 × N Subsequent packets: 56 × (N-1) (N is the number of transmission packets in 100 ms)	27
(b)	MAC – EL header size [bytes] *For details see Table 3-6	65	61
(c)	PLCP header, Tail, Pad Bits sizes	PLCP Header: RATE 4 bits | Reserved 1 bit | LENGTH 12 bits | Parity 1 bit | Tail 6 bits | SERVICE 16 bits | PSDU | Tail 6 bits | Pad Bits SIGNAL portion (BPSK 1/2) = RATE – Tail	

Table 3-6 MAC – EL header size [bytes]

	RSU	OBU
EL header	5	1
L7 header	2	2
IVC-RVC header	22	22
LLC header	8	8
MAC header	24	24
FCS	4	4
Total	65	61

Table 3-7 Number of data bits per OFDM symbol

	Number of data bits per OFDM symbol
BPSK1/2	24
QPSK1/2	48
16QAM1/2	96

3.1.3. Evaluation of RSU installation constraints (slot allocation)

In evaluation of RSU installation constraints (slot allocation), find the RSU installation conditions where it is possible for expressway SIP-UC (a-1-1, a-1-2, a-1-3, and d-1 through d-5) and existing services to coexist. Also, in general road SIP-UC, assume that the expansion of 700 MHz band ITS V2I communication services will enable offering both services with just one RSU.

- An approach to RSU installation conditions that supports coexistence
- Separation distance must be ensured between RSUs transmitting at the same slot timing such that the DU ratio is at least the required DU ratio at the edge of each communication area (Fig. 3-5).
- Slot allocation for existing service RSUs follows the allocation rules for existing model simulations in [1]. Separation distance between RSUs transmitting in the same slot shall be as in Fig. 3-6.

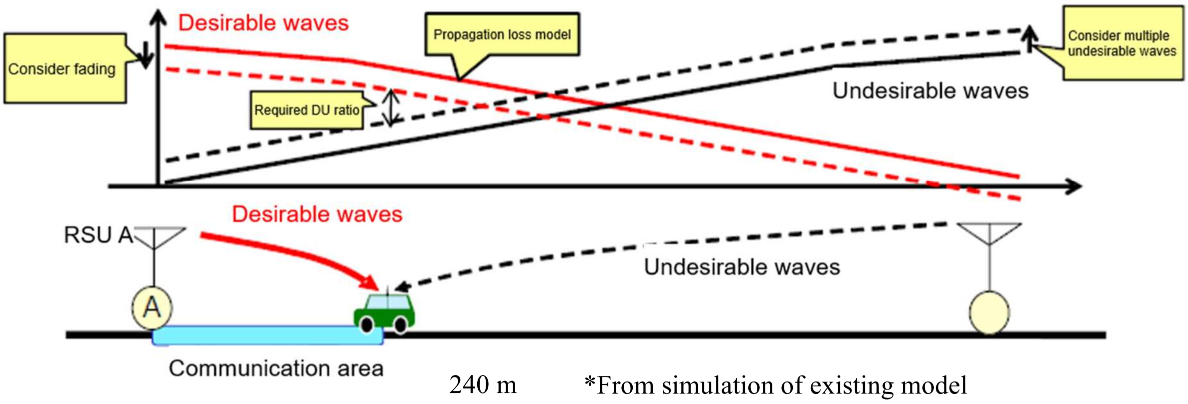


Fig. 3-5 Illustration of separation of RSUs

■ Separation distance between RSUs in same slot (in the case of a 300-m plane layout)

● Within line of sight

1,185 m or more

● Not within line of sight

Within line of sight 300 (600) m + not within line of

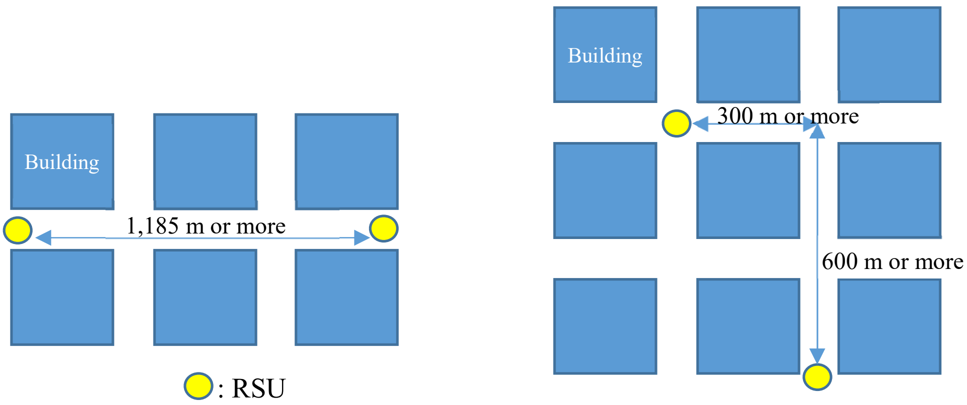


Fig. 3-6 Separation distance within line of sight and not within line of sight

- Conditions in study of coexistence feasibility

Conditions in the study of coexistence feasibility are as below.

(1) Placement of general road RSUs

General road RSUs are placed on a 300-m plane layout (Fig. 3-7), which is the highest placement density among existing model simulations.

(2) RSU slot classification

Slot classification for the existing model simulation described in Fig. 3-8 is used as the basis, but the constraints “(1) Used for V2I communication at critical intersections” and “(2) Used for V2I communication at general intersections” are removed; RSUs at critical intersections and RSUs at general intersections are mixed together in slots 1–12 in the study.

(3) RSU placement of SIP-UC (expressway) RSUs

Place expressway (main lane and merge section) and SIP-UC (expressway) RSUs on the 300-m plane layout described in (1) above (Fig. 3-9) (below, this model is referred to as the "SIP-UC review model").

(4) Propagation loss model between expressway <=> general road

Use ITU-R P.1411.

(5) SIP-UC (expressway) data size

Use 4,986 bytes, which is the data size from a-1-3, which has the longest slot occupation time (Table 3-8).

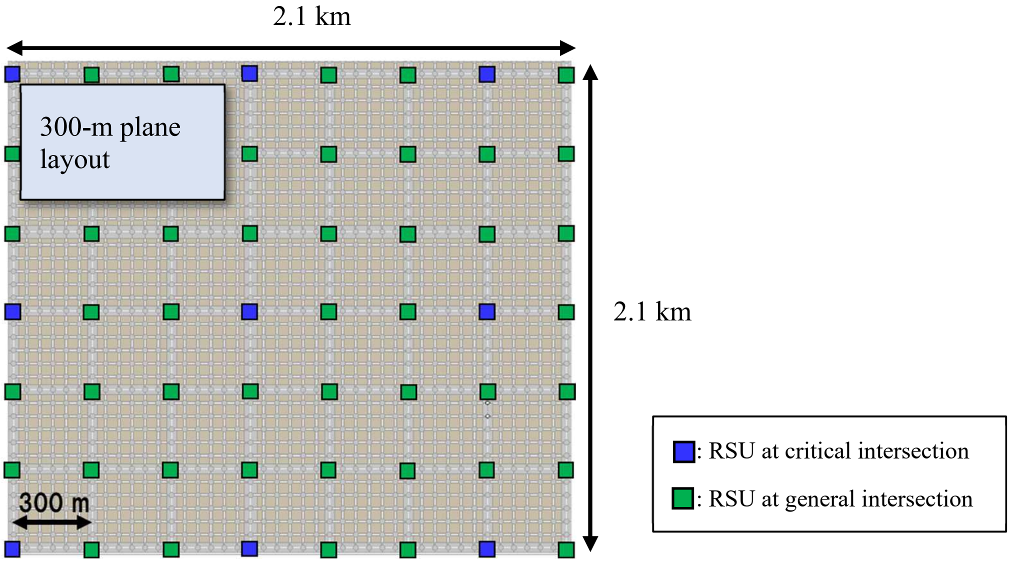


Fig. 3-7 300-m plane layout in existing model

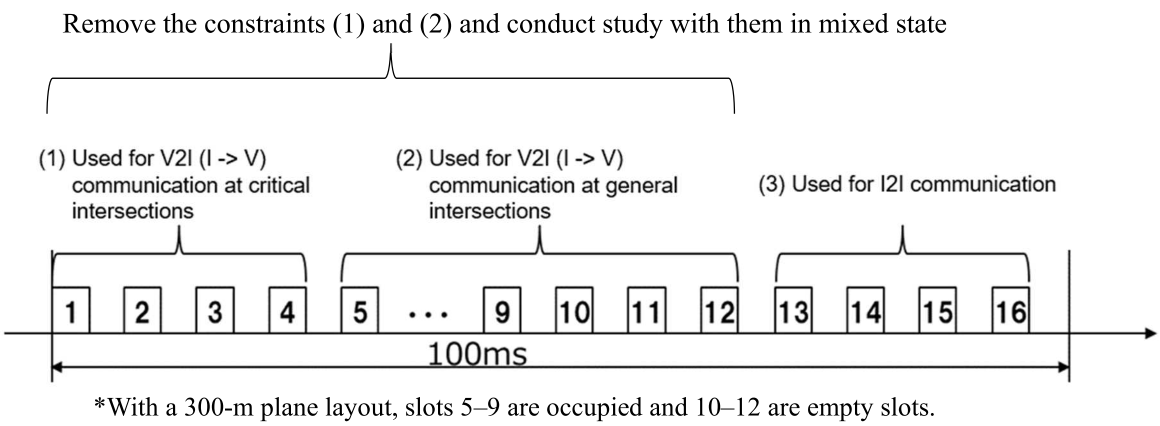


Fig. 3-8 Slot classification

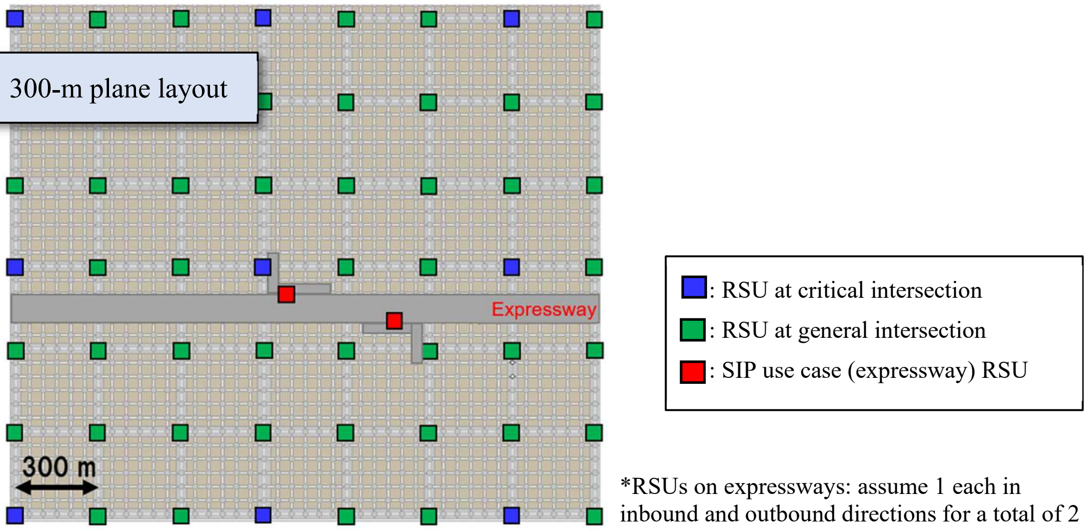


Fig. 3-9 Expressway and RSU placement on grid of 300 m squares (SIP-UC review model)

Table 3-8 List of SIP-UC (expressways)

	Use case number	Use case	Data size [bytes]	Occupied time [μs]
SIP-UC (expressways)	a-1-1	Merging assistance by preliminary acceleration and deceleration	1,260	1,272
	a-1-2	Merging assistance by targeting the gap on the main lane	2,502	2,320
	a-1-3	Cooperative merging assistance with vehicles on the main lane by roadside control	4,986	4,640*
	d-1	Driving assistance by notification of abnormal vehicles	445	584
	d-2	Driving assistance by notification of wrong-way vehicles	445	584
	d-3	Driving assistance based on traffic congestion information	445	584
	d-4	Traffic congestion assistance at branches and exits	445	584
	d-5	Driving assistance based on hazard information	445	584

*2 slots are needed per RSU

3.1.4. Message sets

In this R&D, the policy for messages sent from RSUs and OBUs is to use message sets used in existing safe driving support services (ITS Connect services) (such message sets are called “existing message sets”) as the base. Here, to realize the SIP-UC, messages necessary in SIP-UC in respect to existing message sets are laid out and new SIP-UC message sets are defined.

SIP-UC a-1-3, a-1-4, a-2, and a-3, in which interaction is required, are studied separately because the classification is different from existing broadcast message sets.

- SIP-UC message sets sent by RSU

For messages other than a-1-3 that require interaction (mediation request/update request messages), study message sets sent by RSU. For general road RSU messages, study whether they can be compatible by including them in 700 MHz band ITS V2I communication services or by expansion. If they are not compatible, study SIP-UC message sets sent by RSU (see Fig. 3-10).

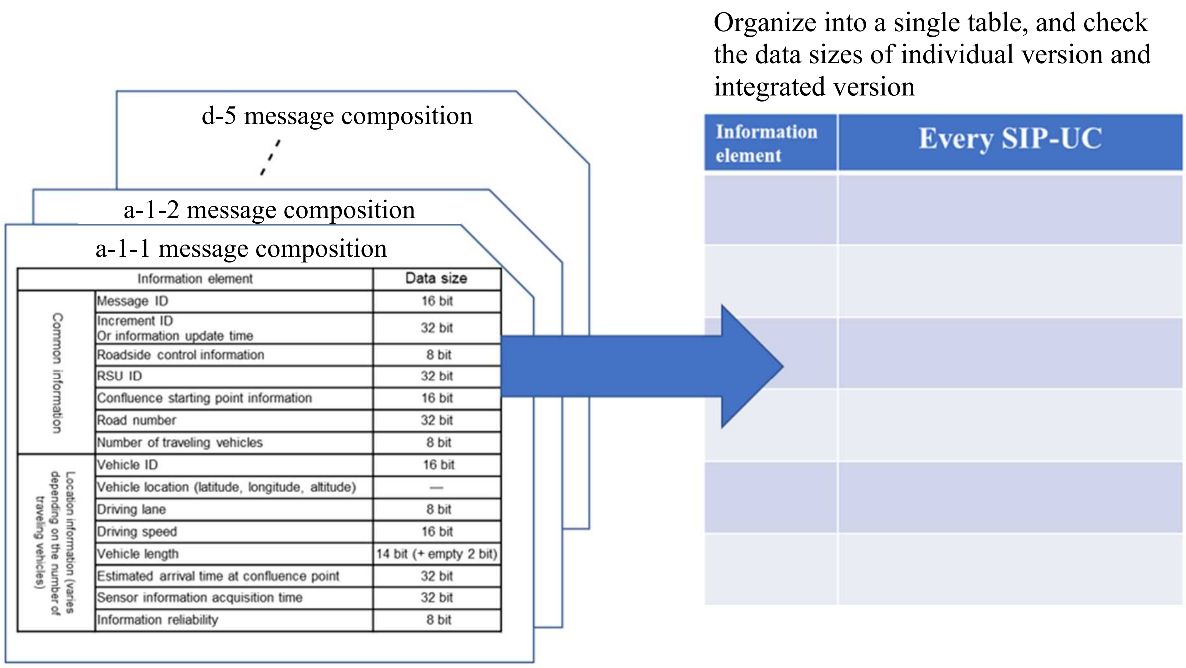


Fig. 3-10 Method of examining message sets sent by RSU

- SIP-UC message sets sent by OBU

For messages sent by OBU in use cases other than SIP-UC a-1-3, a-1-4, a-2, and a-3 that require interaction, confirm whether they are feasible by ITS Connect TD-001, the V2V message standard for current 700 MHz band ITS services. Also, summarize each use case and study whether they can be realized as message sets.

Field	Data structure	DF	Size (bytes)		Remarks
Common field	Common application header field	DF_CommonFieldManagementInformation	8		Mandatory
	Common application data field	DF_TimeInformation	4	28	Mandatory. If no proper value is available, set the "unavailable" value.
		DF_PositionInformation	11		
		DF_VehicleStatusInformation	9		
		DF_VehicleAttributeInformation	4		
		DF_PositionOptional Information (*)	2	0 to 26	Optional. Setting sequence may not be changed.
		DF_GNSSStatusOptional Information (*)	4		
		DF_PositionAcquisitionOptional Information (*)	2		
		DF_VehicleStatusOptional Information (*)	7		
		DF_IntersectionInformation (*)	10		
		DF_ExtendedInformation (*)	1		
Free field	Free application header field	DF_FreeFieldManagement Information	0 to 1	0 to 22	Optional. Size depends on number of individual application data set.
		DF_IndividualAppData ManagementInformationSet	0 to 21		
	Free application data field	(Not specified)	0 to 60		Optional. Setting sequence as specified by DF_IndividualAppDataManagementInformationSet.
			Total 36 to 100		(*): Optional information

Confirm whether messages sent by OBU in SIP-UC fall under ITS Connect TD-001's common application data field, and if not, whether they are within the free application data field.

Fig. 3-11 Method of examining message sets sent by OBU (excerpt from ITS Connect TD-001 [8])

3.2. Conditions

- Road conditions

Enter the road conditions for use in desk study. SIP-UC include both general road and expressway use cases. For general roads, road conditions are the same as those used in existing model simulation [1] and are structured as shown in Fig. 3-7 and Fig. 3-12. For expressways, elevated expressway main lanes and connecting routes are placed on top of general roads, as shown in Fig. 3-9. See the Road Structure Ordinance [9] (Fig. 3-13) concerning road conditions and follow Table 3-9 and Table 3-14.

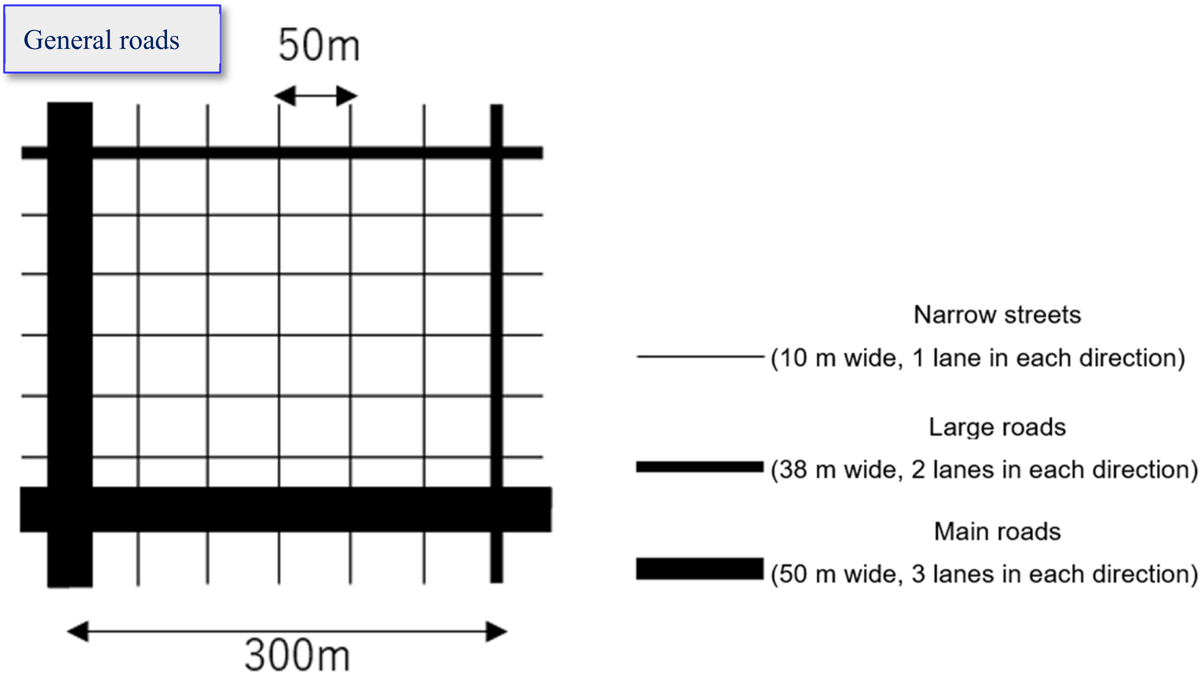


Fig. 3-12 Structure of general roads (from simulation of existing model [1])

Road categories

Areas with these roads / Categorized as national expressways and limited access roads (automobiles only) or other	Local areas	Urban areas
National expressways and limited access roads (automobiles only)	Type 1	Type 2
Other roads	Type 3	Type 4

Type 2 roads

Zones with these roads / Road types	Zones other than urban centers of large cities	Urban centers of large cities
National expressways	Class 1	
Roads other than national expressways	Class 1	Class 2

Median strip width

Category		Width of median (meters)
Type 2	Class 1	2.25
	Class 2	1.75

Road width

Category			Width of lanes (meters)
Type 2	Class 1	Ordinary roads	3.5
		Small roads	3.25

Shoulder width

Category		Width of shoulder on left side of road (meters)
Type 2	Ordinary roads	1.25

Fig. 3-13 Road structure, quoted from Road Structure Ordinance

Table 3-9 Number of lanes and road width of expressway main lanes and connecting routes

	Number of lanes	Road width	Remarks
Expressway main lanes	3 lanes in each direction	25.75 m	Calculated as: lane width 3.5 m × 3 lanes × 2 directions + median strip width 2.25 m + shoulder 1.25 × 2 directions
Connecting routes	1 lane in each direction	4.75 m	Calculated as: lane width 3.5 m × 1 lane + shoulder 1.25

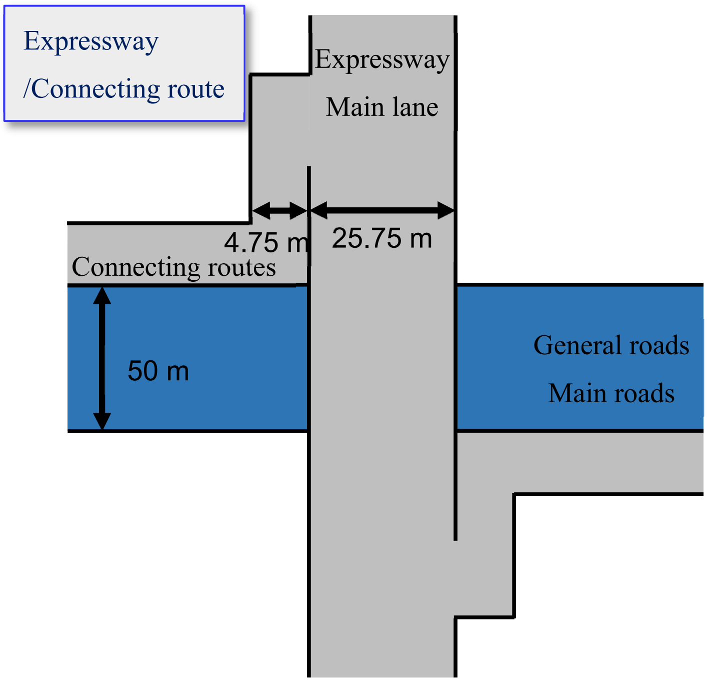
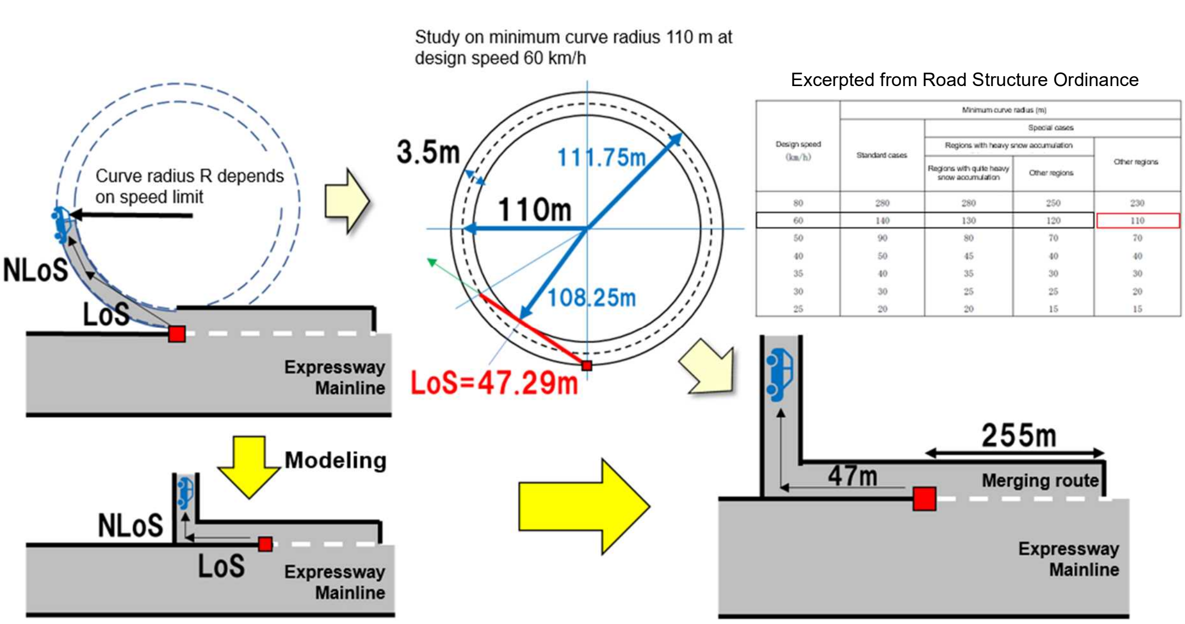


Table 3-14 Structure of expressway main lanes and connecting routes

- Structure of expressway connecting routes

The worst conditions were assumed and expressway connecting routes were structured as shown in Fig. 3-15. For the basic structure, a curve shape was assumed, and modeling was based on a right-angle structure, separating the curve into the part within line of sight and the part not within line of sight. Distances of parts within line of sight were calculated based on the curve's radius of curve.

Based on SIP-UC speed requirements, 60 km/h was used as the design speed, and radius of curvature was set at 110 m based on Road Structure Ordinance. Doing so, the distance of the part within line of sight is 47.29 m, and the structure is as shown at the lower right in Fig. 3-15 when this was modeled.



Design speed (km/h)	Minimum curve radius (m)			
	Standard cases	Special cases		
		Regions with heavy snow accumulation		Other regions
		Regions with quite heavy snow accumulation	Other regions	
80	280	280	250	230
60	140	130	120	110
50	90	80	70	70
40	50	45	40	40
35	40	35	30	30
30	30	25	25	20
25	20	20	15	15

Fig. 3-15 Structure of expressway connecting routes

3.3. Results

3.3.1. Evaluation of communication area & communication quality

Use cases were categorized into the following four groups and the results are reported accordingly.

- V2I (I -> V) communication related : a-1-1, a-1-2, b-1-1, c-2-2, d-1 through d-5
- V2V communication related : c-1, c-3, c-2-1, e-1, g-1, g-2
- V2I (V -> I) communication related : d-1 through d-4, f-2
- SIP-UC that require interaction : a-1-3, a-1-4, a-2, a-3

- V2I (I -> V) communication related

Results of evaluation of communication area & communication quality for V2I (I -> V) communication related use cases are shown in Table 3-10. The results show that the communication requirements presented by the Radio System Technology TG were met.

Table 3-10 Results of evaluation of communication area & communication quality for V2I (I -> V) communication related use cases

	Use case	a-1-1, a-1-2	b-1-1	c-2-2	d-1, d-2, d-3, d-4, d-5	Remarks
	Communication format	V2I (I -> V)	V2I (I -> V)	V2I (I -> V)	V2I (I -> V)	
A	Transmission power	19.2 dBm	19.2 dBm	19.2 dBm	19.2 dBm	
B	Antenna gain	0 dBi	0 dBi	0 dBi	0 dBi	
C	Power loss	0 dB	0 dB	0 dB	0 dB	
D	Radio section distance	**116.7 m (47+69.7 m)**	**206.3 m**	**75.2 m**	**66.6 m**	Required communication distance
E	Radio section propagation loss	85.3 dB	80.3 dB	66.3 dB	65.2 dB	700 MHz ITS V2I and I2I model
F	Fading loss	4.4 dB	4.4 dB	4.4 dB	4.4 dB	
G	Shadowing loss	N/A	N/A	N/A	N/A	Included in 700 MHz ITS V2I and I2I model
H	Receive power = A+(B-C)-(E+F+G)	-70.5 dBm	-65.5 dBm	-51.5 dBm	-50.4 dBm	
I	Signal receive threshold	-75.9 dBm	-75.9 dBm	-75.9 dBm	-75.9 dBm	16QAM1/2
J	Line margin = H-I	**5.4 dB**	**10.4 dB**	**24.4 dB**	**25.5 dB**	
	Judgment $J \geq 0$ dB	**Requirement achieved**	**Requirement achieved**	**Requirement achieved**	**Requirement achieved**	

- V2V communication related

Results of evaluation of communication area & communication quality for V2V communication related use cases are shown in Table 3-11. The results show that the communication requirements presented by the Radio System Technology TG were met.

Table 3-11 Results of evaluation of communication area & communication quality for V2V communication related use cases

	Use case	c-1, c-3	c-2-1	e-1	g-1	g-2	Remarks
	Communication format	V2V	V2V	V2V	V2V	V2V	
A	Transmission power	19.2 dBm	19.2 dBm	19.2 dBm	19.2 dBm	19.2 dBm	
B	Antenna gain	0 dBi	0 dBi	0 dBi	0 dBi	0 dBi	
C	Power loss	3 dB	3 dB	3 dB	3 dB	3 dB	
D	Radio section distance	**250 m**	**190 m**	**150 m**	**60 m**	**141 m**	Required communication distance
E	Radio section propagation loss	83.5 dB	80.8 dB	76.5 dB	65.4 dB	75.7 dB	Ito-Taga model
F	Fading loss	6.4 dB	6.4 dB	6.4 dB	6.4 dB	6.4 dB	
G	Shadowing loss	4 dB	4 dB	4 dB	0 dB	0 dB	
H	Receive power = A+(B-C)-(E+F+G)	-77.7 dBm	-75.0 dBm	-70.7 dBm	-55.6 dBm	-65.9 dBm	
I	Signal receive threshold	-81 dBm	-81 dBm	-81 dBm	-81 dBm	-81 dBm	QPSK1/2
J	Line margin = H-I	**3.3 dB**	**6.0 dB**	**10.3 dB**	**25.4 dB**	**15.1 dB**	
	Judgment J ≥ 0 dB	**Requirement achieved**	**Requirement achieved**	**Requirement achieved**	**Requirement achieved**	**Requirement achieved**	

- V2I (V -> I) communication related

Results of evaluation of communication area & communication quality for V2I (V -> I) communication related use cases are shown in Table 3-12. The results show that the communication requirements presented by the Radio System Technology TG were met.

Table 3-12 Results of evaluation of communication area & communication quality for V2I (V -> I) communication related use cases

	Use case	d-1, d-2, d-3, d-4	f-2	Remarks
	Communication format	V2I (V -> I)	V2I (V -> I)	
A	Transmission power	19.2 dBm	19.2 dBm	
B	Antenna gain	0 dBi	0 dBi	
C	Power loss	3 dB	3 dB	
D	Radio section distance	**66.6 m**	**150 m**	Required communication distance
E	Radio section propagation loss	65.2 dB	75.3 dB	700 MHz ITS V2I and I2I model
F	Fading loss	4.4 dB	4.4 dB	
G	Shadowing loss	N/A	N/A	Included in 700 MHz ITS V2I and I2I model
H	Receive power = A+(B-C)-(E+F+G)	-53.4 dBm	-63.5 dBm	
I	Signal receive threshold	-81 dBm	-81 dBm	QPSK1/2
J	Line margin = H-I	**27.6 dB**	**17.5 dB**	
	Judgment $J \geq 0$ dB	**Requirement achieved**	**Requirement achieved**	

- SIP-UCs that require interaction

Results of evaluation of communication area & communication quality for SIP-UCs that require interaction are shown in Table 3-13 and Table 3-14. The results show that the communication requirements presented by the Radio System Technology TG were met.

Table 3-13 Results of evaluation of communication area & communication quality for a-1-3

	Use case	a-1-3				Remarks
	Communication format	(1) V2I (I -> V) Providing location information (main lane)	(1) V2I (I -> V) Providing location information (connecting route)	(3) V2I (I -> V) Mediation/update request (main lane)	(4) V2I (V ->I) Mediation/update response (main lane)	
A	Transmission power	19.2 dBm	19.2 dBm	19.2 dBm	19.2 dBm	
B	Antenna gain	0 dBi	0 dBi	0 dBi	0 dBi	
C	Power loss	0 dB	0 dB	0 dB	3 dB	
D	Radio section distance	**266.7 m**	**116.7 m (47+69.7 m)**	**266.7 m**	**266.7 m**	Required communication distance Main lane: LoS; Connecting route: NLoS
E	Radio section propagation loss	84.3 dB	82.5 dB	84.3 dB	84.3 dB	700 MHz ITS V2I and I2I model
F	Fading loss	4.4 dB	4.4 dB	4.4 dB	4.4 dB	
G	Shadowing loss	N/A	N/A	N/A	N/A	Included in 700 MHz ITS V2I and I2I model
H	Receive power = A+(B-C)-(E+F+G)	-69.5 dBm	-67.7 dBm	-69.5 dBm	-72.5 dBm	
I	Signal receive threshold	-75.9 dBm *1	-75.9 dBm *1	-75.9 dBm *1	-81 dBm *2	*1: V2I messages: 16QAM1/2, *2: V2V messages: QPSK1/2
J	Line margin = H-I	**6.4 dB**	**8.2 dB**	**6.4 dB**	**8.5 dB**	
	Judgment $J \geq 0$ dB	**Requirement achieved**	**Requirement achieved**	**Requirement achieved**	**Requirement achieved**	

Table 3-14 Results of evaluation of communication area & communication quality for a-1-4, a-2, a-3

	Use case	a-1-4, a-2		a-3		Remarks
	Communication format	(1) V2V Mediation request / update request	(2) V2V Mediation response / update response	(1) V2V Mediation request / update request	(2) V2V Mediation response / update response	
A	Transmission power	19.2 dBm	19.2 dBm	19.2 dBm	19.2 dBm	
B	Antenna gain	0 dBi	0 dBi	0 dBi	0 dBi	
C	Power loss	3 dB	3 dB	3 dB	3 dB	
D	Radio section distance	**255 m**	**255 m**	**111.1 m**	**111.1 m**	Required communication distance
E	Radio section propagation loss	83.7 dB	83.7 dB	83.8 dB	83.8 dB	Ito-Taga model a-3: NLoS
F	Fading loss	6.4 dB	6.4 dB	6.4 dB	6.4 dB	
G	Shadowing loss	4 dB	4 dB	4 dB	4 dB	
H	Receive power = A+(B-C)-(E+F+G)	-77.9 dBm	-77.9 dBm	-78 dBm	-78 dBm	
I	Signal receive threshold	-81 dBm	-81 dBm	-81 dBm	-81 dBm	QPSK1/2
J	Line margin = H-I	**3.1 dB**	**3.1 dB**	**3.0 dB**	**3.0 dB**	
	Judgment J ≥ 0 dB	**Requirement achieved**	**Requirement achieved**	**Requirement achieved**	**Requirement achieved**	

3.3.2. Evaluation of transmission time constraints (transmission packet length)

Results of evaluation of transmission time constraints (transmission packet length) are shown below and in Table 3-15 – Table 3-23.

- In a-1-3, a-1-4, a-2, and a-3, the "number of transmitting vehicles per area" did not achieve requirements
- In g-1 (Unmanned platooning of following vehicles by electronic towbar), 20 ms transmissions in emergencies did not achieve requirements
- Other aspects met requirements

Table 3-15 Results of evaluation of transmission time constraints (transmission packet length) for a-1-1

	Use case	a-1-1		Remarks
	Communication format	V2I (I -> V)		
A	Application data size	**1,260 bytes**		
B	Data partitioning	Partition into 2 parts (1,000+260)		Partitioning at 1,000 bytes
C	Security header size	Lead: 329 bytes	Subsequent: 56 bytes	
D	MAC – EL header size	65 bytes	65 bytes	
E	PLCP header (excluding SIGNAL portion), Tail, Pad Bits sizes	22 bits + α	22 bits + α	α: Pad Bits
F	PLCP header SIGNAL portion	24 bits	24 bits	
G	PLCP data size = A+C+D+E	11,174 bits + α	3,070 bits + α	Total message length of layer 1 DATA portion
H	Number of data bits per OFDM symbol	24(BPSK1/2)	24(BPSK1/2)	SIGNAL portion: BPSK1/2
I		96 (16QAM1/2)	96 (16QAM1/2)	DATA portion: 16QAM1/2
J	Number of OFDM symbols = F/H+G/I	118 OFDMsymbols	33 OFDMsymbols	Fractions are Pad Bits portion
K	Transmission time = J × 8[μs]+32[μs]	**1,272 μs (976 μs+296 μs)**		1 OFDM symbol = 8 μs 32[μs]: PLCP preamble
L	Judgment K ≤ infrastructure: 10.5 ms; Vehicle: 0.33 ms	**Requirement achieved**		

Table 3-16 Results of evaluation of transmission time constraints (transmission packet length) for a-1-2

	Use case	a-1-2			Remarks
	Communication format	V2I (I -> V)			
A	Application data size	**2,502 bytes**			
B	Data partitioning	Partition into 3 parts (1,000 × 2 + 502)			Partitioning at 1,000 bytes
C	Security header size	Lead: 357 bytes	Subsequent (2nd): 112 bytes	Subsequent (3rd): 112 bytes	
D	MAC – EL header size	65 bytes	65 bytes	65 bytes	
E	PLCP header (excluding SIGNAL portion), Tail, Pad Bits sizes	22 bits + α	22 bits + α	22 bits + α	α: Pad Bits
F	PLCP header SIGNAL portion	24 bits	24 bits	24 bits	
G	PLCP data size = A+C+D+E	11,398 bits +α	9,438 bits +α	5,454 bits + α	Total message length of layer 1 DATA portion
H	Number of data bits per OFDM symbol	24	24	24	SIGNAL portion: BPSK1/2
I		96	96	96	DATA portion: 16QAM1/2
J	Number of OFDM symbols = F/H+G/I	120	100	58	Fractions are Pad Bits portion
K	Transmission time = J × 8[μs]+32[μs]	**2,320 μs (992 μs+832 μs+496 μs)**			1 OFDM symbol = 8 μs 32[μs]: PLCP preamble
L	Judgment K ≤ infrastructure: 10.5 ms; Vehicle: 0.33 ms	**Requirement achieved**			

Table 3-17 Results of evaluation of transmission time constraints (transmission packet length) for a-1-3

	Use case	a-1-3			Remarks
	Communication format	V2I (I -> V) Providing location information			
A	Application data size	**4,986 bytes**			
B	Data partitioning	Partition into 5 parts (1,000 × 4 + 986)			Partitioning at 1,000 bytes
C	Security header size	Lead: 413 bytes	Subsequent (2nd – 4th): 224 bytes	Subsequent (5th): 224 bytes	
D	MAC – EL header size	65 bytes	65 bytes	65 bytes	
E	PLCP header (excluding SIGNAL portion), Tail, Pad Bits sizes	22 bits + α	22 bits + α	22 bits + α	α: Pad Bits
F	PLCP header SIGNAL portion	24 bits	24 bits	24 bits	
G	PLCP data size = A+C+D+E	11,846 bits +α	10,334 bits +α	10,222 bits + α	Total message length of layer 1 DATA portion
H	Number of data bits per OFDM symbol	24	24	24	SIGNAL portion: BPSK1/2
I		96	96	96	DATA portion: 16QAM1/2
J	Number of OFDM symbols = F/H+G/I	125	109	108	Fractions are Pad Bits portion
K	Transmission time = J × 8[μs]+32[μs]	**2,320 μs (992 μs+832 μs+496 μs)**			1 OFDM symbol = 8 μs 32[μs]: PLCP preamble
L	Judgment K ≤ infrastructure: 10.5 ms; Vehicle: 0.33 ms	**Requirement achieved**			

Table 3-18 Results of evaluation of transmission time constraints (transmission packet length) for b-1-1 and c-2-2

	Use case	b-1-1	c-2-2		Remarks
	Communication format	V2I (I -> V)	V2I (I -> V)		
A	Application data size	**1,000 bytes**	**1,150 bytes**		
B	Data partitioning	None	Partition into 2 parts (1,000+150)		
C	Security header size	301 bytes	Lead: 329 bytes	Subsequent : 56 bytes	
D	MAC – EL header size	65 bytes	65 bytes	65 bytes	
E	PLCP header (excluding SIGNAL portion), Tail, Pad Bits sizes	22 bits + α	22 bits + α	22 bits + α	α: Pad Bits
F	PLCP header SIGNAL portion	24 bits	24 bits	24 bits	
G	PLCP data size = A+C+D+E	10,950 bits + α	11,174 bits + α	2,190 bits + α	Total message length of layer 1 DATA portion
H	Number of data bits per OFDM symbol	24	24	24	SIGNAL portion: BPSK1/2
I		96	96	96	DATA portion: 16QAM1/2
J	Number of OFDM symbols = F/H+G/I	116	118	24	Fractions are Pad Bits portion
K	Transmission time = J × 8[μs]+32[μs]	**960 μs**	**1,200 μs (976 μs+224 μs)**		1 OFDM symbol = 8 μs 32[μs]: PLCP preamble
L	Judgment K ≤ infrastructure: 10.5 ms; Vehicle: 0.33 ms	**Requirement achieved**	**Requirement achieved**		

Table 3-19 Results of evaluation of transmission time constraints (transmission packet length) for d-1 through d-5

	Use case	d-1 to d-5	Remarks
	Communication format	V2I (I -> V)	
A	Application data size	**445 bytes**	
B	Data partitioning	None	
C	Security header size	301 bytes	
D	MAC – EL header size	65 bytes	
E	PLCP header (excluding SIGNAL portion), Tail, Pad Bits sizes	22 bits + α	α: Pad Bits
F	PLCP header SIGNAL portion	24 bits	
G	PLCP data size = A+C+D+E	6,510 bits + α	Total message length of layer 1 DATA portion
H	Number of data bits per OFDM symbol	24(BPSK1/2)	SIGNAL portion: BPSK1/2
I		96 (16QAM1/2)	DATA portion: 16QAM1/2
J	Number of OFDM symbols = F/H+G/I	69 OFDMsymbols	Fractions are Pad Bits portion
K	Transmission time = J × 8[μs]+32[μs]	**584 μs**	1 OFDM symbol = 8 μs 32[μs]: PLCP preamble
L	Judgment K ≤ infrastructure: 10.5 ms; Vehicle: 0.33 ms	**Requirement achieved**	

Table 3-20 Results of evaluation of transmission time constraints (packet length) in V2I (V -> I) communication related use cases

	Use case	d-1 to d-4	f-2	Remarks
	Communication format	V2I (V -> I)	V2I (V -> I)	
A	Application data size	**27 bytes**	**29 bytes**	
B	Data partitioning	None	None	
C	Security header size	27 bytes	27 bytes	
D	MAC – EL header size	61 bytes	61 bytes	
E	PLCP header (excluding SIGNAL portion), Tail, Pad Bits sizes	22 bits + α	22 bits + α	α: Pad Bits
F	PLCP header SIGNAL portion	24 bits	24 bits	
G	PLCP data size = A+C+D+E	942 bits + α	958 bits + α	Total message length of layer 1 DATA portion
H	Number of data bits per OFDM symbol	24(BPSK1/2)	24(BPSK1/2)	SIGNAL portion: BPSK1/2
I		48 (QPSK1/2)	48 (QPSK1/2)	DATA portion: 16QAM1/2
J	Number of OFDM symbols = F/H+G/I	21 OFDMsymbols	21 OFDMsymbols	Fractions are Pad Bits portion
K	Transmission time = J × 8[μs]+32[μs]	**200 μs**	**200 μs**	1 OFDM symbol = 8 μs 32[μs]: PLCP preamble
L	Judgment K ≤ infrastructure: 10.5 ms; Vehicle: 0.33 ms	**Requirement achieved**	**Requirement achieved**	

Table 3-21 Results of evaluation of transmission time constraints (packet length) in V2V communication related use cases

	Use case	c-1/c-3	c-2-1	e-1	g-1		g-2	Remarks
	Communication format	V2V	V2V	V2V	V2V (Normal times)	V2V (In emergencies)	V2V	
A	Application data size	**62 bytes**	**32 bytes**	**40 bytes**	**100 bytes**	**2 bytes**	**100 bytes**	
B	Data partitioning	None	None	None	None	None	None	Partitioning at 1,000 bytes
C	Security header size	27 bytes	27 bytes	27 bytes	27 bytes	27 bytes	27 bytes	
D	MAC – EL header size	61 bytes	61 bytes	61 bytes	61 bytes	61 bytes	61 bytes	
E	PLCP header (excluding SIGNAL portion), Tail, Pad Bits sizes	22 bits + α	22 bits + α	22 bits + α	22 bits + α	22 bits + α	22 bits + α	α: Pad Bits
F	PLCP header SIGNAL portion	24 bits	24 bits	24 bits	24 bits	24 bits	24 bits	
G	PLCP data size = A+C+D+E	1,222 bits + α	982 bits + α	1,046 bits + α	1,526 bits + α	742 bits + α	1,526 bits + α	Total message length of layer 1 DATA portion
H	Number of data bits per OFDM symbol	24	24	24	24	24	24	SIGNAL portion: BPSK1/2
I		48	48	48	48	48	48	DATA portion: QPSK1/2
J	Number of OFDM symbols = F/H+G/I	27	22	23	33	17	33	Fractions are Pad Bits portion
K	Transmission time = J × 8[μs]+32[μs]	**248 μs**	**208 μs**	**216 μs**	**296 μs**	**840 μs (= 168 μs × 5)**	**296 μs**	1 OFDM symbol = 8 μs 32[μs]: PLCP preamble
L	Judgment K ≤ infrastructure: 10.5 ms; Vehicle: 0.33 ms	**Requirement achieved**	**Requirement achieved**	**Requirement achieved**	**Requirement achieved**	**Requirement not met**	**Requirement achieved**	

Table 3-22 Results of evaluation of transmission time constraints (packet length) for a-1-3

	Use case	a-1-3			Remarks
	Communication format	V2I (I -> V) Mediation request	V2I (I -> V) Update request	V2I (V -> I) Mediation response / update response	
A	Application data size	**23 bytes**	**23 bytes**	**37 bytes**	
B	Data partitioning	None	None	None	Partitioning at 1,000 bytes
C	Security header size	301 bytes	301 bytes	27 bytes	
D	MAC – EL header size	65 bytes	65 bytes	61 bytes	
E	PLCP header (excluding SIGNAL portion), Tail, Pad Bits sizes	22 bits + α	22 bits + α	22 bits + α	α: Pad Bits
F	PLCP header SIGNAL portion	24 bits	24 bits	24 bits	
G	PLCP data size = A+C+D+E	3,134 bits + α	3,134 bits + α	1,022 bits + α	Total message length of layer 1 DATA portion
H	Number of data bits per OFDM symbol	24	24	24	SIGNAL portion: BPSK1/2
I		96	96	48	DATA portion: 16QAM1/2 (infrastructure), QPSK1/2(vehicle)
J	Number of OFDM symbols = F/H+G/I	34	34	23	Fractions are Pad Bits portion
K	Transmission time = J × 8[µs]+32[µs]	**304 µs**	**304 µs × number of vehicles**	**216 µs**	1 OFDM symbol = 8 µs 32[µs]: PLCP preamble
L	Judgment K ≤ infrastructure: 10.5 ms; Vehicle: 0.33 ms	**Requirement achieved**	**Requirement not met (up to 34 vehicles can be supported)**	**Requirement achieved**	

Table 3-23 Results of evaluation of transmission time constraints (packet length) for a-1-4, a-2, and a-3

	Use case	a-1-4, a-2, a-3			Remarks
	Communication format	V2V Mediation request	V2V Update request	V2V Mediation response / Update response	
A	Application data size	**41 bytes**	**41 bytes**	**37 bytes**	
B	Data partitioning	None	None	None	Partitioning at 1,000 bytes
C	Security header size	27 bytes	27 bytes	27 bytes	
D	MAC – EL header size	61 bytes	61 bytes	61 bytes	
E	PLCP header (excluding SIGNAL portion), Tail, Pad Bits sizes	22 bits + α	22 bits + α	22 bits + α	α: Pad Bits
F	PLCP header SIGNAL portion	24 bits	24 bits	24 bits	
G	PLCP data size = A+C+D+E	1,054 bits + α	1,054 bits + α	1,022 bits + α	Total message length of layer 1 DATA portion
H	Number of data bits per OFDM symbol	24	24	24	SIGNAL portion: BPSK1/2
I		48	48	48	DATA portion: QPSK1/2
J	Number of OFDM symbols = F/H+G/I	23	23	23	Fractions are Pad Bits portion
K	Transmission time = J × 8[μs]+32[μs]	**216 μs**	**216 μs × number of vehicles**	**216 μs**	1 OFDM symbol = 8 μs 32[μs]: PLCP preamble
L	Judgment K ≤ infrastructure: 10.5 ms; Vehicle: 0.33 ms	**Requirement achieved**	**Requirement not met (only 1 vehicle can be supported)**	**Requirement achieved**	

3.3.3. Evaluation of RSU installation constraints (slot allocation)

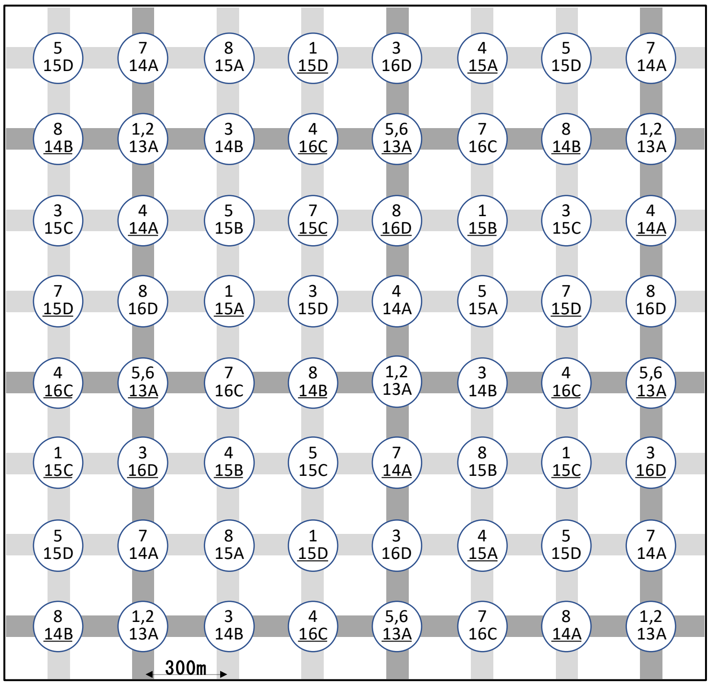
Under the TDMA system, there are 16 slots in RSUs in 700 MHz band ITS, as shown in Fig. 3-1. Slots must be allocated such that RSU transmission times do not overlap (i.e., services do not affect each other). Based on the slot allocation at the time of the 2016 existing model simulation [1], RSUs that are allocated the same slot are kept at a certain distance from each other so that services do not affect each other.

SIP use case (expressway) RSUs use a total of four slots, because as described in Section 3.1.3, there is one RSU each at the inbound and outbound expressway merge point, and each RSU uses two slots. Because RSUs have a maximum of 16 slots available for transmission (Fig. 3-1), if existing service RSUs use no more than 12 slots, they can coexist with SIP-UC (expressway) RSUs.

I2I communication slots are not currently used and it is undecided how they will be operated in future, but here it is assumed that four slots have been ensured for I2I communication to coincide with the 2016 existing model simulation [1]. Based on the above, a slot allocation that enables simultaneous coexistence of existing services and SIP-UC is possible if the number of slots that existing service RSUs use for V2I communication can be kept within eight (the above 12 slots minus four slots).

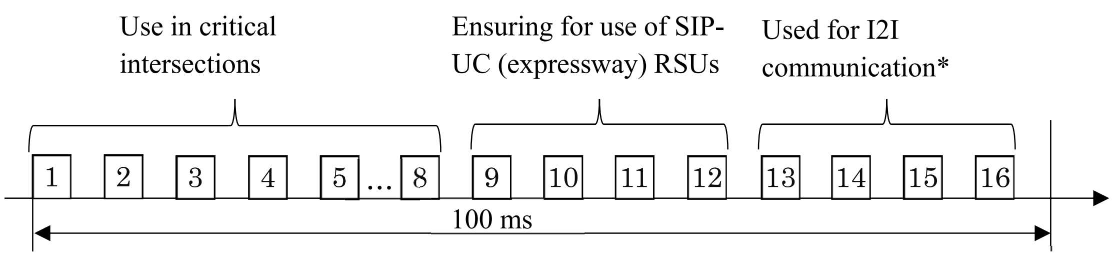
Moreover, in general road SIP-UC the use of RSUs happens in two use cases: b-1-1 and c-2-2. Since these can be made compatible by expanding messages of existing ITS Connect V2I communication services (see section 3.3.4), the premise is that these will be supported with existing service RSUs.

Based on the above, the study considers whether existing service RSUs can be kept within eight slots for V2I communication. If slots are sorted into critical intersections and general intersections, which is how they have been studied in the past, nine slots are used, so there are not enough slots. Therefore, the study looked at whether it is possible to allocate slots without sorting them as critical intersections or general intersections. The results show that slots 1 through 8 could be allocated to critical intersections and general intersections, as in Fig. 3-, so four slots (9 through 12) could be allocated to SIP-UC (expressway) RSUs (Fig. 3-17).



Upper row: V2I communication slot numbers
Lower row: I2I communication slot numbers*
*A through D show how one slot gets partitioned into four parts. Underlined codes are cases where the timing differs.

Fig. 3-16 Example of slot allocation for existing service RSUs



*Since the slot numbers for I2I communication must be larger than the slot numbers for V2I communication, the slots for I2I communication are fixed at 13–16

Fig. 3-17 Slot allocation for existing service RSUs and SIP-UC (expressway) RSUs

3.3.4. Message sets

3.3.4.1. SIP-UC message sets sent by RSU

Within SIP-UC, there are messages sent from RSUs both for expressways and general roads, so each is studied separately.

- SIP-UC (expressway) RSU messages

In existing message sets, there are no RSU message sets for expressways, so these are newly defined. Messages that SIP-UC (expressway) RSUs send are in the a series (a-1-1, a-1-2, a-1-3) and d series (d-1 through d-5). The results of integrating these are shown in Table 3-24.

Table 3-24 SIP-UC (expressway) RSU message sets (MS)

Information element		a-1-1		a-1-2		a-1-3		a series MS	d-1 to d-5		d series MS	Total MS
Total		754 bytes		2,502 bytes		4,986 bytes		4,986 bytes	445 bytes		445 bytes	5,426 bytes
		6,032 bits		20,016 bits		39,888 bits		39,888 bits	3,560 bits		3,560 bits	43,408 bits
Common information	Message ID	16	144 bits	16	144 bits	16	144 bits	144 bits	8	40 bits	40 bits	144 bits
	Increment ID or information update time	32		32		32						
	Roadside control information	8		8		8						
	RSU (ID), vehicle ID (self)	32		32		32			32			
	Merge starting point information	16		16		16						
	Road number	32		32		32						
	Number of traveling vehicles	8		8		8						
Location information × number of vehicles	Vehicle ID	16	128 bits × 46 vehicles	16	216 bits × 92 vehicles	16	216 bits × 184 vehicles	216 bits × 184 vehicles		-	-	216 bits × 184 vehicles
	Vehicle location (latitude, longitude, altitude)			88		88						
	Driving lane	8		8		8						
	Driving speed	16		16		16						
	Vehicle length	14 (+2 empty)		14 (+2 empty)		14 (+2 empty)						
	Estimated arrival time at merge point	32		32		32						
	Sensor information acquisition time	32		32		32						
	Information reliability	8		8		8						
Individual hazard information × 20 hazards	Time of occurrence		-		-		-	-	32	176 bits ×20 Hazards	176 bits ×20 Hazards	176 bits ×20 Hazards
	Event (hazard type)								8			
	Speed								16			
	Vehicle location (latitude, longitude, altitude)								88			
	Event distance information								16			
	Lane information / inbound or outbound								4			

	Road type, etc.								8			
	Passability (is lane change necessary or not)								2			
	(empty)								2			

*a series MS, d series MS, and total MS are the integrated message set

While organizing messages for each use case in this study, duplicate data when messages were integrated was defined as common information. Common information is aggregated into one in integrated message sets, so that should make message size more efficient. Also, in actual operation, besides messages carried in the scenarios presented by the Radio System Technology TG, it is necessary to separately add management information such as message identification information. Which message system to use is an issue going forward, and study and consultation with related organizations, including management information, is necessary.

Table 3-25 and Table 3-26 provide information about data sizes of individual messages and integrated messages. In simulations, it is decided to use 4,986 bytes, which is the maximum size in individual SIP-UC.

Table 3-25 SIP-UC (expressway) individual messages

No.	SIP-UC (expressways)	Maximum size	Remarks
a-1-1	Merging assistance by preliminary acceleration and deceleration	754 bytes	Location information is for a maximum of 46 vehicles
a-1-2	Merging assistance by targeting the gap on the main lane	2,502 bytes	Location information is for a maximum of 92 vehicles
a-1-3	Cooperative merging assistance with vehicles on the main lane by roadside control	4,986 bytes	Location information is for a maximum of 184 vehicles
d-1 to d-5	Notification of information on abnormal vehicles, wrong-way vehicles, traffic jams, etc.	445 bytes	Hazard information is for up to 20 hazards

Table 3-26 Integrated SIP-UC (expressway) message sets

No.	SIP-UC (expressways)	Maximum size	Remarks
1	a-1-1, a-1-2, a-1-3 integrated Main lane vehicle cooperative merging support by roadside control	4,986 bytes	Location information is for a maximum of 184 vehicles
2	d-1 to d-5 integrated Notification of information on abnormal vehicles, wrong-way vehicles, traffic jams, etc.	445 bytes	Hazard information is for up to 20 hazards
3	All message sets integrated	5,426 bytes	Location information is for a maximum of 184 vehicles Hazard information is for up to 20 hazards

- SIP-UC (general road) RSU messages

There are two use cases that require transmissions from general road RSUs: b-1-1 and c-2-2. Study results for each are shown below.

- b-1-1 (Driving assistance by using traffic signal information) requires adding information ("generation time" and "seconds remaining from generation time") based on the 700 MHz band ITS V2I communication system, so the existing 700 MHz band ITS V2I communication system needs to be partially expanded.
- c-2-2 (Driving assistance based on intersection information) was confirmed to be included within the 700 MHz band ITS V2I communication system.

Moreover, the SIP-UC (general road) RSU data size used in simulations was the 1,150 bytes of c-2-2, which is the largest data size presented by the Radio System Technology TG.

3.3.4.2. SIP-UC message sets sent by OBU

First, it was confirmed whether messages sent by OBUs in each SIP-UC are included in the common field of ITS Connect TD-001 [8]. Items included in the common field were put into the common field and others were put in the free field. Then, the data size of the free field necessary in each use case was confirmed (Fig. 3-18). The results indicated that the size of the free application data field when the messages of all OBU transmission use cases were integrated is 50 bytes and fits within the ITS Connect TD-001 free application data field's maximum size of 60 bytes.

ITS Connect TD-001

Field	Data structure	Stored DF	Size [bits]	BM (basic message) [bits]: c-2-1	c-3/c-1	d-1 to d-4	e-1	c-2-1, c-3/c-1, d-1 to d-5, e-1 Total	g-1	g-2	f-2	g-1, g-2, f-2 Total
Common field	Common application header field	DF_CommonFieldManagementInformation	64	48	32	32	32				32	
	Common application data field	DF_TimeInformation	32	32	32				32		32	
		DF_PositionInformation	88	88	88				88	88	88	
		DF_VehicleStatusInformation	72	48	32				72	32	48	
		DF_VehicleAttributeInformation	32	24	24				32			
		DF_PositionOptionalInformation	16									
		DF_GNSSStatusOptionalInformation	32									
		DF_PositionAcquisitionOptionalInformation	16									
		DF_VehicleStatusOptionalInformation	56									
		DF_IntersectionInformation	80									
		DF_ExtendedInformation	8									
Free field	Free application header field	DF_FreeFieldManagementInformation	0 to 8									
		DF_IndividualAppDataManagementInformationSet	0 to 168									
	Free application data field	(Not specified)	0 to 480									
Total bytes in free fields [bytes]			50	2	37	24	36	40	7	7	4	11
Total bits in free fields [bits]			398	16	296	190	282	316	56	50	32	82
Free field messages		Message ID	16	16	16	16	16	16			16	
		Time of occurrence of emergency action (target)	32		32	32	32	32				
		Type of emergency action (target)	8		8	8	8	8				
		Target object information (target)	24		24	16	24	24				
		Event location information (target)	88		88	88	88	88				
		Event distance information (target)	16		16	16		16				
		Lane information (target)	8		8	4	4	8				
		Road type information (target)	8		8	8	8	8				
		Traffic passability information (target)	8		8	2	2	8				
		Transmitting OBU ID (target)	32		32		32	32				
		Target lane information for distribution (target)	8		8			8				
		Valid time of information (target)	32		32		32	32				
		Redelivery distance (target)	16		16		16	16				
		Distance	16				16	16				
		Redelivery target lane/inbound & outbound	4				4	4				
		Following vehicle information	24						24	24		24
		Vehicle interval distance	16						16			16
		Acceleration, braking	16						16	16		16
		Availability of adaptive cruise control	2							2		2
		Manufacturer information	8							8		8
		Lane information	14								14	14
		V2I/periodic/event distribution	2								2	2

Common application field

Free application field

Empty spaces indicate value does not need to be set
Option fields (orange box) not used

*Values in yellow highlight are assumed values, since none were included in the original scenarios. Values in gray highlight are those listed as "assumed they will not be used" in scenarios presented by the Radio System Technology TG.

Fig. 3-18 Confirmation of OBU transmission message set free field sizes

However, free fields that can be used in ITS Connect TD-001 are of variable size from 0 to 60 bytes. If all common application data fields are used, or depending on the degree to which free application data fields are used by existing services, the compatibility to SIP-UC may vary.

Fig. 3-18 and Fig. 3-19 show that if option fields are not used (Pattern III in Fig. 3-19), it is feasible in all OBU transmission use cases, but in use cases that require 16 bytes or more of the free field, there are constraints on the use of the option field. Because there are situations where option fields are used in ITS Connect services and SIP-UC cannot use them in some cases, it will be necessary to consult with the ITS Connect Promotion Consortium concerning social implementation. Also, 73 bytes, which is the maximum size in individual SIP-UC, is used in simulations (Table 3-27).

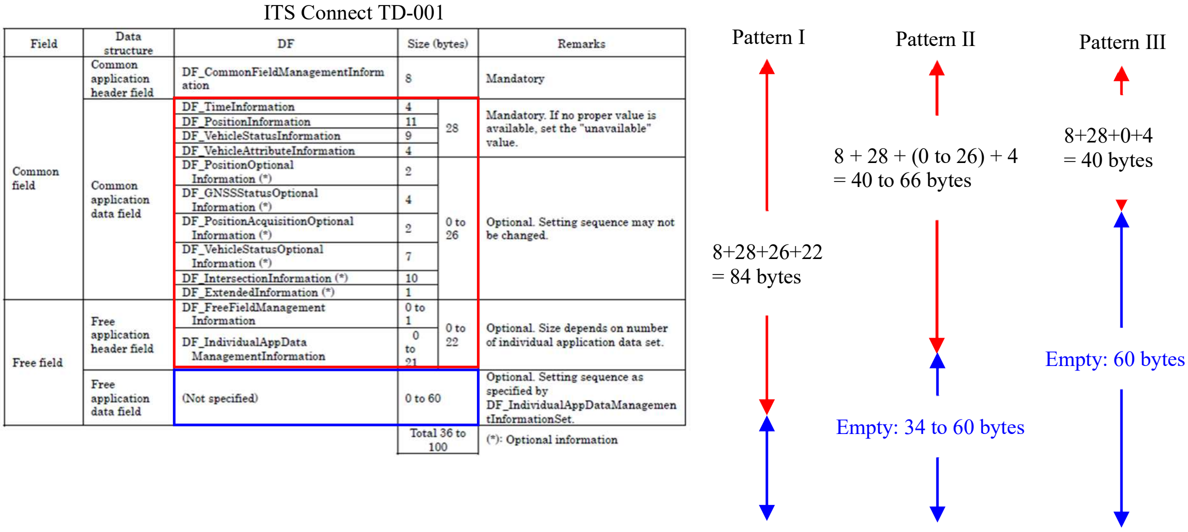


Fig. 3-19 Confirmation of free fields that can be used in ITS Connect TD-001

Breakdown of 4 bytes in free application header field

- DF_FreeFieldManagementInformation: 1 byte (8 bits) total
  - DE_IndividualAppHeaderLength: 5 bits
  - DE_NumberOfindividualAppData: 3 bits
- DF_IndividualAppDataManagementInformation: 3 bytes (24 bits) total
  - DE_IndividualServiceStandardID: 8 bits
  - DE_IndividualAppDataAddress: 8 bits
  - DE_IndividualAppDataLength: 8 bits

Fig. 3-20 Breakdown of free application header field (4 bytes)

Table 3-27 SIP-UC individual message sets

No.	SIP-UC	Common field	Free field	Total
c-2-1	Intersection information	36 bytes	2 bytes	38 bytes
c-3/c-1	Collision avoidance assistance by using hazard information Collision avoidance when a vehicle ahead stops or decelerates suddenly	36 bytes	37 bytes	73 bytes
d-1 to d-5	Notification of information on abnormal vehicles, wrong-way vehicles, traffic jams, etc.	36 bytes	24 bytes	60 bytes
e-1	Emergency vehicle information	36 bytes	36 bytes	72 bytes
g-1	Electronic towbar	36 bytes	7 bytes	43 bytes
g-2	Adaptive cruise control	36 bytes	7 bytes	43 bytes
f-2	Optimize the traffic flow	36 bytes	4 bytes	39 bytes

It was found to be feasible even in integrated cases, as shown in Table 3-28. However, as noted above, cases that require 16 bytes or more of the free field will have restrictions on the use of the option field.

Table 3-28 SIP-UC integrated message sets

No.	SIP-UC	Common field	Free field	Total
1	Total of c-2-1, c-3 / c-1, d-1 to d-5, e-1	36 bytes	40 bytes	76 bytes
2	Total of c-2-1, c-3 / c-1, d-1 to d-5, e-1, f-2	36 bytes	42 bytes	78 bytes
3	Total of g-1, g-2, f-2	36 bytes	11 bytes	47 bytes
4	Total of No. 1 to 3	36 bytes	50 bytes	86 bytes

Finally, the advantages and disadvantages of the OBU transmission message set proposal are listed in Table 3-29.

Table 3-29 Advantages and disadvantages of OBU transmission message set proposal

	Advantages	Disadvantages
If message sets are prepared for each SIP-UC	- Messages are only as long as necessary in each case, so data size is small if only one is being operated	- There are seven message sets in total, which means many controls and definitions - If multiple SIP-UC happen simultaneously, data sizes are simply added together so the data becomes large - If multiple SIP-UC happen simultaneously, many pieces of individual application data management information must be prepared
Message sets combining SIP-UC	- Few message sets for controlling and defining - If multiple SIP-UC happen simultaneously, duplicated parts are combined, so data sizes are small	- Even if a message is needed for only one SIP-UC, it is sent in combined format, so data size becomes large

3.4. Summary of results

Results of communication area evaluation and evaluation of transmission time constraints (packet length) are summarized in Table 3-30. In the evaluation of transmission time constraints, the communication requirements of the Radio System Technology TG were not met in SIP-UC a-1-3, a-1-4, a-2, and a-3, which require interaction, and in g-1 (platooning), but other cases met the communication requirements.

Table 3-30 Summary of results of communication area & transmission quality evaluation and evaluation of transmission time constraints (packet length)

No.	Broad category	Middle category	Use case	Evaluation results	Results of evaluation of communication area & communication quality	Results of evaluation of transmission time constraints
1	(1) Use cases in which information outside the detection range of on-board sensors must be obtained	a. Merging / lane change assistance	a-1-1. Merging assistance by preliminary acceleration and deceleration	V2I	●	●
2			a-1-2. Merging assistance by targeting the gap on the main lane	V2I	●	●
3		b. Traffic signal information	b-1-1. Driving assistance by using traffic signal information (V2I)	V2I	●	●
4			b-1-2. Driving assistance by using traffic signal information (V2N)	V2N		
5		c. Lookahead information: Collision avoidance	c-1. Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly	V2V	●	●
6			c-2-1. Driving assistance based on intersection information (V2V)	V2V	●	●
7			c-2-2. Driving assistance based on intersection information (V2I)	V2I	●	●
8			c-3. Collision avoidance assistance by using hazard information	V2V	●	●
9		d. Lookahead information: Trajectory change	d-1. Driving assistance by notification of abnormal vehicles	V2I, V2N	●	●
10			d-2. Driving assistance by notification of wrong-way vehicles	V2I, V2N	●	●
11			d-3. Driving assistance based on traffic congestion information	V2I, V2N	●	●
12			d-4. Traffic congestion assistance at branches and exits	V2I, V2N	●	●
13			d-5. Driving assistance based on hazard information	V2I, V2N	●	●
14		e. Lookahead information: Emergency vehicle notification	e-1. Driving assistance based on emergency vehicle information	V2I, V2N	●	●
15	(2) Use cases in which information of one's own vehicle must be provided	f. Information collection / distribution by infrastructure	f-1. Request for rescue (e-Call)	V2N		
16			f-2. Collection of information to optimize the traffic flow	V2I, V2N	●	●
17			f-3. Update and automatic generation of maps	V2N		
18			f-4. Distribution of dynamic map information	V2N		
19	(3) Use cases in which V2V and V2I interaction must be ensured	a. Merging / lane change assistance	a-1-3. Cooperative merging assistance with vehicles on the main lane by roadside control	V2I	●	*1
20			a-1-4. Merging assistance based on negotiations between vehicles	V2V	●	*1
21			a-2. Lane change assistance when the traffic is heavy	V2V	●	*1
22			a-3. Entry assistance from non-priority roads to priority roads during traffic congestion	V2V	●	*1
23		g. Platooning / adaptive cruise control	g-1. Unmanned platooning of following vehicles by electronic towbar	V2V	●	*2
24			g-2. Adaptive cruise control and manned platooning of following vehicles using adaptive cruise control	V2V	●	●
25		h. Teleoperation	h-1. Operation and management of mobility service cars	V2N		

*The symbol ● means that the requirements of the Radio System Technology TG were met in the desk study

*1 Did not meet Radio System Technology TG communication requirements for “Number of transmitting vehicles per area”

*2 Did not meet the Radio System Technology TG communication requirements for 20 ms transmission in emergencies

Results of the study on slot allocation without sorting them as critical intersections or general intersections indicate that slots 1 to 8 can be allocated to critical intersections and general intersections and slots 9 to 12 to SIP-UC (expressway) RSUs, and that it is possible to allocate so that there is no interference between expressway and general road RSUs.

Concerning message sets, SIP-UC (expressway) RSU message sets were defined. Simulations use 4,986 bytes, which is the maximum size in individual SIP-UC. It was found that SIP-UC (general road) RSU message sets can be made compatible by including them in 700 MHz band ITS V2I communication systems or just by partial expansion. Simulations use the 1,150 bytes of c-2-2, which is the largest size presented by the Radio System Technology TG.

SIP-UC OBU transmission message sets were defined, and it was indicated that these message sets could be included in ITS Connect TD-001. However, because there are situations where option fields are used in ITS Connect services and SIP-UC cannot use them in some cases, it will be necessary to consult with the ITS Connect Promotion Consortium concerning social implementation. Simulations used 73 bytes, which is the maximum size in individual SIP-UC.

4. Simulations

In Part 3, we examined whether communications could be established from the link budget viewpoint in a single SIP-UC and examined communication time constraints in ARIB STD T-109 [2], and we conducted a desk study on applicability with 700 MHz band ITS in respect to Radio System Technology TG requirements. Taking account of this, we modeled the communication environment and conducted simulations in which multiple RSUs and OBUs were placed to study the feasibility of simultaneous SIP-UC and existing services and whether they could coexist.

4.1. Use case category

For the simulations, SIP-UC were categorized into the following four models based on where the service is offered and the communication section. The use cases with the severest conditions in each category were used as the representative use cases and a simulation environment was built that included the four representative models. This should make it possible to study situations where all SIP-UC happen at the same time.

(1) Model 1: Expressway, V2I communication

Use cases where there is communication between RSU and OBU on expressways were categorized as Model 1, as shown in Fig. 4-1. Table 4-1 lists the use cases categorized as Model 1 and the corresponding communication requirements of the Radio System Technology TG. The vehicle densities shown in the table were selected to represent the worst conditions in each use case scenario. For d-1 to d-5 and f-2, communication frequency is 1/10 that of other use cases, so the communication volume is equivalent to a situation where there is 1/10 the vehicle density.

a-1-3 (Main lane vehicle cooperative merging support by roadside control), which has the severest conditions in terms of data size and vehicle density, was chosen as the representative use case among these.

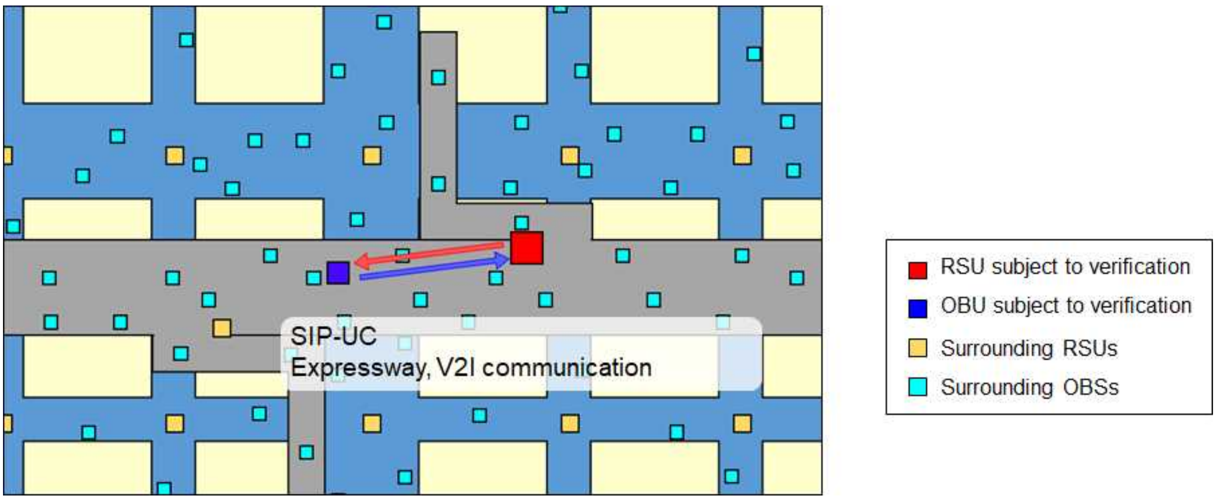


Fig. 4-1 Conceptual diagram of Model 1

Table 4-1 Model 1 use cases and communication requirements

	Merging assistance by preliminary acceleration and deceleration	Merging assistance by targeting the gap on the mainline	Mainline vehicle cooperative merging support by roadside control				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	Collection of information to optimize the traffic flow
No.	a-1-1	a-1-2	a-1-3				d-1	d-2	d-3	d-4	d-5	f-2
Message name	-	-	Location information provided	Control request	Mediation request Agreement request	Mediation response Agreement response	-	-	-	-	-	-
Communication format	V2I (I -> V)	V2I (I -> V)	V2I (I -> V)	V2I (V -> I)	V2I (I -> V)	V2I (V -> I)	V2I (I -> V)	V2I (I -> V)	V2I (I -> V)	V2I (I -> V)	V2I (I -> V)	V2I (V -> I)
Communication quality	PAR ≥ 99%	PAR ≥ 99%	PAR ≥ 99%	PAR ≥ 99%	PAR ≥ 99%	PAR ≥ 99%	PAR ≥ 99%	PAR ≥ 99%	PAR ≥ 99%	PAR ≥ 99%	PAR ≥ 99%	PAR ≥ 99%
Required communication distance [m]	95	116.7	266.7	266.7	266.7	266.7	66.6	66.6	66.6	66.6	66.6	33.3
Data size [bytes]	514	1,692	**4,986**	37	21	37	Uplink: 27 Downlink: 445	Uplink: 27 Downlink: 445	Uplink: 27 Downlink: 445	Uplink: 27 Downlink: 445	Downlink: 445	29
Communication counterpart	Non-specified vehicles	Non-specified vehicles	Non-specified vehicles	Non-specified vehicles	Specified vehicles	Roadside infrastructure	Non-specified vehicles	Non-specified vehicles	Non-specified vehicles	Non-specified vehicles	Non-specified vehicles	Non-specified vehicles
Target area	Expressway merging route	Expressway merging route	Expressway merging route	Expressway merging route	Expressway merging route	Expressway merging route	Expressway mainline	Expressway mainline	Expressway mainline	Expressway mainline	Expressway mainline	Expressway mainline / general roads
Frequency of communication	100 ms	100 ms	100 ms	100 ms	100 ms	100 ms	1 sec	1 sec	1 sec	1 sec	1 sec	1 sec
Vehicle density per lane	Mainline: 20 km/h, 2-second vehicle interval Connecting route: 20 km/h, 1-second vehicle interval ⇒ 62 vehicles/km, 95 vehicles/km		Mainline: 20 km/h, 1-second vehicle interval Connecting route: 20 km/h, 1-second vehicle interval **=> 95 vehicles/km**				20 km/h, 1-second vehicle interval => 95 vehicles/km (equivalent to 9.5 vehicles/km)					Vehicle length: 5 m, 1 m vehicle interval => 167 vehicles/km (equivalent to 16.7 vehicles/km)
Priority use case	-		✓				-					-

(2) Model 2: Expressway, V2V communication

Use cases where there is communication between OBUs on expressways were categorized as Model 2, as shown in Fig. 4-2. Table 4-2 lists the use cases categorized as Model 2 and the corresponding communication requirements of the Radio System Technology TG. As in Model 1, the vehicle densities shown in the table were selected to represent the worst conditions in each use case scenario. a-1-4 (Merging assistance based on negotiations between vehicles), which has the highest vehicle density per lane and the greatest number of vehicles because it includes connecting routes, was chosen as the representative use case.

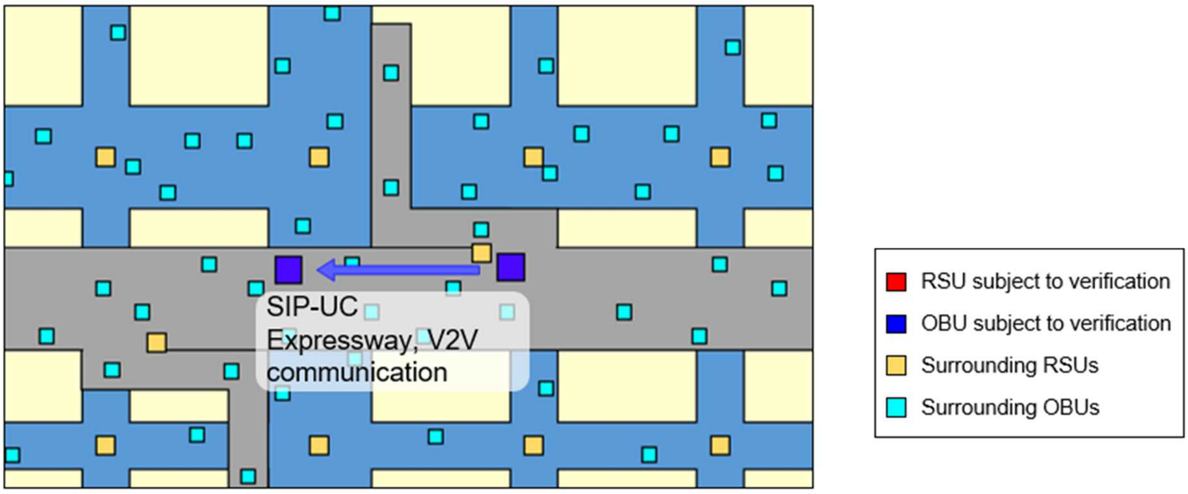


Fig. 4-2 Conceptual diagram of Model 2

Table 4-2 Model 2 use cases and communication requirements

	Merging assistance based on negotiations between vehicles		Lane change assistance when the traffic is heavy		Collision avoidance assistance by using hazard information / collision avoidance assistance when a vehicle ahead stops or decelerates suddenly	Driving assistance based on emergency vehicle information	Unmanned platooning of following vehicles by electronic towbar	Adaptive cruise control and manned platooning of following vehicles using adaptive cruise control
No.	a-1-4		a-2		c-3/c-1	e-1	g-1	g-2
Message name	Mediation request Agreement request	Mediation response Agreement response	Mediation request Agreement request	Mediation response Agreement response				
Communication format	V2V	V2V	V2V	V2V	V2V	V2V	V2V	V2V
Communication quality	PAR ≥ 99%	PAR ≥ 99%	PAR ≥ 99%	PAR ≥ 99%	PAR ≥ 99%	PAR ≥ 99%	PAR ≧ 98% per 100 ms in normal times PAR ≧ 99.99% per 100 ms in emergencies	Packet accumulation rate 95% in 10 m of travel
Required communication distance [m]	255 m *JAMA requirement		255 m *JAMA requirement		250	150	Relative distance about 60 m	141 (vehicle interval distance 35 m + vehicle length 12 m) × 3)
Data size [bytes]	43	38	43	38	62	40	100	100
Communication counterpart	Non-specified vehicles (mediation request) Specified vehicles (agreement request)	Specified vehicles	Non-specified vehicles (mediation request) Specified vehicles (agreement request)	Specified vehicles	Non-specified vehicles	Non-specified vehicles	Specified vehicles (use 1:N to achieve 1:1)	Non-specified vehicles
Target area	Expressway junction	Expressway junction	Expressway mainline	Expressway mainline	Expressway mainline	General roads	Expressway mainline	Expressway mainline / general roads
Frequency of communication	100 ms	100 ms	100 ms	100 ms	100 ms	100 ms	100 ms, in emergencies 20 ms	100 ms
Vehicle density per lane	Mainline: 5 m vehicle length, 2 m vehicle interval, connecting routes: 5 m vehicle length, 2 m vehicle interval **=> 143 vehicles/km**		5-m vehicle length, 2-m vehicle interval **=> 143 vehicles/km**		60 km/h, 1-second vehicle interval => 46 vehicles/km	40 km/h, 1-second vehicle interval => 62 vehicles/km	12-m vehicle length, 5-m vehicle interval => 59 vehicles/km	12 m vehicle length, 30 m vehicle interval => 24 vehicles/km
Priority use case	✓		-		-	-	-	-

(3) Model 3: General road, V2I communication

Use cases where there is communication between RSU and OBU on general roads were categorized as Model 3, as shown in Fig. 4-3. Table 4-3 lists the use cases categorized as Model 3 and the corresponding communication requirements of the Radio System Technology TG. The vehicle densities shown in the table are the worst conditions in each use case scenario. As in Model 1, f-2 shows the equivalent of 1/10 of vehicle density.

c-2-2 (Driving assistance based on intersection information (V2I)), which has the severest conditions in terms of data size and vehicle density, was chosen as the representative use case among these.

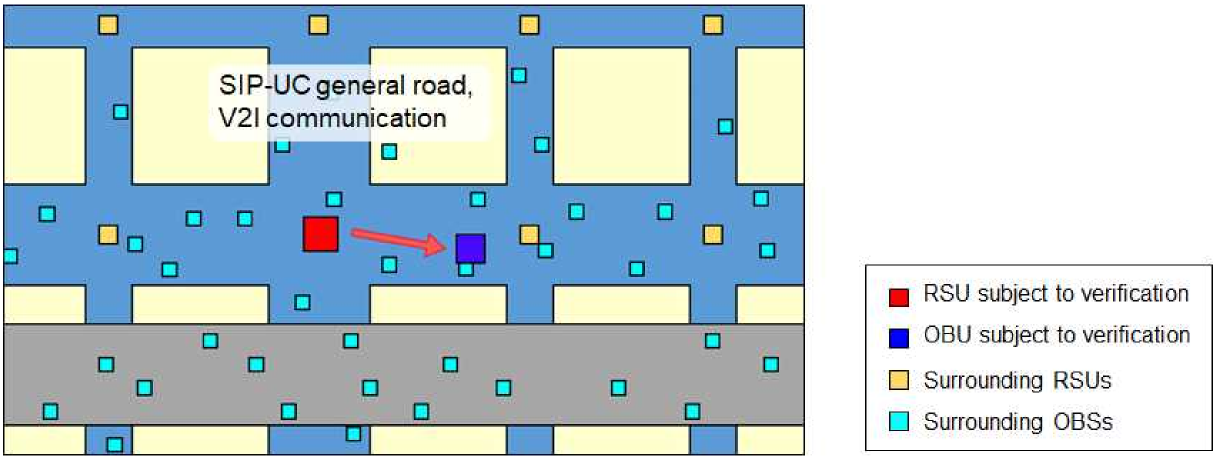


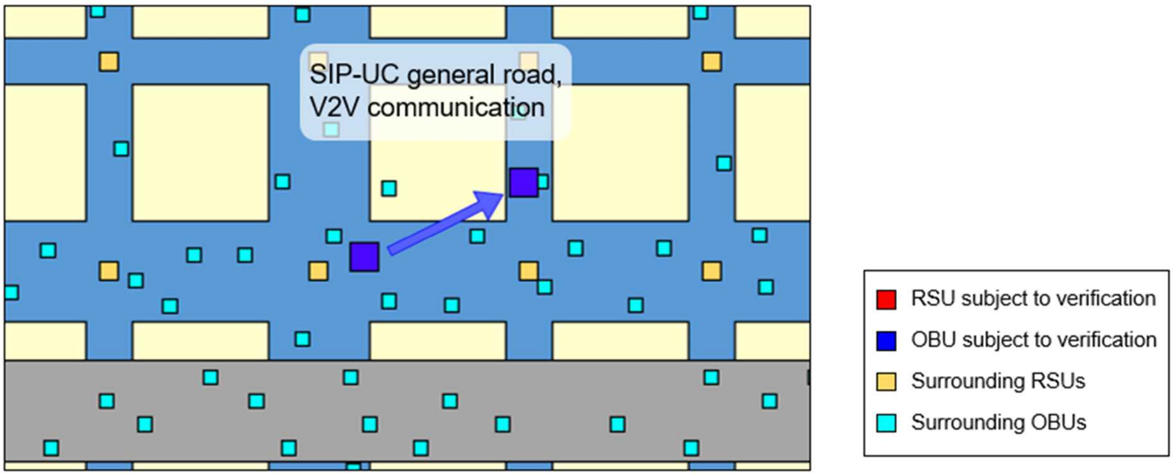
Fig. 4-3 Conceptual diagram of Model 3

Table 4-3 Model 3 use cases and communication requirements

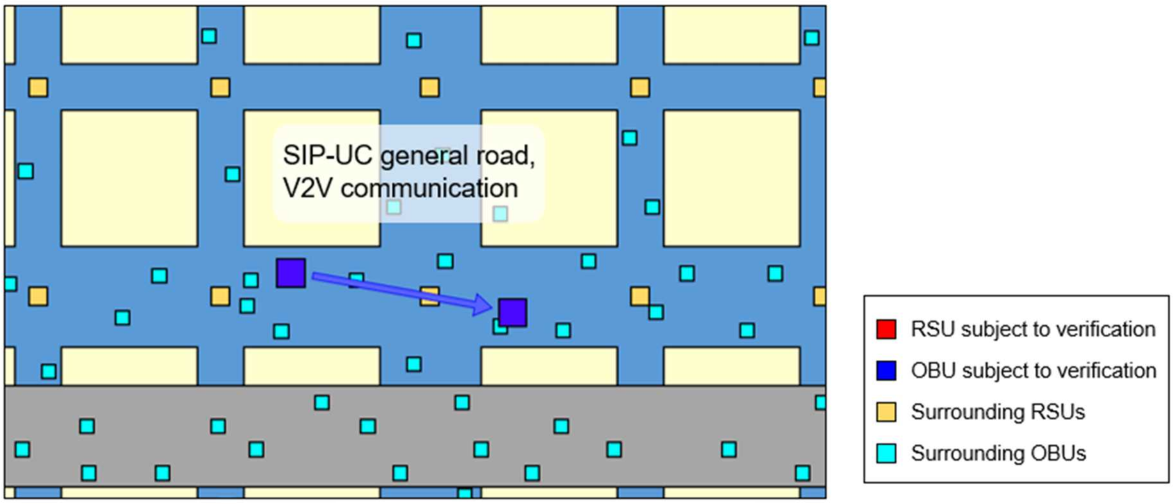
	Driving assistance by using traffic signal information (V2I)	Driving assistance based on intersection information (V2I)	Collection of information to optimize the traffic flow
No.	b-1-1	c-2-2	f-2
Message name			
Communication format	V2I (I -> V)	V2I (I -> V)	V2I (V -> I)
Communication quality	At least 99% in 5 m evaluation section (same as 700 MHz band system)	PAR ≥ 99%	PAR ≥ 99%
Required communication distance [m]	206.3	75.2	33.3
Data size [bytes]	1,000	**1,150**	29
Communication counterpart	Non-specified vehicles	Non-specified vehicles	Non-specified vehicles
Target area	General road intersection	General road intersection	Expressway mainline / general roads
Frequency of communication	100 ms	100 ms	1 sec
Vehicle density per lane	70 km/h, 2-second vehicle interval => 23 vehicles/km	30 km/h, 2-second vehicle interval **=> 46 vehicles/km**	Vehicle length: 5 m, 1 m vehicle interval => 167 vehicles/km (equivalent to 17 vehicles/km)

(4) Model 4: General road, V2V communication

Use cases where there is communication between OBUs on general roads were categorized as Model 4, as shown in Fig. 4-4. Table 4-4 lists the use cases categorized as Model 4 and the corresponding communication requirements of the Radio System Technology TG. a-3 anticipates that there will be communication with vehicles on priority roads from within non-priority roads; unlike other use cases shown on the table, this is communication not within the line of sight (NLoS). In this model, therefore, a-3 (Entry assistance from non-priority roads to priority roads during traffic congestion), where there is NLoS communication, and c-2-1 (Driving assistance based on intersection information (V2V)), which has the highest vehicle density of the use cases with line of sight (LoS) communication, were modeled as the corresponding use cases.



(a) Not within line of sight (NLoS)



(b) Within line of sight (LoS)

Fig. 4-4 Conceptual diagram of Model 4

Table 4-4 Model 4 use cases and communication requirements

	Entry assistance from non-priority roads to priority roads during traffic congestion		Driving assistance based on intersection information (V2V)	Driving assistance based on emergency vehicle information	Adaptive cruise control and manned platooning of following vehicles using adaptive cruise control
No.	a-3		c-2-1	e-1	g-2
Message name	Mediation request Agreement request	Mediation response Agreement response			
Communication format	V2V	V2V	V2V	V2V	V2V
Communication quality	PAR ≥ 99%	PAR ≥ 99%	PAR ≥ 99%	PAR ≥ 99%	Packet accumulation rate 95% in 10 m of travel
Required communication distance [m]	111.1	111.1	190	150	141 (vehicle interval distance 35 m + vehicle length 12 m) × 3)
Data size [bytes]	43	38	32	40	100
Frequency of communication	100 ms	100 ms	100 ms	100 ms	100 ms
Communication counterpart	Non-specified vehicles (mediation request) Specified vehicles (agreement request)	Specified vehicles	Non-specified vehicles	Non-specified vehicles	Non-specified vehicles
Target area	General road intersection	General road intersection	General road intersection	General roads	Expressway mainline / general roads
Vehicle density per lane	5-m vehicle length, 2-m vehicle interval **=> 143 vehicles/km**		30 km/h, 2-second vehicle interval **=> 46 vehicles/km**	30 km/h, 2-second vehicle interval => 46 vehicles/km	80 km/h, 1-second vehicle interval => 37 vehicles/km

Categories and corresponding use cases are summarized in Table 4-5.

Table 4-5 Summary of use case categories

Model	Environment	Communication format	Use cases evaluated	Included use cases
1	Expressway	V2I (I -> V) communication	a-1-3	a-1-1, a-1-2, d-1 to d-5, f-2
2		V2V communication	a-1-4	a-2, c-3/c-1, e-1, g-1, g-2
3	General roads	V2I (I -> V) communication	c-2-2	b-1-1, f-2
4		V2V communication	a-3, c-2-1	e-1, g-2

4.2. Simulation conditions

4.2.1. Road models

In the road models, which used the existing road simulation [1] as reference, an expressway main lane and connecting routes were placed on a 300-m plane layout. It is anticipated that OBUs on expressways and OBUs on general roads will interfere with each other's communication packets. To study this under the worst conditions, an expressway was placed adjacent to a main road where use cases on general roads are placed.

4.2.2. Model placement

By placing the models classified in Section 4.1 in close proximity to each other, we simulated situations where SIP-UC were in close proximity to each other.

Fig. 4-5 is a conceptual diagram of the placement of the models and existing services.

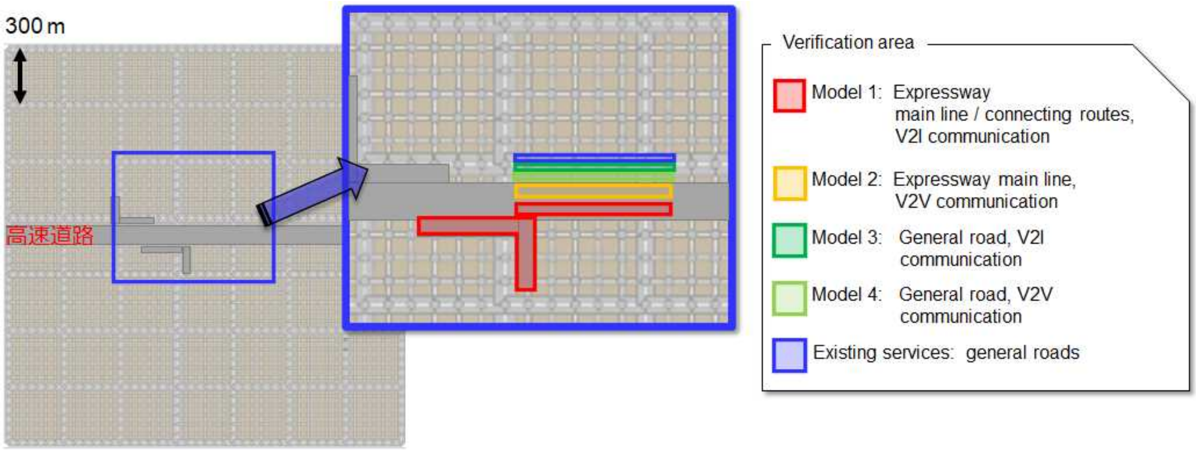


Fig. 4-5 Placement of SIP-UC and existing services

4.2.3. RSU placement and slot allocation

Reflecting the desk study results in Part 3, RSUs were placed and slots were allocated as in Fig. 4-6. For general roads, two slots of slots 1 to 8 were allocated for critical intersections and one slot for general intersections. Of slots 9 to 12, two slots were allocated to each of two expressway RSUs. Slots 13 to 16 were allocated for I2I communication.

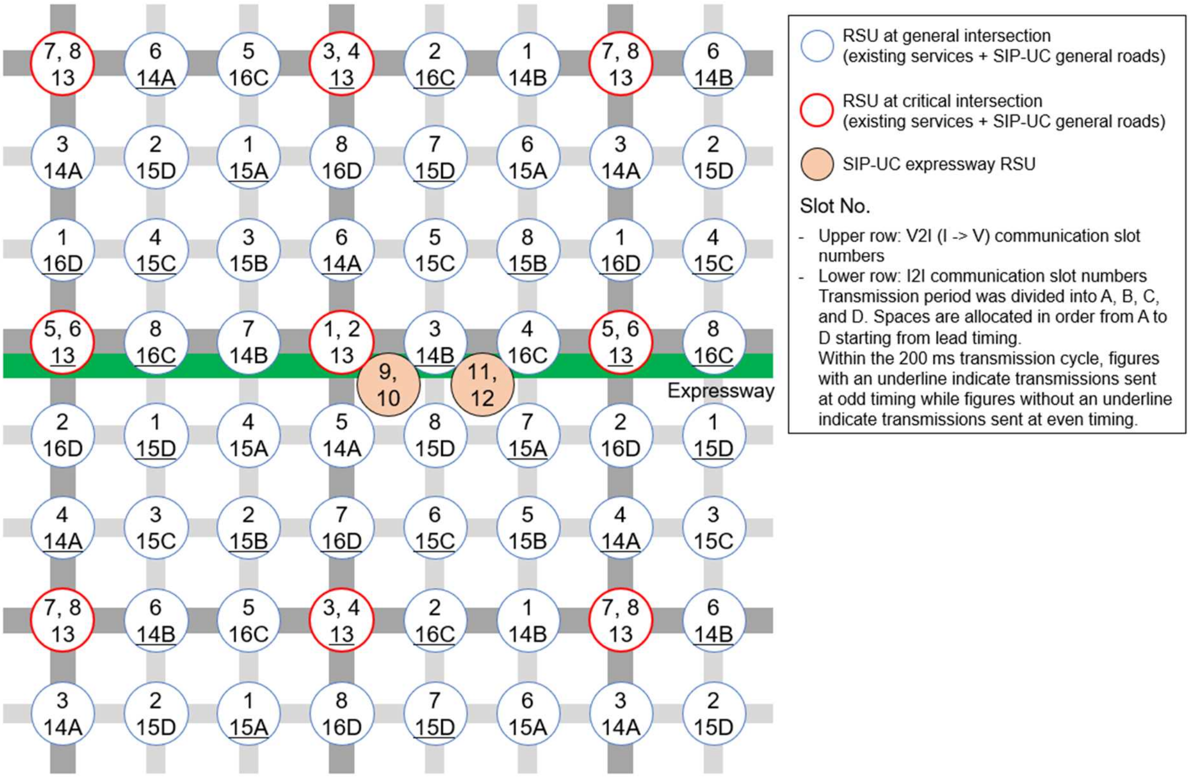


Fig. 4-6 RSU placement and slot allocation

4.2.4. Vehicle placement

Vehicles carrying OBUs were placed to create the vehicle density for the following conditions. Under these circumstances, if vehicle location is fixed at regular intervals, there is a possibility that messages sent from OBUs will collide with each other and specifically cause interference, so vehicle location was randomized each time a simulation was run. Also, for the simulations, all vehicles were defined as ordinary vehicles measuring 1.5 m high and 5 m long.

Based on the scenarios presented by the Radio System Technology TG, vehicle density was simulated based on the two patterns described below.

(1) Maximum vehicle density conditions when moving at low speed

The most severe conditions considered, based on the Radio System Technology TG's scenarios, were 20 km/h as a condition of slow movement in expressway main lanes and on connecting routes and 10 km/h on general roads, and simulations were done under the following conditions.

Table 4-6 RSU and vehicle density under maximum density conditions at low speeds

	SIP-UC		Existing services
	Expressway	General roads	
RSU	2 units	1 unit	Critical intersections 9 units General intersections 55 units
OBU	95 vehicles/km (20 km/h)	143 vehicles/km (10 km/h)	43 vehicles/km (25 km/h)

(2) Maximum vehicle density conditions at regulated speed

Simulations were done under maximum density conditions when vehicles drive at the regulated speed, as in Table 4-7, to represent conditions that are more realistic as based on the Radio System Technology TG's scenarios.

Table 4-7 RSU and vehicle density under maximum density conditions at regulated speed

	SIP-UC			Existing services
	Expressway main lanes	Expressway connecting route	General roads	
RSU	2 units	-	1 unit	Critical intersections 9 units General intersections 55 units
OBU	17 vehicles/km (120 km/h)	23 vehicles/km (70 km/h)	23 vehicles/km (70 km/h)	23 vehicles/km (70 km/h)

4.2.5. Communication conditions and propagation model

The communication conditions and propagation model are as shown in Table 4-8. Communication conditions unrelated to expressways follow the 2016 existing simulation conditions.

Propagation loss from expressway sound-insulating walls was set at 10 dB based on results of experiments done on actual expressways.

The model for propagation between general roads and expressways was decided by comparing results found by propagation simulation with two models: the Ito-Taga model and ITU-R P.1411. The results of comparison showed that propagation to the area not within line of sight (NLoS) is excessive in the ITU-R P.1411 model, so the Ito-Taga model was used.

For RSUs placed on expressways, omnidirectional antennas were used under maximum density conditions at low speeds, since those antennas would be the more severe condition, while at maximum vehicle density conditions at the regulated speed, assuming actual services, directional antennas with directionality in the direction covered by each of the two RSUs were used.

Table 4-8 Communication conditions and propagation model

	RSU	OBU
Frequency	760 MHz	
Transmission power	19.2 dBm	
Modulation method	16QAM1/2	QPSK1/2
Transmission cycle	100 ms	100 ms
Antenna height	Road height + 6 m	Road height + 1.5 m
Antenna gain	0 dBi	0 dBi
Power loss	0 dB	3 dB
Signal receive threshold *2	-75.9 dBm (16QAM1/2), -81 dBm (QPSK1/2)	
Required DU ratio	14 dB (16QAM1/2), 9 dB (QPSK1/2)	
Carrier sense level	-	-85 dBm
CW size	-	63
Propagation loss model	700 MHz ITS V2I, I2I model	Ito-Taga model
	General roads <=> Expressways : Ito-Taga model	
Propagation loss from expressway sound-insulating walls	10 dB	
Fading *3	V2I: 4.4 dB	V2V: 6.4 dB
Vehicle shielding loss	-	0.5 dB / vehicle (maximum 8 dB)

*1 Transmissions partitioned at 1,000 bytes; *2 Receive power with a receive success rate of 99%
*3 Probability distribution of fading loss is the same normal distribution as in the 2016 existing model simulation

4.2.6. Message size

Table 4-9 lists the application data sizes in the simulations. For SIP-UC RSUs and OBUs, we used the largest from the message sets of the use cases from the desk study in 3.1.2. For existing use cases, the data sizes used in the existing model simulation [1] were used.

Table 4-9 Application data sizes for RSUs and OBUs

	SIP-UC		Existing services	
	Expressway	General roads	Critical intersection	General intersection
RSU	4,986 bytes	1,150 bytes	2,750 bytes	1,150 bytes
OBU	73 bytes			

In simulations, various headers conforming to the ARIB STD-T109 standard, etc., are added to the application data size and sent. At this time, simulation is conducted using the security overhead used by existing services, similar to 3.1.2.

4.2.7. Item evaluated

The applicability of 700 MHz band ITS to SIP-UC and the impact to existing service was evaluated based on the packet arrival rate and wireless communication delay at each distance.

- Packet arrival rate

The packet arrival rate was defined as the ratio of number of packets successfully received to number of packets sent in the application layer. That is to say, even packets that could not be sent within one transmission cycle (100 ms) as a result of postponed transmissions caused by CSMA/CA carrier sense are included in the denominator and are treated as transmission failures. The number of transmitted packets is the number occurring in 10 seconds and is evaluated based on the average packet arrival rate when performed at least twice with the seed being changed.

- Wireless communication delay

Wireless communication delay was defined as the time until the probability that at least one packet can be received reaches the desired packet arrival rate. That is, the number of transmissions until the desired packet arrival rate is reached is multiplied by the transmission cycle of 100 ms, using the following formula where P_x represents the packet arrival rate for one packet transmission and P_D represents the desired packet arrival rate.

$$\text{Wireless communication delay} = \text{ceil}\left[\frac{\log(1 - P_D)}{\log(1 - P_x)}\right] \times 100\ \text{ms}$$

This wireless communication delay indicates the time during which at least one packet can be received, based on the probability of P_D. Also, because vehicles are being driven and are therefore moving, the packet arrival rate gradually changes, but in this study, calculations were done based on packet arrival rates at the same point. Based on these considerations, an evaluation was done to determine whether the required communication distance in each use case and the allowable communication delay in the radio section meet the requirements.

- Integrated packet arrival rate

The potential for coexistence with existing services was evaluated using the integrated packet arrival rate, an indicator for system implementation. The integrated packet arrival rate is the probability that at least one of the packets sent in the evaluation section can be received and is defined by the following formula.

$$\text{Integrated packet arrival rate} = 1 - (1 - P_x)^{N_x}$$

P_x: Packet arrival rate per one transmission in x[m] section

N_x: Average number of packets sent by communication counterpart while vehicle is driving through x[m] section

Here, the evaluation section is $x = 5$ [m] for V2I communication and $x = 10$ [m] for V2V communication.

4.3. Simulation results

4.3.1. Maximum vehicle density conditions when moving at low speed

4.3.1.1. SIP-UC compatibility with 700 MHz band ITS

Results of SIP-UC simulation under the greatest vehicle density conditions when moving at low speed are described. For use cases where the required communication distance changes with driving speed in the scenarios of the Radio System Technology TG [5], the required communication distance while driving at low speed was calculated and that value was used as the judgment criterion.

(1) Expressway main lanes, V2I (I -> V) communication

The V2I (I -> V) communication packet arrival rate and wireless communication delay time on expressway main lane are shown in Fig. 4-7. Also, the delay time and the travel distance during that time in each use case is shown in Table 4-10. The results show that in 266.7 m, the required communication distance in a-1-3, the packet arrival rate was at least 99%, which meets the Radio System Technology TG's communication requirements.

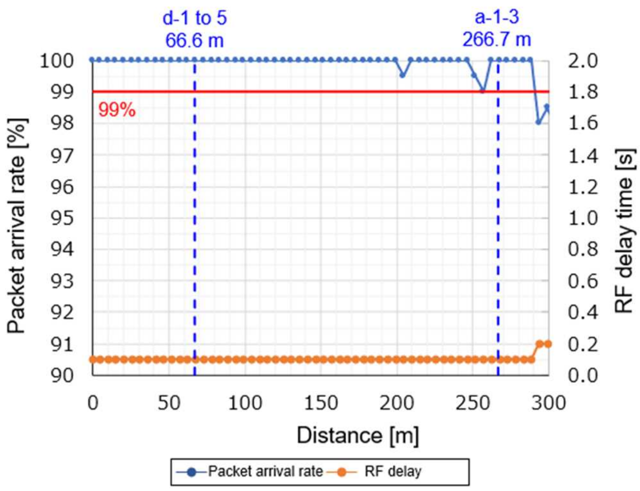


Fig. 4-7 Expressway main lanes, traffic congestion conditions
V2I (I -> V) communication simulation results

Table 4-10 Delay time and travel distance during delay time in each use case

Use case	Delay	Travel distance
a-1-3	100 ms	0.6 m
d-1 to d-5	100 ms	0.6 m

(2) Expressway connecting routes, V2I (I -> V) communication

Simulation results for V2I (I -> V) communication on the expressway connecting route are shown in Fig. 4-8. Also, the delay time and the travel distance during that time in each use case is shown in Table 4-11. The results show that in 116.7 m, the required communication distance in a-1-2 and a-1-3, which have the longest required communication distance, the packet arrival rate was at least 99%, which meets the Radio System Technology TG's communication requirements for V2I (I -> V) communication, even on connecting routes.

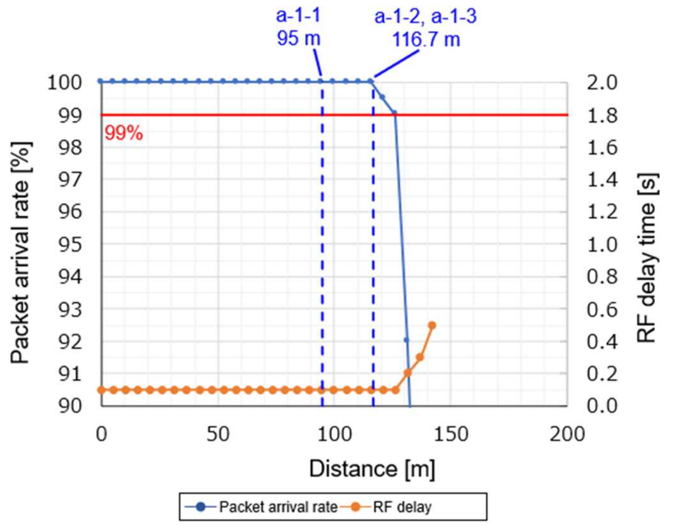


Table 4-11 Delay time and travel distance during delay time in each use case

Use case	Delay	Travel distance
a-1-1	100 ms	0.6 m
a-1-2	100 ms	0.6 m
a-1-3	100 ms	0.6 m

Fig. 4-8 Expressway connecting route, traffic congestion conditions V2I (I -> V) communication simulation results

(3) Expressway main lanes, V2I (V -> I) communication

The V2I (V -> I) communication packet arrival rate and wireless communication delay time on expressway main lane are shown in Fig. 4-9. Also, the delay time and the travel distance during that time in each use case is shown in Table 4-12. The delay time shown in the table is calculated from the minimum packet arrival rate at or under the required distance for each use case.

The results show that there are places where the packet arrival rate dropped sharply, such as at 0 m, close to 60 m, and in the range 130 to 160 m. These match the places where the road running north to south provides a line of sight, and it seems that the packet arrival rate declines because messages sent by OBUs are colliding with each other.

Even at short distances, the packet arrival rate is quite low, about 40% to 70%, so the wireless communication delay time was 900 ms in all use cases. Based on this, d-1 to d-4 and f-2 meet the communication requirements of the Radio System Technology TG, but a-1-3, where the maximum acceptable delay of radio communication part is 100 ms, does not meet them.

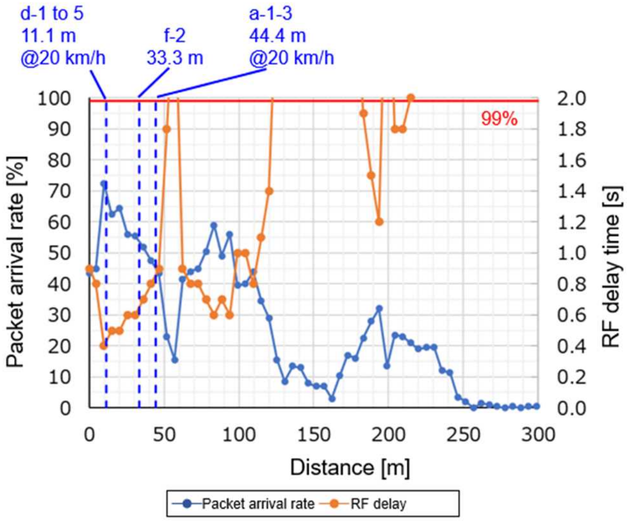


Fig. 4-9 Expressway main lanes, traffic congestion conditions
V2I (V -> I) communication simulation results

Table 4-12 Delay time and travel distance during delay time in each use case

Use case	Delay	Travel distance
a-1-3	900 ms	5.0 m
d-1 to d-4	900 ms	5.0 m
f-2	900 ms	5.0 m

(4) Expressway connecting routes, V2I (V -> I) communication

The V2I (V -> I) communication packet arrival rate and wireless communication delay time on expressway connecting route are shown in Fig. 4-10. Also, the delay time and the travel distance during that time in each use case is shown in Table 4-13. The results show that, similar to the main lane, even at short distances, the packet arrival rate is quite low, about 40% to 70%, and the requirement for a 99% packet arrival rate is not met.

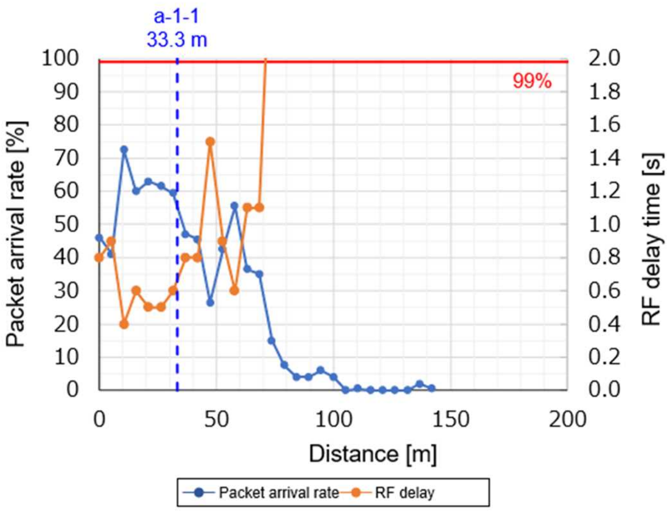


Table 4-13 Delay time and travel distance during delay time in each use case

Use case	Delay	Travel distance
a-1-3	900 ms	5.0 m

Fig. 4-10 Expressway connecting route, traffic congestion conditions V2I (V -> I) communication simulation results

(5) Expressway main lanes, V2V communication

The V2V communication packet arrival rate and wireless communication delay time on expressway main lane are shown in Fig. 4-11. Also, the delay time and the travel distance during that time in each use case is shown in Table 4-14. The results show that even at short distances, the packet arrival rate is quite low and the requirement for a 99% packet arrival rate is not met. There are some places where the packet arrival rate suddenly worsens, but because these match the places where the road running north to south provides a line of sight, it seems that the packet arrival rate falls because messages sent by OBUs are colliding with each other, the same as in V2I (V -> I) communication in (3).

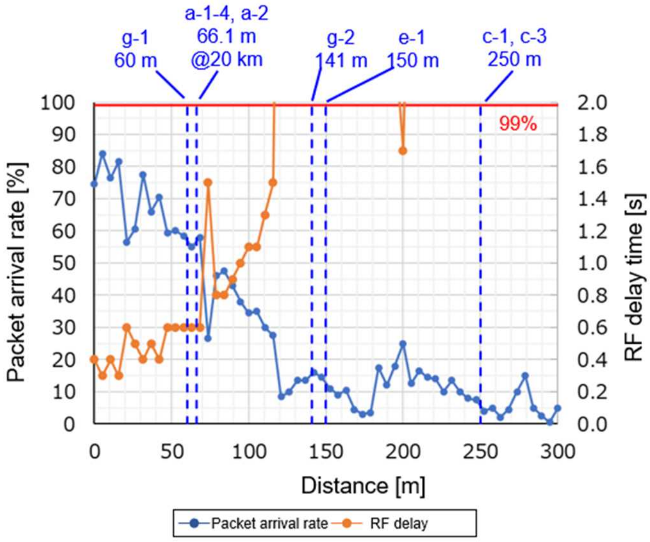


Fig. 4-11 Expressway main lanes, traffic congestion conditions V2V communication simulation results

Table 4-14 Delay time and travel distance during delay time in each use case

Use case	Delay	Travel distance
a-1-4	600 ms	3.3 m
a-2	600 ms	3.3 m
c-3/c-1	15.2 s	84.4 m
e-1	5.2 s	28.9 m
g-1	600 ms	3.3 m
g-2	5.2 s	28.9 m

(6) General road, V2I (I -> V) communication

The V2I (I -> V) communication packet arrival rate on general roads and the wireless communication delay time are shown in Fig. 4-12. Also, the delay time and the travel distance during that time in each use case is shown in Table 4-15. The results show that in 206.3 m, the required communication distance in b-1-1, the packet arrival rate was at least 99%, which meets the Radio System Technology TG's communication requirements.

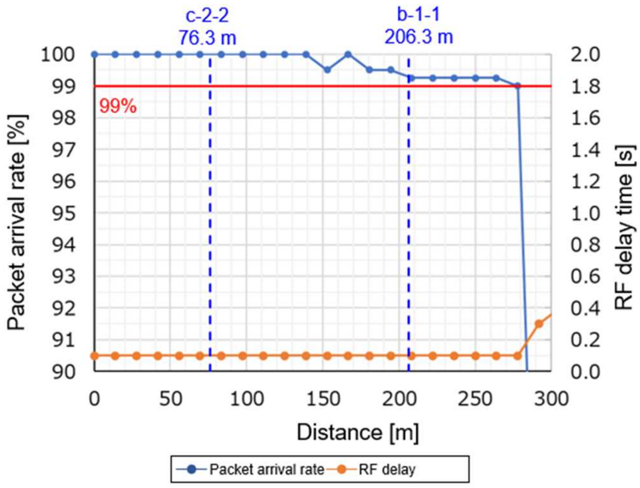


Fig. 4-12 General road, traffic congestion conditions V2I (I -> V) communication simulation results

Table 4-15 Delay time and travel distance during delay time in each use case

Use case	Delay	Travel distance
b-1-1	100 ms	1.1 m
c-2-2	100 ms	1.1 m

(7) General road, NLoS, V2V communication

The V2V communication packet arrival rate not within line of sight (NLoS) on general roads and the wireless communication delay time are shown in Fig. 4-13. Also, the delay time and the travel distance during that time in each use case is shown in Table 4-16. Because this scenario assumes a slow driving speed, the required communication distances are short, but even at short distances, the packet arrival rate was too low and did not meet the requirement of a 99% packet arrival rate. Also, the wireless communication delay time was 900 ms, which corresponds to the time it takes for a vehicle to move forward 5 m.

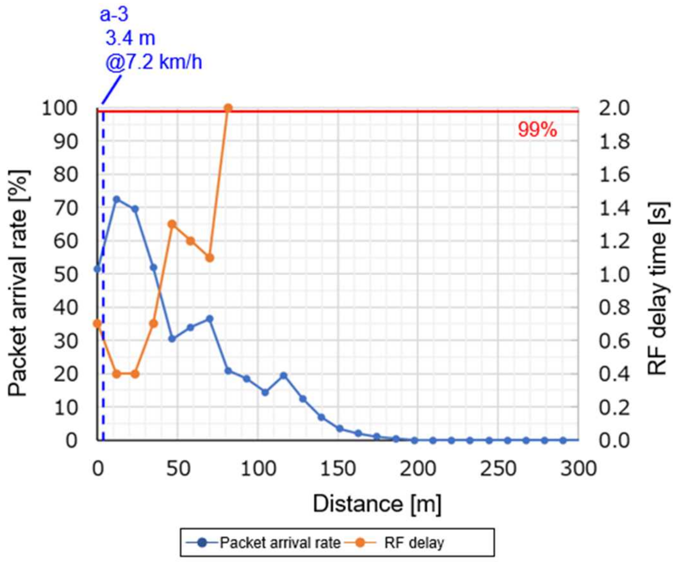


Fig. 4-13 General road, NLoS, traffic congestion conditions V2V communication simulation results

Table 4-16 Delay time and travel distance during delay time in each use case

Use case	Delay	Travel distance
a-1-3	900 ms	5.0 m

(8) General road, LoS, V2V communication

The V2V communication packet arrival rate within line of sight (LoS) on general roads and the wireless communication delay time are shown in Fig. 4-14. Also, the delay time and the travel distance during that time in each use case is shown in Table 4-17. The packet arrival rate is low at 10 to 60 m, but the place is inside an intersection with a main road running north to south, so it appears that the packet arrival rate is low because packets sent by OBUs are colliding with each other. The packet arrival rate was low overall and did not meet the requirement of a 99% packet arrival rate.

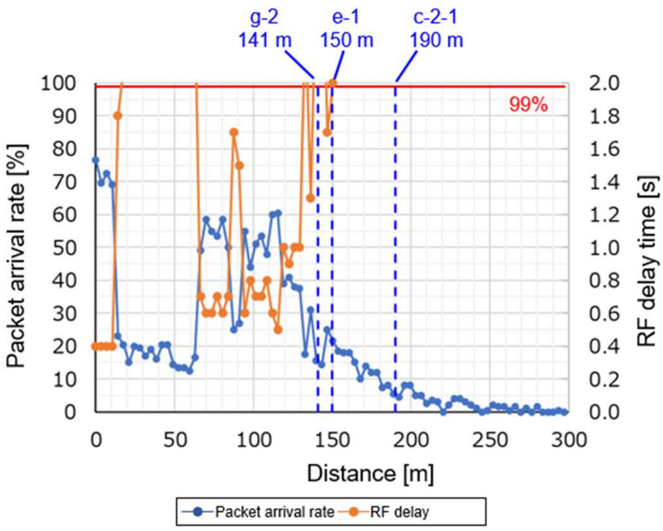


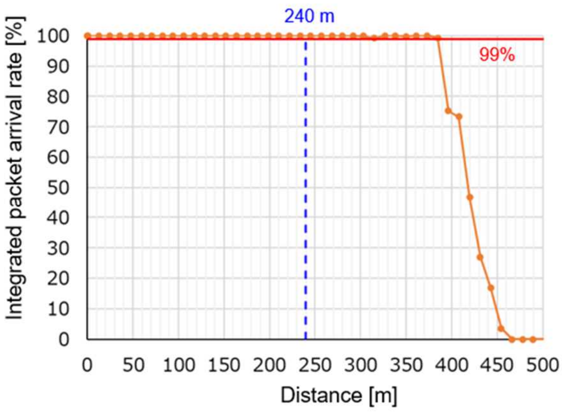
Fig. 4-14 General road, LoS, traffic congestion conditions V2V communication simulation results

Table 4-17 Delay time and travel distance during delay time in each use case

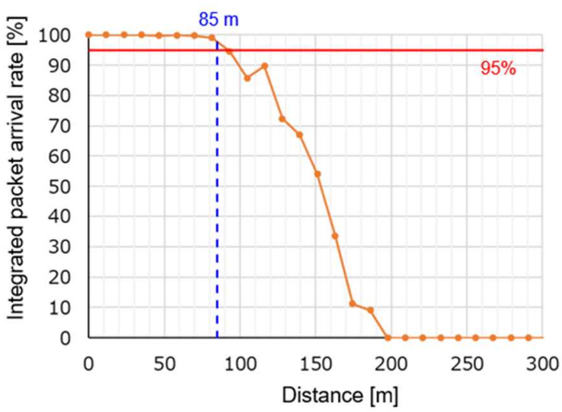
Use case	Delay	Travel distance
c-2-1	10.1 s	56.1 m
e-1	3.5 s	19.4 m
g-2	3.5 s	19.4 m

4.3.1.2. Check of potential for coexistence with existing services

Results of existing service simulation under the greatest vehicle density conditions when moving at low speed are shown in Fig. 4-15. As described in Section 4.2.7, the graph in (a), which is V2I (I -> V) communication, shows packet arrival integrated at 5 m, while (b), which is V2V communication, is integrated at 10 m. The graphs show that communication requirements (integrated packet arrival rate of 99% at 240 m for V2I (I -> V) communication and 95% at 85 m for V2V communication) were satisfied, which confirms the potential for coexistence with SIP-UC.



(a) V2I (I -> V) communication



(b) V2V communication

Fig. 4-15 Existing service simulation results

4.3.2. Maximum vehicle density conditions at regulated speed

4.3.2.1. SIP-UC compatibility with 700 MHz band ITS

This part describes the results of SIP-UC simulation under maximum vehicle density conditions where vehicles are driving at the regulated speed.

(1) Expressway main lanes, V2I (I -> V) communication

The V2I (I -> V) communication packet arrival rate and wireless communication delay time on expressway main lane are shown in Fig. 4-16. Also, the delay time and the travel distance during that time in each use case is shown in Table 4-18.

In the same way that a packet arrival rate of at least 99% was met under maximum vehicle density conditions when moving at low speed, in this case also a packet arrival rate of at least 99% was met at 266.7 m, the required communication distance in a-1-3, which shows that the communication requirements of the Radio System Technology TG are met.

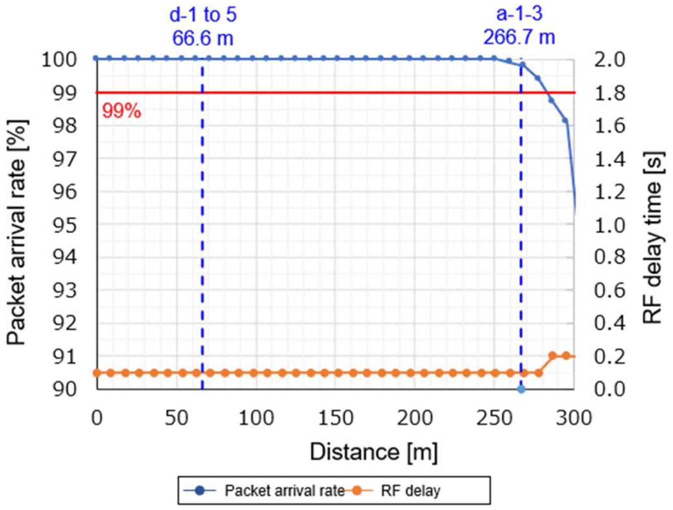


Table 4-18 Delay time and travel distance during delay time in each use case

Use case	Delay	Travel distance
a-1-3	100 ms	3.3 m
d-1 to d-4	100 ms	3.3 m

Fig. 4-16 Expressway main lanes, normal moving conditions V2I (I -> V) communication simulation results

(2) Expressway connecting routes, V2I (I -> V) communication

Simulation results for V2I (I -> V) communication on the expressway connecting route are shown in Fig. 4-17. Also, the delay time and the travel distance during that time in each use case is shown in Table 4-19. Similar to the main lane, vehicle density appears to cause very little change, and the results show that the Radio System Technology TG communication requirements were met.

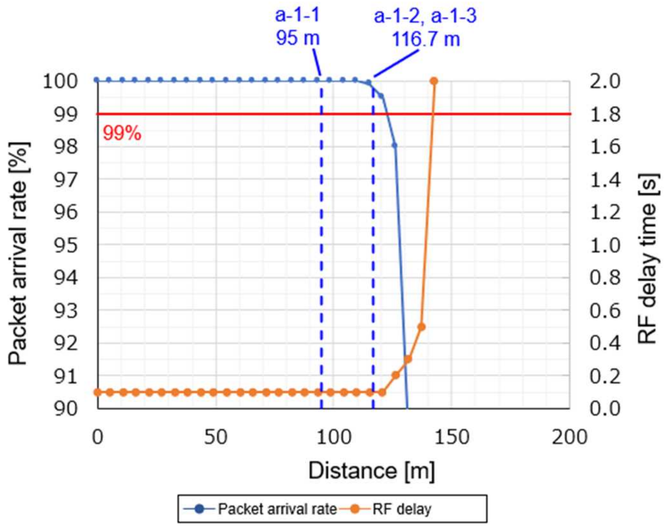


Fig. 4-17 Expressway connecting route, normal driving conditions V2I (I -> V) communication simulation results

Table 4-19 Delay time and travel distance during delay time in each use case

Use case	Delay	Travel distance
a-1-1	100 ms	1.9 m
a-1-2	100 ms	1.9 m
a-1-3	100 ms	1.9 m

(3) Expressway main lanes, V2I (V -> I) communication

The V2I (V -> I) communication packet arrival rate and wireless communication delay time on expressway main lane are shown in Fig. 4-18. Also, the delay time and the travel distance during that time in each use case is shown in Table 4-20. The results show that the packet arrival rate has greatly improved compared to maximum vehicle conditions when moving at low speed. However, in use case a-1-3, the wireless communication delay at the required distance is 700 ms, which does not meet the communication requirements of the Radio System Technology TG. In use cases d-1 through d-4 and f-2, communication requirements were met, similarly to when moving at low speed.

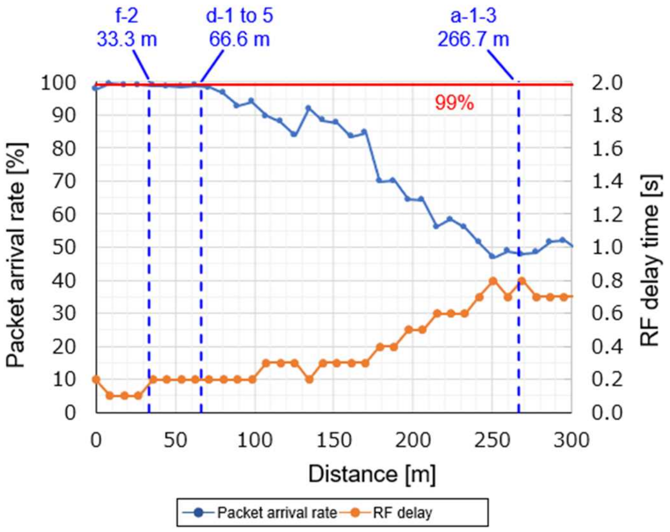


Fig. 4-18 Expressway main lanes, normal moving conditions V2I (V -> I) communication simulation results

Table 4-20 Delay time and travel distance during delay time in each use case

Use case	Delay	Travel distance
a-1-3	800 ms	26.7 m
d-1 to d-5	200 ms	6.7 m
f-2	200 ms	6.7 m

(4) Expressway connecting routes, V2I (V -> I) communication

The V2I (V -> I) communication packet arrival rate and wireless communication delay time on expressway connecting route are shown in Fig. 4-19. Also, the delay time and the travel distance during that time in each use case is shown in Table 4-21. Similar to the main lane, the packet arrival rate increased because of a decline in vehicle density, but even so the communication requirements of the Radio System Technology TG were not met.

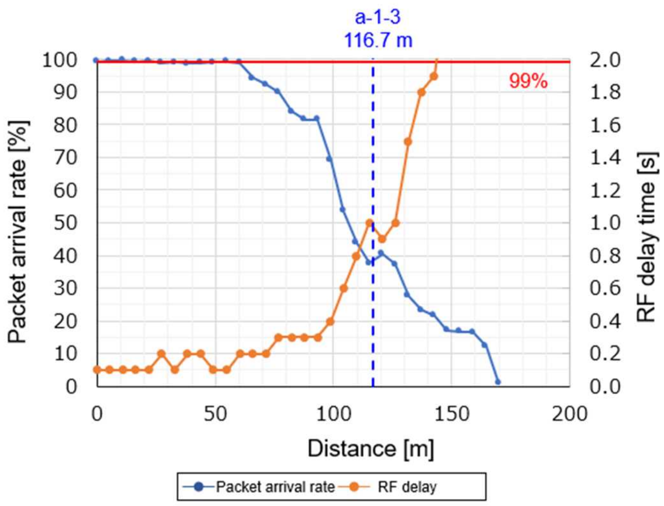


Fig. 4-19 Expressway connecting route, normal driving conditions V2I (V -> I) communication simulation results

Table 4-21 Delay time and travel distance during delay time in each use case

Use case	Delay	Travel distance
a-1-1	900 ms	17.5 m

(5) Expressway main lanes, V2V communication

The V2V communication packet arrival rate and wireless communication delay time on expressway main lane are shown in Fig. 4-20. Also, the delay time and the travel distance during that time in each use case is shown in Table 4-22. Although the packet arrival rate increased compared to when moving at low speed, it was still less than 99%, and even at 60 m, the required communication distance in use case g-1, the wireless communication delay was 200 ms, which does not meet the communication requirements of the Radio System Technology TG.

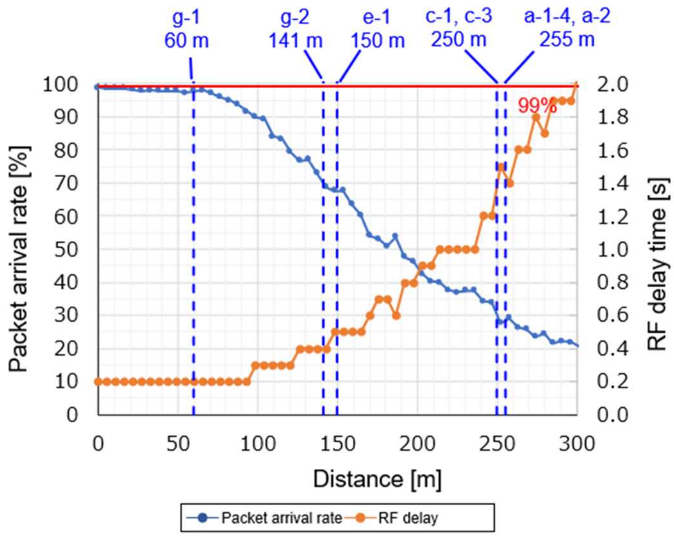


Fig. 4-20 Expressway main lanes, normal moving conditions V2V communication simulation results

Table 4-22 Delay time and travel distance during delay time in each use case

Use case	Delay	Travel distance
a-1-4	1.4 s	27.2 m
a-2	1.4 s	27.2 m
c-3/c-1	1.5 s	29.2 m
e-1	500 ms	9.7 m
g-1	200 ms	3.9 m
g-2	400 ms	7.8 m

(6) General road, V2I (I -> V) communication

The V2I (I -> V) communication packet arrival rate on general roads and the wireless communication delay time are shown in Fig. 4-21. Also, the delay time and the travel distance during that time in each use case is shown in Table 4-23. Similar to maximum density conditions when moving at low speed, the communication requirements of the Radio System Technology TG were met even under the maximum density conditions at the regulated speed.

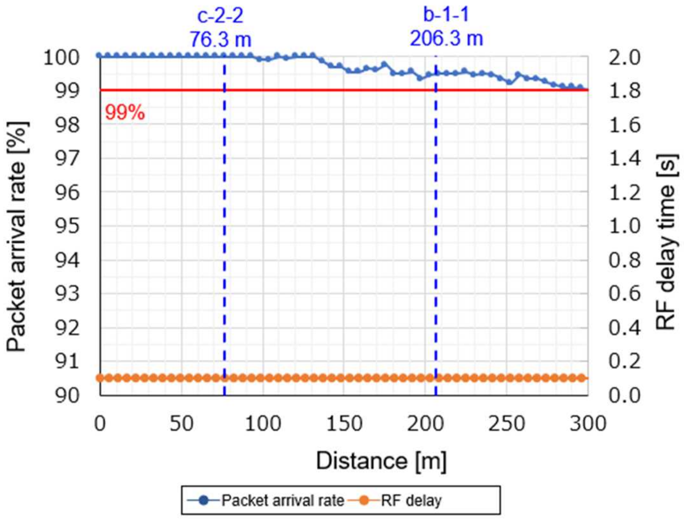


Fig. 4-21 General road, normal driving conditions V2I (I -> V) communication simulation results

Table 4-23 Delay time and travel distance during delay time in each use case

Use case	Delay	Travel distance
b-1-1	100 ms	1.9 m
c-2-2	100 ms	1.9 m

(7) General road, NLoS, V2V communication

The V2V communication packet arrival rate not within line of sight (NLoS) on general roads and the wireless communication delay time are shown in Fig. 4-22. Also, the delay time and the travel distance during that time in each use case is shown in Table 4-24. Although the packet arrival rate at the 0 m point improved from about 50% to about 95%, the communication requirements of the Radio System Technology TG were not met.

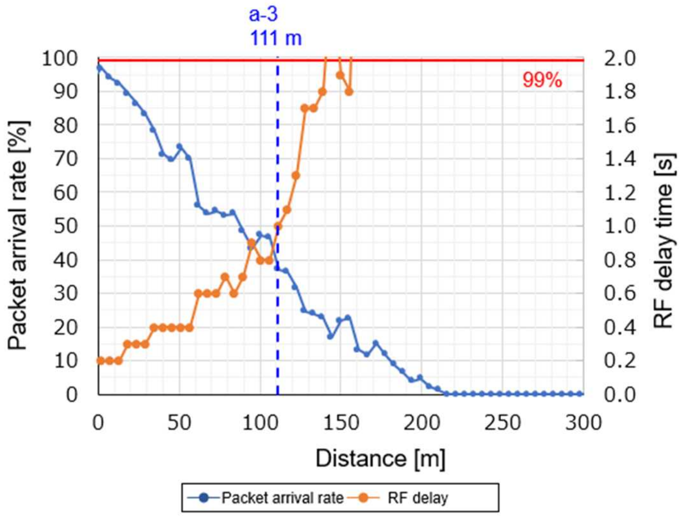


Fig. 4-22 General road, NLoS, normal driving conditions V2V communication simulation results

Table 4-24 Delay time and travel distance during delay time in each use case

Use case	Delay	Travel distance
a-3	1 s	19.4 m

(8) General road, LoS, V2V communication

The V2V communication packet arrival rate within line of sight (LoS) on general roads and the wireless communication delay time are shown in Fig. 4-23. Also, the delay time and the travel distance during that time in each use case is shown in Table 4-25. The drop in the packet arrival rate at 10 to 60 m that was seen under maximum density conditions when moving at low speed is mostly unseen because of the lower vehicle density. Also, although the packet arrival rate overall is improved, the communication requirements of the Radio System Technology TG were not met.

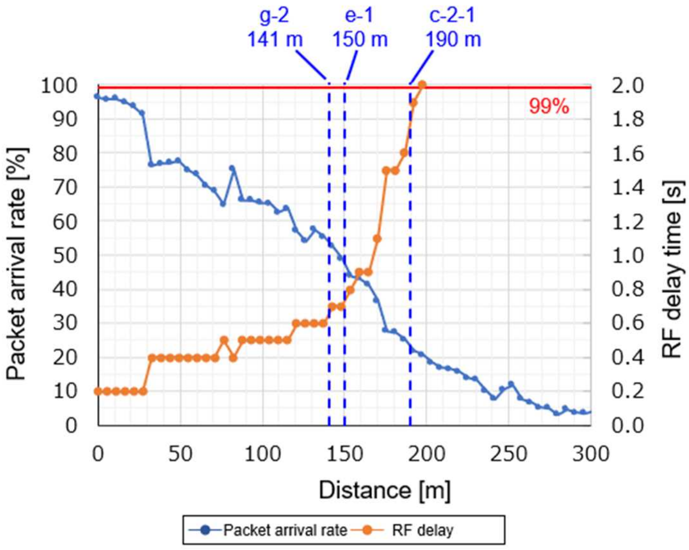


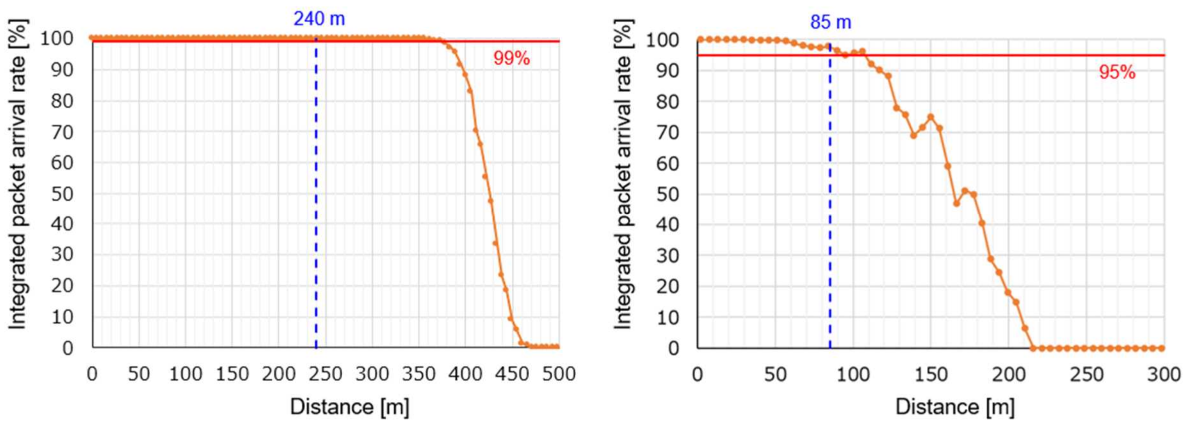
Fig. 4-23 General road, LoS, normal driving conditions V2V communication simulation results

Table 4-25 Delay time and travel distance during delay time in each use case

Use case	Delay	Travel distance
c-2-1	1.9 s	36.9 m
e-1	800 ms	15.6 m
g-1	700 ms	13.6 m

4.3.2.2. Check of potential for coexistence with existing services

The results of existing service simulation under maximum vehicle density conditions where vehicles are driving at the regulated speed are shown in Fig. 4-24. As described in Section 4.2.7, the graph in (a), which is V2I (I -> V) communication, shows packet arrival integrated at 5 m, while (b), which is V2V communication, is integrated at 10 m. The graphs show that communication requirements (integrated packet arrival rate of 99% at 240 m for V2I (I -> V) communication and 95% at 85 m for V2V communication) were satisfied, which confirms the potential for coexistence with SIP-UC.



(a) V2I (I -> V) communication (b) V2V communication

Fig. 4-24 Existing service simulation results

4.3.3. Summary of results

Table 4-3 shows the applicability with 700 MHz band ITS in each use case based on simulation results.

In V2I (I -> V) communication use cases (a-1-1, a-1-2, a-1-3, b-1-1, c-2-2, and d-1 through d-5), the communication requirements of the Radio System Technology TG were met under maximum vehicle density conditions both when moving at low speed and when moving at the regulated speed. For all RSUs in the distance range where they affect each other, it is possible to allocate slots of time when it is possible for RSUs to transmit without overlapping with each other, and it is possible to communicate without interfering the messages sent from each RSU when received by the OBU.

In V2V communication use cases (a-1-4, a-2, a-3, c-1, c-2-1, c-3, e-1, g-1, g-2), the communication requirements of the Radio System Technology TG could not be met. Under maximum vehicle density conditions when moving at low speed, the packet arrival rate was low even at those points where it would seem to be possible to get sufficient receive power, and there appear to be collisions between messages sent from OBUs because of the hidden terminal problem. The hidden terminal problem occurs in CSMA/CA, which is used in V2V communication in the T109 standard. In cases where it was possible for two OBUs (A and B) that are outside of each other's carrier sense range to transmit to receiving OBU C, collisions occur because A and B do not know if the other is transmitting, so messages sent by A and B could reach C at the same time.

Moreover, in places such as intersections where there are many vehicles within the line of sight from the transmitting vehicle, much lower packet arrival rate was observed causing insufficient radio communication capacity, which is assumed to have often resulted in the transmission failure. Although there is improvement even under the maximum vehicle density conditions at the regulated speed, the communication requirements of the Radio System Technology TG were not met.

In V2I (V -> I) communication use cases (d-1 through d-4, f-2, and a-1-3), the communication requirements of the Radio System Technology TG were met in d-1 through d-4 and in f-2. Although some impact from collisions of messages sent from OBUs is seen, the assumed maximum acceptable delay of radio communication part is 1 second, which is longer than other use cases, so the requirements were met. As for a-1-3, the communication requirements of the Radio System Technology TG were not fulfilled with 100m of the maximum acceptable delay of radio communication part .

Table 4-26 Summary of results of applicability with 700 MHz band ITS in each SIP-UC

	Broad category	Middle category	Use case	Communication requirements			Compatibility with 700 MHz ITS	RF delay (distance, delay) that satisfies the designated PAR of the TG's communication distance requirements	
				Distance	Delay	PAR		Maximum vehicle density at regulated speeds	Maximum density at low speed
1	(1) Use cases in which information outside the detection range of on-board sensors must be obtained	a. Merging / lane change assistance	**a-1-1.** Merging assistance by preliminary acceleration and deceleration	95 m	100 ms	99%	✓	See traffic congestion column	95 m / 100 ms(*)
2			**a-1-2.** Merging assistance by targeting the gap on the mainline	116.7 m	100 ms	99%	✓	See traffic congestion column	116.7 m / 100 ms(*)
3		b. Traffic signal information	**b-1-1.** Driving assistance by using traffic signal information (V2I)	206.3 m	5 m section	99%	✓	See traffic congestion column	206.3 m / 100 ms(*)
4			**b-1-2.** Driving assistance by using traffic signal information (V2N)						
5		c. Lookahead information: collision avoidance	**c-1.** Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly	250 m	100 ms	99%	×	250 m / 1.5 s	250 m / 15.2 s
6			**c-2-1.** Driving assistance based on intersection information (V2V)	190 m	100 ms	99%	×	190 m / 1.9 s	190 m / 10.1 s
7			**c-2-2.** Driving assistance based on intersection information (V2I)	76.3 m	100 ms	99%	✓	See traffic congestion column	76.3 m / 100 ms(*)
8			**c-3.** Collision avoidance assistance by using hazard information	250 m	100 ms	99%	×	250 m / 1.5 s	250 m / 15.2 s
9		d. Lookahead information: Trajectory change	**d-1.** Driving assistance by notification of abnormal vehicles	120 km/h: 66.6 m 20 km/h: 11.1 m	1 s	99%	✓	V -> I 66.6 m / 200 ms I -> V See traffic congestion column	V -> I: 11.1 m / 900 ms I -> V: 66.6 m, 100 ms (*)
10			**d-2.** Driving assistance by notification of wrong-way vehicles	120 km/h: 66.6 m 20 km/h: 11.1 m	1 s	99%	✓	V -> I 66.6 m / 200 ms I -> V See traffic congestion column	V -> I: 11.1 m / 900 ms I -> V: 66.6 m, 100 ms (*)
11			**d-3.** Driving assistance based on traffic congestion information	120 km/h: 66.6 m 20 km/h: 11.1 m	1 s	99%	✓	V -> I 66.6 m / 200 ms I -> V See traffic congestion column	V -> I: 11.1 m / 900 ms I -> V: 66.6 m, 100 ms (*)
12			**d-4.** Traffic congestion assistance at branches and exits	120 km/h: 66.6 m 20 km/h: 11.1 m	1 s	99%	✓	V -> I 66.6 m / 200 ms I -> V See traffic congestion column	V -> I: 11.1 m / 900 ms I -> V: 66.6 m, 100 ms (*)
13			**d-5.** Driving assistance based on hazard information	120 km/h: 66.6 m 20 km/h: 11.1 m	1 s	99%	✓	See traffic congestion column	66.6 m / 100 ms(*)
14		e. Lookahead information: Emergency vehicle avoidance	**e-1.** Driving assistance based on emergency vehicle information	150 m	100 ms	99%	×	150 m / 800 ms	150 m / 5.2 s
15	(2) Use cases in which information of one's own vehicle must be provided	f. Information collection / distribution by infrastructure	**f-1.** Request for rescue (e-Call)						
16			**f-2.** Collection of information to optimize the traffic flow	33.3 m	1 s	99%	✓	V -> I 33.3 m / 200 ms	V -> I: 33.3 m / 900 ms
17			**f-3.** Update and automatic generation of maps						
18			**f-4.** Distribution of dynamic map information						
19	(3) Use cases in which V2V and V2I (I -> V) interaction must be ensured	a. Merging / lane change assistance	**a-1-3.** Cooperative merging assistance with vehicles on the mainline by roadside control	Expressway mainlines 120 km/h: 266.7 m 20 km/h: 44.4 m Expressway connecting route 70 km/h: 116.7 m 20 km/h: 33.3 m	100 ms	99%	×	Expressway mainlines V -> I 266.7 m / 800 ms I -> V See traffic congestion column Expressway connecting route V -> I 116.7 m / 900 ms I -> V See traffic congestion column	Expressway mainlines V -> I: 44.4 m / 900 ms I -> V 266.6 m, 100 ms (*) Expressway connecting route V -> I: 33.3 m / 900 ms I -> V 116.7 m, 100 ms (*)
20			**a-1-4.** Merging assistance based on negotiations between vehicles	120 km/h: 255 m 20 km/h: 66.1 m	100 ms	99%	×	255 m / 1.4 s	66.1 m / 600 ms
21			**a-2.** Lane change assistance when the traffic is heavy	120 km/h: 255 m 20 km/h: 66.1 m	100 ms	99%	×	255 m / 1.4 s	66.1 m / 600 ms
22			**a-3.** Entry assistance from non-priority roads to priority roads during traffic congestion	60 km/h: 111.1 m 7.2 km/h: 3.4 m	100 ms	99%	×	111.1 m / 1.0 s	3.4 m / 700 ms
23		g. Platooning / adaptive cruise control	**g-1.** Unmanned platooning of following vehicles by electronic towbar	60 m	100 ms	99%	×	60 m / 200 ms	Outside scenario range
24			**g-2.** Adaptive cruise control and manned platooning of following vehicles using adaptive cruise control	141 m	10 m section	95%	×	141 m / 700 ms	Outside scenario range
25		h. Teleoperation	**h-1.** Operation and management of mobility service cars						

(*): Meets communication requirements for maximum vehicle density conditions at the regulated speed, even under maximum vehicle density conditions at maximum speed
*Concerning security during communication, the results are based on the overhead length used in 700 MHz band ITS, not the overhead length presented by the Radio System Technology TG

4.3.4. Discussion

In V2V communications, there would appear to be two main reasons that the Radio System Technology TG's communication requirements are not met, as described below.

(i) Decline in transmission rate

With higher density of OBUs, it is difficult to send out messages within 100 ms loosing proper transmission timing.

(ii) Inability to receive messages because of simultaneous transmissions

The hidden terminal problem, which causes simultaneous transmissions because an OBU outside of carrier sense range cannot determine the transmission timing of the OBU under evaluation, causes OBUs to transmit at the same time as each other and the required DU ratio is not met, making it impossible to receive messages.

In V2I (V -> I) communication use cases also, for similar reasons as in V2V communication, the packet arrival rate declines. It is considered that the requirements were not met in a-1-3, where the maximum acceptable delay of radio communication part is 100 ms.

4.4. Additional verification simulations

Simulations were conducted with different environmental conditions as examples, to use as reference for studies aiming for social implementation of SIP-UC with 700 MHz band ITS.

4.4.1. Simulation conditions

As additional verification, simulations were conducted under the four types of conditions.

- Condition 1: Maximum vehicle density conditions at regulated speed

To see the changes resulting from changing conditions, the results of simulation of maximum vehicle density conditions at regulated speed as indicated in 4.3.2 are provided.

- Condition 2: Change of receiver sensitivity

As studied in 3.1.1, receiver sensitivity of RSUs and OBUs was determined by referring to references [6] and [7], but receiver sensitivity seems likely to increase as the technology advances. Here, a simulation was conducted in which receiver sensitivity was improved by 8 dB as an example, as shown in Table 4-27. Carrier sense level of the OBU was not changed.

The change is expected to expand the communication distance.

Table 4-27 Changes of receiver sensitivity in additional verification

Modulation method	Before	After
QPSK1/2	-82 dBm	-90 dBm
16QAM1/2	-77 dBm	-85 dBm

- Condition 3: Change of receiver sensitivity + I2I communication OFF

In the simulation, results of which are described in Section 4.3, slots 13 to 16 were allocated for I2I communication, as shown in Fig. 4-25. There are some cases where there is no I2I communication depending on location, so a simulation was conducted under the condition that I2I communication is suspended, in addition to Condition 2.

This change freed up the I2I communication slots for OBU communication, so that is expected to increase the transmission rate and reduce collisions between OBU transmissions.

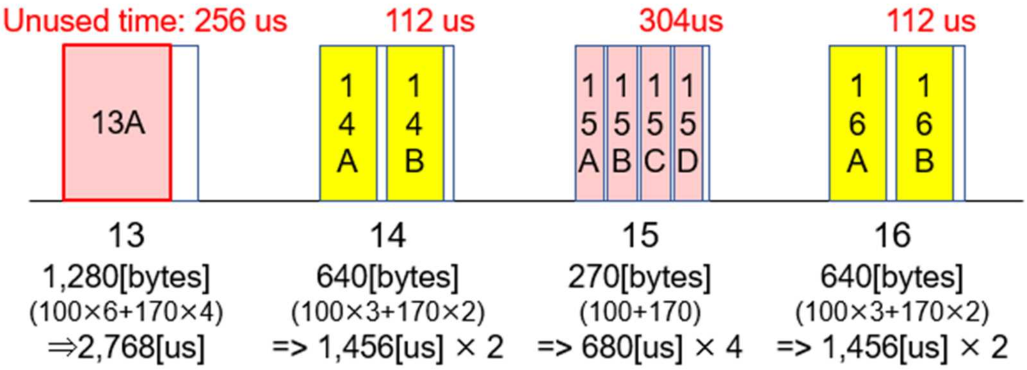


Fig. 4-25 I2I communication periods

- Condition 4: Change of receiver sensitivity + I2I communication OFF + change of vehicle density

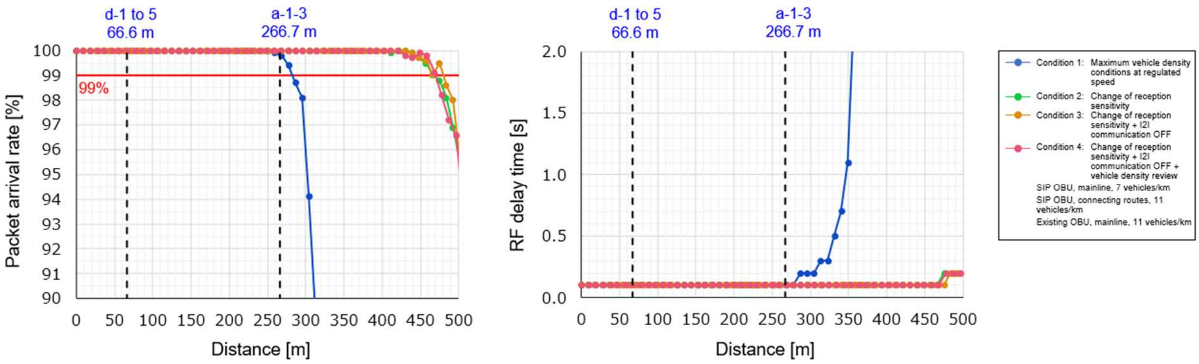
The vehicle density is the highest at the regulated speed, but to evaluate the ability of 700 MHz band ITS in an environment with low vehicle density, a simulation was conducted in which vehicle density was set at about half the level assumed for a hub city, in addition to Condition 3.

This change of condition is expected to increase the transmission rate and reduce collisions between OBU transmissions, the same as with Condition 3.

4.4.2. Simulation results

(1) Expressway, V2I (I -> V) communication

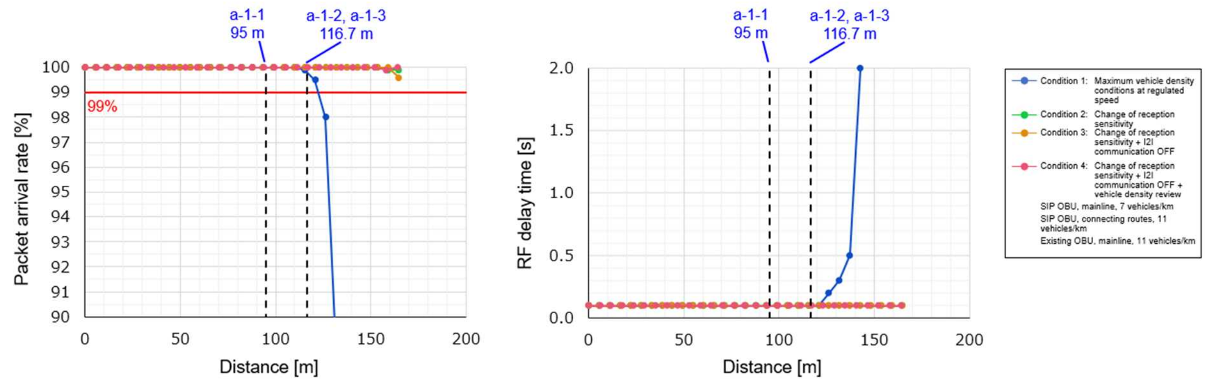
For the additional simulation of V2I (I -> V) communication on expressways, results for the main lane are given in Fig. 4-26 and results for connecting routes are given in Fig. 4-27. The communication distance is longer under Condition 2, but the changes in Conditions 3 and 4 have almost no impact on whether RSUs can transmit, and messages sent from RSUs can be received, so there was no difference.



(a) Packet arrival rate **(b) Wireless communication delay time**

Fig. 4-26 Simulation results with conditions changed

(expressway main lanes, V2I (I -> V) communication)



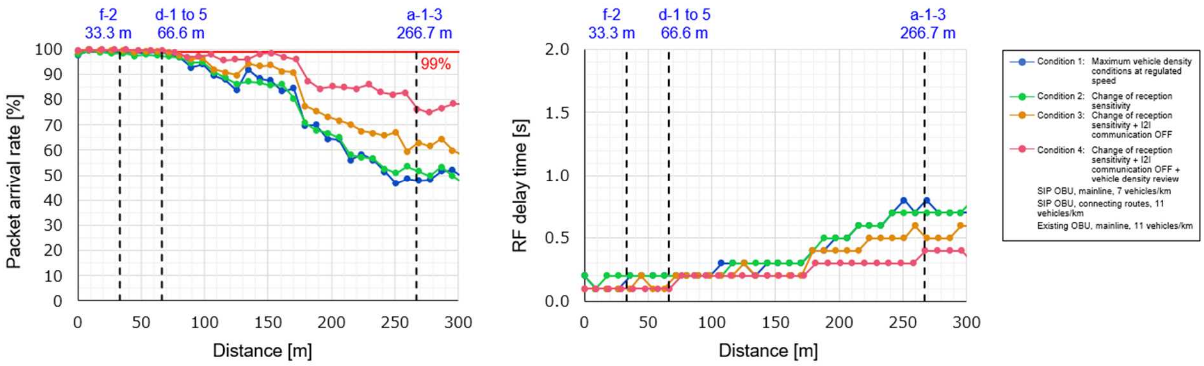
(a) Packet arrival rate **(b) Wireless communication delay time**

Fig. 4-27 Simulation results with conditions changed

(expressway connecting routes, V2I (I -> V) communication)

(2) Expressway, V2I (V -> I) communication

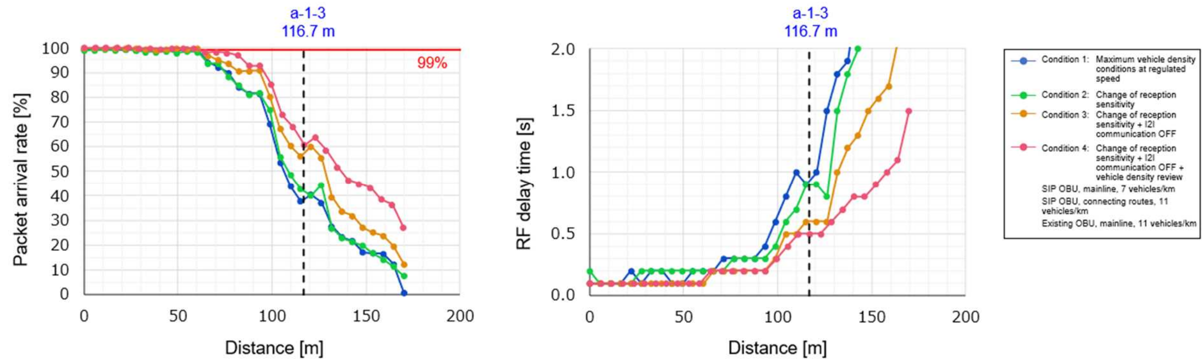
For the additional simulation of V2I (V -> I) communication on expressways, results for the main lane are given in Fig. 4-28 and results for connecting routes are given in Fig. 4-29. Compared to the impact of changing the receiver sensitivity in Condition 2, Conditions 3 and 4 had a greater effect, showing that a transmission rate decline and collisions between OBU transmissions lowered the packet arrival rate.



(a) Packet arrival rate **(b) Wireless communication delay time**

Fig. 4-28 Simulation results with conditions changed

(expressway main lanes, V2I (V -> I) communication)

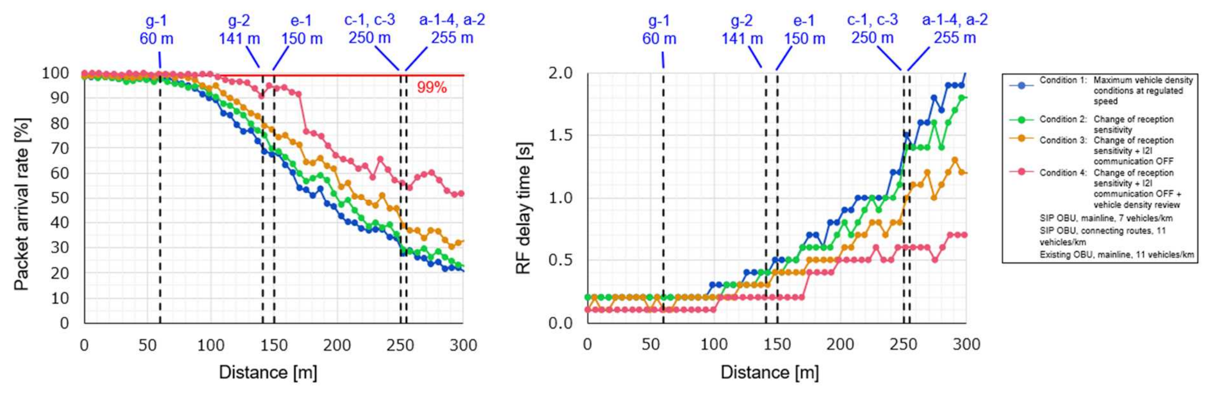


(a) Packet arrival rate **(b) Wireless communication delay time**

Fig. 4-29 Simulation results with conditions changed (expressway connecting routes, V2I (V -> I) communication)

(3) Expressway main lanes, V2V communication

Results of additional simulation of V2V communication on expressway main lane are shown in Fig. 4-30. The change of receiver sensitivity in Condition 2 made almost no difference, while freeing up the I2I communication slots for OBUs in Conditions 3 and reducing the number of vehicles in Conditions 4 resulted in a better packet arrival rate and wireless communication delay time.

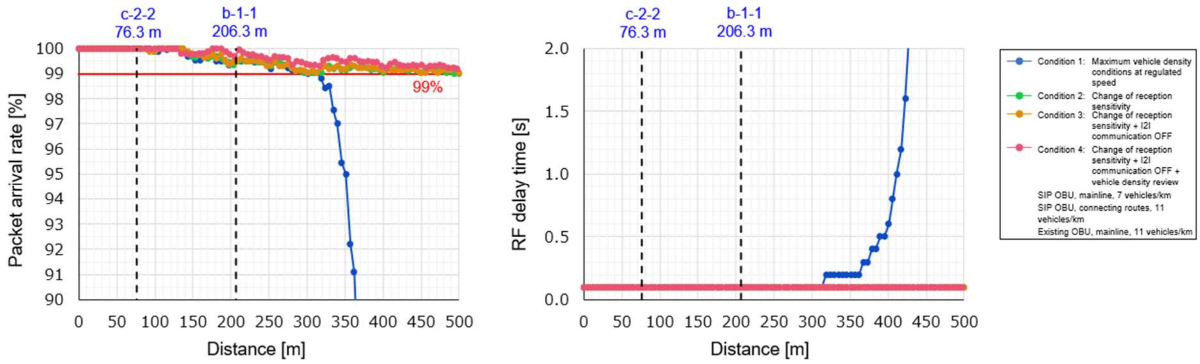


(a) Packet arrival rate (b) Wireless communication delay time

Fig. 4-30 Simulation results with conditions changed
(expressway main lanes, V2V communication)

(4) General road, V2I (I -> V) communication

Results of additional simulation of V2I (I -> V) communication on general roads are shown in Fig. 4-31. Similarly to (1), the communication distance changed as a result of changing the receiver sensitivity, but turning I2I communication off and changing vehicle density had almost no impact.

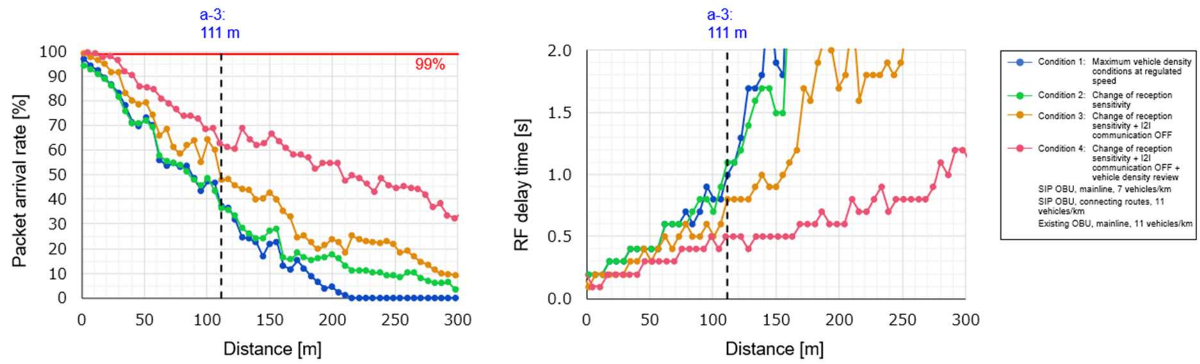


(a) Packet arrival rate (b) Wireless communication delay time

Fig. 4-31 Simulation results with conditions changed (general road, V2I (I -> V) communication)

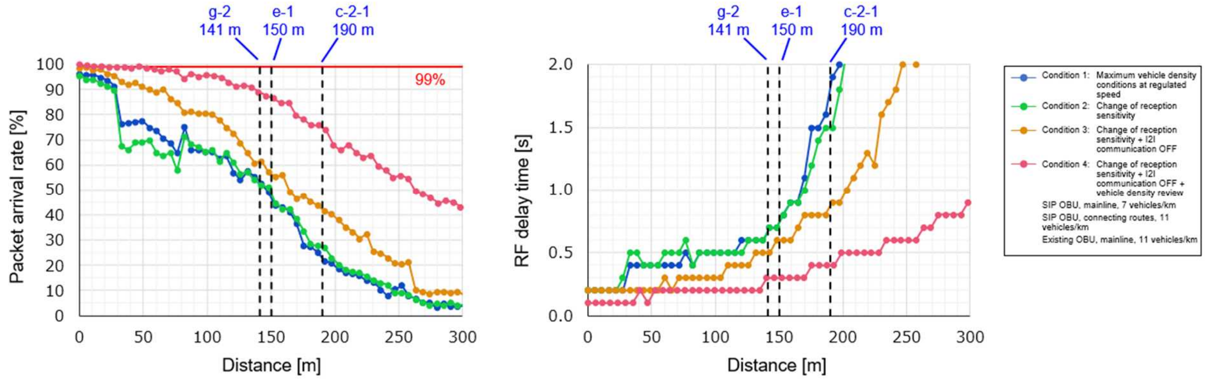
(5) General road, V2V communication

For the additional simulation of V2I (I -> V) communication on general roads, results for communication not within the line of sight (NLoS) are given in Fig. 4-32 and results for communication within the line of sight (LoS) are given in Fig. 4-33. The results indicate that in Condition 4, changing the vehicle density has a noteworthy impact. The vehicle density seems to have a big impact because general roads are under the condition that vehicle density is higher than on expressways.



(a) Packet arrival rate (b) Wireless communication delay time

Fig. 4-32 Simulation results with conditions changed (general road, NLoS, V2V communication)



(a) Packet arrival rate　　　　　　(b) Wireless communication delay time

Fig. 4-33 Simulation results with conditions changed (general road, LoS, V2V communication)

(6) Summary

Increasing receiver sensitivity did not improve V2I (V -> I) and V2V communication quality. On the other hand, by not using I2I communication slots, there was a slight improvement to V2I (V -> I) and V2V communication quality, and that quality was further improved by reducing vehicle density.

Also, under Condition 4, in which vehicle density was reduced, the wireless communication delay was improved by 0.1 to 1.4 seconds, which made it possible to meet the communication quality requirements of the Radio System Technology TG in use case g-2 (Adaptive cruise control and manned platooning of following vehicles using adaptive cruise control).

Table 4-28 Improvements to communication delay by changing conditions

No.	Broad category	Middle category	Use case	TG communication requirements distance, delay, PAR	Compatibility with 700 MHz ITS	RF delay (distance, delay) that satisfies the designated PAR of the TG's communication distance requirements *Maximum vehicle density conditions at regulated speeds: Before change of conditions (Condition 1)	After change of conditions (Condition 4)
1	(1) Use cases in which information outside the detection range of on-board sensors must be obtained	a. Merging / lane change assistance	**a-1-1.** Merging assistance by preliminary acceleration and deceleration				
2			**a-1-2.** Merging assistance by targeting the gap on the mainline				
3		b. Traffic signal information	**b-1-1.** Driving assistance by using traffic signal information (V2I)				
4			**b-1-2.** Driving assistance by using traffic signal information (V2N)				
5		c. Lookahead information: Collision avoidance	**c-1.** Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly	250 m / 100 ms / 99%	×	250 m / 1.5 s Travel distance in 1.5 s: 29.2 m	**250 m / 600 ms Distance per 600 ms: 11.7 m**
6			**c-2-1.** Driving assistance based on intersection information (V2V)	190 m / 100 ms / 99%	×	190 m / 1.9 s distance per 1.9 s: 36.9 m	**190 m / 400 ms distance per 400 ms: 7.8 m**
7			**c-2-2.** Driving assistance based on intersection information (V2I)				
8			**c-3.** Collision avoidance assistance by using hazard information	250 m / 100 ms / 99%	×	250 m / 1.5 s Travel distance in 1.5 s: 29.2 m	**250 m / 600 ms Distance per 600 ms: 11.7 m**
9		d. Lookahead information: Trajectory change	**d-1.** Driving assistance by notification of abnormal vehicles				
10			**d-2.** Driving assistance by notification of wrong-way vehicles				
11			**d-3.** Driving assistance based on traffic congestion information				
12			**d-4.** Traffic congestion assistance at branches and exits				
13			**d-5.** Driving assistance based on hazard information				
14		e. Lookahead information: Emergency vehicle avoidance	**e-1.** Driving assistance based on emergency vehicle information	150 m / 100 ms / 99%	×	150 m / 500 ms distance per 500 ms: 9.7 m	**150 m / 200 ms distance per 200 ms: 3.9 m**
15	(2) Use cases in which information of one's own vehicle must be provided	f. Information collection / distribution by infrastructure	**f-1.** Request for rescue (e-Call)				
16			**f-2.** Collection of information to optimize the traffic flow				
17			**f-3.** Update and automatic generation of maps				
18			**f-4.** Distribution of dynamic map information				
19	(3) Use cases in which V2V and V2I (I -> V) interaction must be ensured	a. Merging / lane change assistance	**a-1-3.** Cooperative merging assistance with vehicles on the mainline by roadside control	Expressway mainlines 120 km/h: 266.7 m / 100 ms / 99% 20 km/h: 44.4 m / 100 ms / 99% Expressway connecting route 70 km/h: 116.7 m /100 ms / 99% 20 km/h: 33.3 m / 100 ms / 99%	×	Mainline 120 km/h 266.7 m/ 800 ms distance per 800 ms: 26.7 m Connecting routes 70 km/h 116.7 m/ 900 ms distance per 900 ms: 17.5 m	**Mainline 120 km/h 266.7 m/ 400 ms distance per 400 ms: 13.3 m Connecting routes 70 km/h 116.7 m / 500 ms distance per 500 ms: 9.7 m**
20			**a-1-4.** Merging assistance based on negotiations between vehicles	120 km/h: 255 m / 100 ms / 99% 20 km/h: 66.1 m / 100 ms / 99%	×	255 m / 1.4 s Travel distance in 1.4 s: 27.2 m	**255 m / 600 ms Distance per 600 ms: 11.7 m**
21			**a-2.** Lane change assistance when the traffic is heavy	120 km/h: 255 m / 100 ms / 99% 20 km/h: 66.1 m / 100 ms / 99%	×	255 m / 1.4 s Travel distance in 1.4 s: 27.2 m	**255 m / 600 ms Distance per 600 ms: 11.7 m**
22			**a-3.** Entry assistance from non-priority roads to priority roads during traffic congestion	60 km/h:111.1 m / 100 ms / 99% 7.2 km/h: 3.4 m / 100 ms / 99%	×	111.1 m / 1.0 s distance per 1.0 s: 19.4 m	**111.1 m / 500 ms distance per 500 ms: 9.7 m**
23		g. Platooning / adaptive cruise control	**g-1.** Unmanned platooning of following vehicles by electronic towbar	Normal: 60 m, 100 ms, 99% Emergency: 60 m, 20 ms, 99%	×	60 m / 200 ms distance per 200 ms: 3.89 m	**60 m / 100 ms distance per 100 ms: 1.9 m**
24			**g-2.** Adaptive cruise control and manned platooning of following vehicles using adaptive cruise control	141 m, 10 m section, 95% * 10 m section = 500 ms @ 70 km/h	✓	141 m / 700 ms distance per 800 ms: 13.6 m	**141 m / 300 ms distance per 300 ms: 5.8 m**
25		h. Teleoperation	**h-1.** Operation and management of mobility service cars				

4.4.3. Discussion

Results of additional verification simulations indicate that in V2V and V2I (V -> I) communications, changing the receiver sensitivity does not make a difference in communication quality, but freeing up I2I communication time for OBUs and revising vehicle density led to a noteworthy improvement. This appears to be because freeing up I2I communication time and reducing vehicle density result in increasing the number of OBU terminals that can be accommodated corresponding to the amount of communication time freed up for OBUs and mitigating the decline of the packet arrival rate caused by OBU transmission timing collisions. That is to say, under the conditions used in this study, the fact that insufficient OBU transmission time causes the transmission rate to decline and that there are simultaneous transmissions among OBUs are big factors.

The results came close to meeting the communication quality requirements of the Radio System Technology TG in use cases like g-1 and d-1 through d-5, and it appears possible the communication requirements could be met by a deeper examination of the service requirements for those use cases.

5. Issues and future actions

Issues were identified and actions were proposed in light of the results of the desk study in Part 3 and simulations in Part 4.

(i) Deeper examination of service requirements for cooperative driving automation use cases

<Issues>

When the desk study and evaluations by simulation were conducted on the Radio System Technology TG's scenarios and communication requirements, the TG's communication requirements were not met in some SIP-UC. In the communication requirements of the TG, PAR and maximum acceptable delay of radio communication partn are assumed values because details of the service requirements were uncertain. In addition, there is one set of service requirements that includes differences in vehicle congestion status and multiple situations such as driving conditions and surrounding environment, so that makes the required communication distance even stricter. This shows that in confirming these communication requirements in detail, it will be necessary to further organize the service requirements for automated driving, such as the applicable scenarios for each SIP-UC (road conditions: vehicle density, driving speed) and means of collecting information (communications, autonomous sensors). Specifically, it will be necessary to study what kind of movement automated vehicles will make, to what point they will need to be controlled, and how much is required of communications, such as: necessary inter-vehicle-distance between automated vehicles to be kept in usual cases or in case that driver gets limited visibility due to large vehicles in front, or proper turning speed to be kept on curves or in intersections. The communication requirements will change depending on the automated driving behavior, control methods, and segregation from autonomous sensors. Based on the above, it will be necessary to set clear detailed service requirements according to the circumstances and define communication requirements for those requirements.

<Future actions>

Necessary actions to take in response to the above issues include each advocacy organizations for SIP-UC, such as the Japan Automobile Manufacturers Association and ITS Info-communications Forum, working together to further specify service requirements based on congestion of surrounding vehicles, behavior and control methods of automated vehicles, and the like, and to define practical and optimal communication requirements (required communication distance, maximum acceptable delay of radio communication part, etc.) based on service requirements. Another action that could be considered would be lengthening the transmission cycle in a situation where surrounding vehicles are congested, since the vehicles will be driving at a slow speed.

For reference, Table 5-1 lists communication requirements proposed by an assignee for those use cases in Table 4-26 that are marked as not compatible with 700 MHz band ITS.

Use case g-1 is not subject to study because it does not meet maximum acceptable delay of radio communication part requirements under the T109 standard, as indicated in the study in Part 3.

Table 5-1 Proposed communication requirements *Green indicates use case is compatible with the communication requirements of the Radio System Technology TG

	Broad category	Middle category	Use case	Proposed communication requirements distance, delay, PAR	Applicability with 700 MHz ITS
1	(1) Use cases in which information outside the detection range of on-board sensors must be obtained	a. Merging / lane change assistance	a-1-1. Merging assistance by preliminary acceleration and deceleration		
2			a-1-2. Merging assistance by targeting the gap on the main lane		
3		b. Traffic signal information	b-1-1. Driving assistance by using traffic signal information (V2I)		
4			b-1-2. Driving assistance by using traffic signal information (V2N)		
5		c. Lookahead information: Collision avoidance	c-1. Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly	120 km/h: 81.7 m / 200 ms / 99 % 20 km/h: 17.8 m / 600 ms / 99 %	✓
6			c-2-1. Driving assistance based on intersection information (V2V)	70 km/h:157.6 m/900 ms/99 % 20 km/h:45.1 m/2.9 s/99 %	✓
7			c-2-2. Driving assistance based on intersection information (V2I)		
8			c-3. Collision avoidance assistance by using hazard information	120 km/h: 81.7 m / 200 ms / 99 % 20 km/h: 17.8 m / 600 ms / 99 %	✓
9		d. Lookahead information: Trajectory change	d-1. Driving assistance by notification of abnormal vehicles		
10			d-2. Driving assistance by notification of wrong-way vehicles		
11			d-3. Driving assistance based on traffic congestion information		
12			d-4. Traffic congestion assistance at branches and exits		
13			d-5. Driving assistance based on hazard information		
14		e. Lookahead information: Emergency vehicle avoidance	e-1. Driving assistance based on emergency vehicle information	120 km/h:150 m/900 ms/99 % 20 km/h:150 m/5.2 s/99 %	✓
15	(2) Use cases in which information of one's own vehicle must be provided	f. Information collection / distribution by infrastructure	f-1. Request for rescue (e-Call)		
16			f-2. Collection of information to optimize the traffic flow		
17			f-3. Update and automatic generation of maps		
18			f-4. Distribution of dynamic map information		
19	(3) Use cases in which V2V and V2I interaction must be ensured	a. Merging / lane change assistance	a-1-3. Cooperative merging assistance with vehicles on the main lane by roadside control	Expressway main lanes 120 km/h:266.7 m/600 ms/99 % 20 km/h:44.4 m/900 ms/99 % Expressway connecting route 120 km/h:116.7 m/600 ms/99 % 20 km/h:33.3 m/900 ms/99 %	✓
20			a-1-4. Merging assistance based on negotiations between vehicles	70 km/h:124.4 m/2 s/99 % 20 km/h:65.8 m/2 s/99 %	× *1
21			a-2. Lane change assistance when the traffic is heavy	Relative speed 60 km/h: 166.6 m / 2 s / 99% Relative speed 20 km/h: 77.7 m / 2 s / 99%	× *1
22			a-3. Entry assistance from non-priority roads to priority roads during traffic congestion	60 km/h:127.8 m/2 s/99 % 7.2 km/h:34.8 m/2 s/99 %	× *1
23		g. Platooning / adaptive cruise control	g-1. Unmanned platooning of following vehicles by electronic towbar	Normal: 60 m, 200 ms, 99% Emergency: 60 m, 20 ms, 99.99%	× *2
24			g-2. Adaptive cruise control and manned platooning of following vehicles using adaptive cruise control	100 km/h:141 m/800 ms/95 %	✓
25		h. Teleoperation	h-1. Operation and management of mobility service cars		

(*1) Negotiation not achieved, basic messages achieved

(*2) Not achieved in times of emergency, achieved in normal times

(ii) Response to SIP-UC that require interaction (a-1-3, a-1-4, a-2, a-3)

<Issues>

For SIP-UC a-1-3, a-1-4, a-2, and a-3, which require interaction and in which messages are exchanged between OBU and RSU or between OBUs, there is a large “number of transmitting vehicles per area” indicated for the communication requirements of the Radio System Technology TG, and the results did not fall within the transmission time constraints in a 100 ms cycle as established by ARIB STD-T109 [2]. Therefore, it will be necessary to use a new communication method. However, radio waves in the 700 MHz band, with their distant reach and ability to travel around obstacles, are ideally used for basic exchanges for confirmation of mutual positioning, and deeper discussion on how to use 700 MHz band ITS is the issue.

<Future actions>

As Table 5-2 indicates, messages exchanged by communication in SIP-UC are considered by categorizing them as either basic messages, which use one-way communication to provide information on road status, traffic signal information, the location, speed, and direction of each vehicle, and other information essential to automated driving and safe driving support (below, “basic information”), or advanced messages, which use two-way communication to exchange information necessary for interaction.

SIP-UC can be categorized as SIP-UC that do not require interaction and SIP-UC that do require it. SIP-UC that do not require interaction are ones that can be achieved by receiving basic information provided by RSU or OBU; that is, they can be achieved with basic messages. On the other hand, SIP-UC a-1-3, a-1-4, a-2, and a-3, which do require interaction, in addition to receiving messages on surrounding conditions as in SIP-UC that do not require interaction, also require interaction with other vehicles, such as when changing lanes or merging. These can be achieved by a combination of basic messages and advanced messages. In light of these, we propose the following two actions.

Proposal 1: Achieve with new communication method only

When using only a new communication method that includes receiving information on surrounding conditions (location, speed information, etc.) and interaction, then bandwidth and propagation on the frequency band of the new communication method need to be considered. The relationship between the new communication method and existing safe driving support services (ITC Connect services) also needs to be considered. Specifically, if SIP-UC and safe driving support services coexist, issues include the cost and the great impact on OBUs to support two communication methods: the new one and 700 MHz band ITS. If safe driving support services were to transition to a new communication method along with SIP-UC, there would be issues with the deployment and dissemination of vehicles and quality assurance, both of which need to be considered.

Proposal 2: Achieve with 700 MHz band ITS + new communication method

With their distant reach and ability to travel around obstacles, radio waves in 700 MHz band ITS can provide information to a wide range of RSUs and OBUs. They are also optimally used for basic messages, since they are transmitted cyclically, which allows them to transmit information about the surrounding area, which changes moment by moment.

In SIP-UC that do require interaction, separating messages makes it unnecessary to exchange basic information when interacting, which can mitigate what is required of the new communication method that handles advanced messages. However, just as in Proposal 1, the cost and the impact on OBUs to support two communication methods, the new one and 700 MHz band ITS, are issues.

Going forward, ensuring social implementation at an early date will require the approach that 700 MHz band ITS will cover SIP-UC that do not require interaction and both 700 MHz band ITS and a new communication method will cover SIP-UC a-1-3, a-1-4, a-2, and a-3, which do require interaction.

Table 5-2 Message definitions and communication methods

	Content	Communication method
Basic messages	Messages that use one-way communication to provide basic information, such as information on road status, traffic signal information, location, speed, and direction of each vehicle, and other information essential to automated driving and safe driving support.	700 MHz band ITS
Advanced messages	Messages that use two-way communication to exchange information necessary for interaction.	New communication method

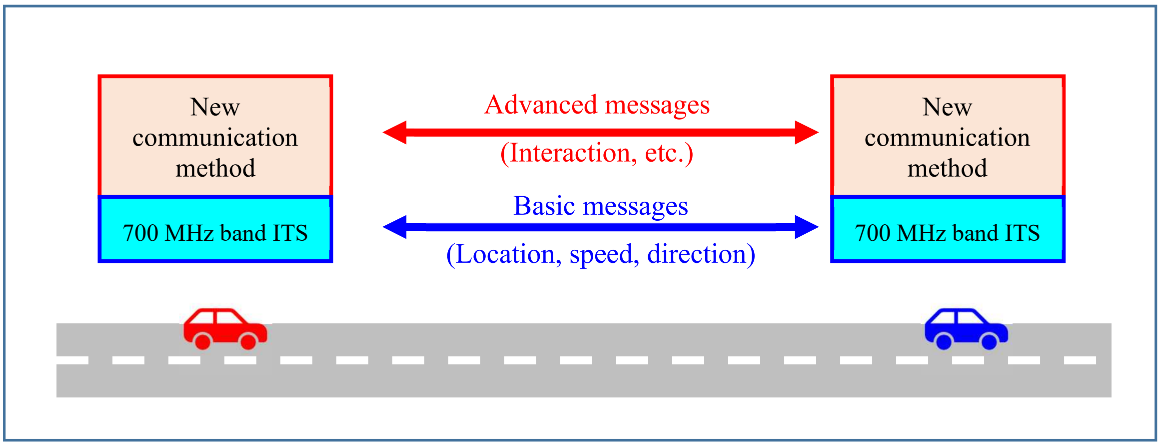


Fig. 5-1 Image of messages and communication method

(iii) Definitions for practical application of system

<Issues>

This R&D used a number of parameters and settings that were provisionally set for simulation purposes. For example, the policy on messages sent from OBUs was to use TD-001's free field (option field), which is used by ITS Connect services. For messages sent by RSUs, new message sets were defined for expressway use. For general roads, we assumed that 700 MHz band ITS V2I communication services would be partially expanded and used the premise that services would be provided with a single RSU.

Moreover, concerning security, we used the overhead length used in 700 MHz band ITS, not the overhead length presented by the Radio System Technology TG.

Defining these will be an issue going forward for the practical application of the system.

<Future actions>

It will be necessary to make adjustments with related organizations on the SIP-UC message sets defined in this R&D as a measure for the practical application of the system. Concerning the newly defined expressway V2I communication message sets, if there are any organizations studying expressway use cases in other automated driving projects, it will be necessary to make adjustments with them on the use of messages. Also in terms of security, it will be necessary to confer with the different related organizations on how to approach security policy for the system as a whole, for example, a method to verify legitimacy of automated vehicles.

(iv) Formulate placement rules (guidelines) for RSU transmission slot allocation

<Issues>

At present, there is no slot allocation arrangement rule for RSUs, so one issue is the efficient allocation of RSU transmission slots if services spread going forward and there are many RSUs placed close together in a particular space.

<Future actions>

In terms of allocating slots efficiently, it is even conceivable to use an allocation method that does not segregate slot numbers for each RSU type (critical intersection RSUs, general intersection RSUs, and I2I communication RSUs), so it is desirable to confer with related organizations on these and set rules as guidelines.

(v) Support for vehicle platooning use cases

<Issues>

In the use case g-1 (Unmanned platooning of following vehicles by electronic towbar), scenarios are defined for normal times and during hard braking (emergencies). During normal times, the use case can be achieved with 700 MHz band ITS, but 20 ms cycle transmission during hard braking does not meet the communication requirements of the Radio System Technology TG, so how to respond during hard braking is an issue.

<Future actions>

One action that can be mentioned is to change standards so that “five consecutive packet transmissions at 20 ms intervals,” as described in the communication requirements of the Radio System Technology TG, can be used to achieve the time when it is possible to transmit as standardized in ARIB STD-T109. In this case, it would be less difficult to change the standard if the change were limited to a very short time during emergencies, and did not mean that transmissions could always be sent in a 20 ms cycle. Among other alternatives, after a deeper examination of the service requirements of SIP-UC listed under Issue (1), the communication requirements could be redefined.

Table 5-3 Issues and future actions for use cases

No.	Broad category	Middle category	Use case	Communication method	Issues and future actions
1	(1) Use cases in which information outside the detection range of on-board sensors must be obtained	a. Merging / lane change assistance	a-1-1. Merging assistance by preliminary acceleration and deceleration	V2I	(3), (4)
2			a-1-2. Merging assistance by targeting the gap on the main lane	V2I	(3), (4)
3		b. Traffic signal information	b-1-1. Driving assistance by using traffic signal information (V2I)	V2I	(3), (4)
4			b-1-2. Driving assistance by using traffic signal information (V2N)	V2N	
5		c. Lookahead information: Collision avoidance	c-1. Collision avoidance assistance when a vehicle ahead stops or decelerates suddenly	V2V	(1), (3)
6			c-2-1. Driving assistance based on intersection information (V2V)	V2V	(1), (3)
7			c-2-2. Driving assistance based on intersection information (V2I)	V2I	(3), (4)
8			c-3. Collision avoidance assistance by using hazard information	V2V	(1), (3)
9		d. Lookahead information: Trajectory change	d-1. Driving assistance by notification of abnormal vehicles	V2I, V2N	(3), (4)
10			d-2. Driving assistance by notification of wrong-way vehicles	V2I, V2N	(3), (4)
11			d-3. Driving assistance based on traffic congestion information	V2I, V2N	(3), (4)
12			d-4. Traffic congestion assistance at branches and exits	V2I, V2N	(3), (4)
13			d-5. Driving assistance based on hazard information	V2I, V2N	(3), (4)
14		e. Lookahead information: Emergency vehicle notification	e-1. Driving assistance based on emergency vehicle information	V2I, V2N	(1), (3)
15	(2) Use cases in which information of one's own vehicle must be provided	f. Information collection / distribution by infrastructure	f-1. Request for rescue (e-Call)	V2N	
16			f-2. Collection of information to optimize the traffic flow	V2I, V2N	(3)
17			f-3. Update and automatic generation of maps	V2N	
18			f-4. Distribution of dynamic map information	V2N	
19	(3) Use cases in which V2V and V2I interaction must be ensured	a. Merging / lane change assistance	a-1-3. Cooperative merging assistance with vehicles on the main lane by roadside control	V2I	(1) – (4)
20			a-1-4. Merging assistance based on negotiations between vehicles	V2V	(1), (2), (3)
21			a-2. Lane change assistance when the traffic is heavy	V2V	(1), (2), (3)
22			a-3. Entry assistance from non-priority roads to priority roads during traffic congestion	V2V	(1), (2), (3)
23		g. Platooning / adaptive cruise control	g-1. Unmanned platooning of following vehicles by electronic towbar	V2V	(1), (2), (3), (5)
24			g-2. Adaptive cruise control and manned platooning of following vehicles using adaptive cruise control	V2V	(1), (3)
25		h. Teleoperation	h-1. Operation and management of mobility service cars	V2N	

6. Summary and future prospects

6.1. Summary

To verify the technical feasibility of "cooperative driving automation use cases" in terms of communication, such as specific requirements of radio communication technology, this project used a desk study and simulations to evaluate the applicability of 700 MHz band ITS in respect to the communication requirements of the Radio System Technology TG. Based on the evaluation results, issues were identified, and future actions were drafted. The results of this study were input into the roadmap to be formulated for the study of the cellular V2X method, which is being conducted separately from this R&D theme.

● Desk study

The results of the communication quality evaluation and transmission time constraints evaluation by desk study indicated that the communication requirements of the Radio System Technology TG were not met in use cases that require interaction (a-1-3, a-1-4, a-2, a-3) and in g-1 (Unmanned platooning of following vehicles by electronic towbar). Regarding RSU slot allocation, we conducted a study on the placement of SIP-UC service RSUs, referring to the 300-m plane layout considered in the 2016 "Study for the Advancement of 700 MHz Band Intelligent Transport Systems" [1] and were able to allocate slots for all RSUs, including existing service RSUs. We also studied message sets sent from RSUs and OBUs and confirmed that they could coexist with ITS Connect services.

● Simulations

In the desk study, we evaluated communication quality with transmissions from a single unit as a basic investigation, but in simulations, we conducted evaluations in which multiple OBUs were actually in place. We also built an SIP-UC model using RSU slot allocation results from the desk study and conducted simulations of a time when services would be offered with use cases in close proximity to each other, checking the feasibility of SIP-UC in 700 MHz band ITS and whether they could coexist with existing services. The following describes whether communication requirements of the Radio System Technology TG could be met.

In V2I (I -> V) communication use cases (a-1-1, a-1-2, a-1-3, b-1-1, c-2-2, d-1 through d-5), communication requirements were met because for all RSUs in the distance range where they affect each other, we were able to allocate slots of time when it is possible for RSUs to transmit without overlapping with each other.

In V2V communication use cases (a-1-4, a-2, a-3, c-1, c-2-1, c-3, e-1, g-1, g-2), the communication requirements were not met, primarily because of the impact of interference between OBU transmissions.

In V2I (V -> I) communication use cases (d-1 through d-4, f-2, a-1-3), cases d-1 through d-4 and f-2 met the communication requirements. This is because, although some impact from interference between OBU transmissions was observed, the maximum acceptable delay of radio communication part was 1 second, which is longer than in other use cases, and the approach was that if even just one of the multiple opportunities to receive the message resulted in reception, which was sufficient. a-1-3 did not meet communication requirements because the maximum acceptable delay of radio communication part is 100 ms.

In use cases that require interaction (a-1-3, a-1-4, a-2, a-3), 700 MHz band ITS basically transmits in 100 ms cycles by broadcasting, which makes interaction with multiple OBUs difficult.

Existing services were checked by simulation, the results of which showed that existing services requirements were met. One reason is that the common parts of messages used by SIP-UC and existing services were shared with the message set.

● Issues and future actions

A deep exploration of SIP-UC service requirements is an issue; it will be necessary to further organize the service requirements for automated driving for each SIP-UC such as road conditions (vehicle density, driving speed, etc.) and means of collecting information (communications, autonomous sensors).

Because SIP-UC a-1-3, a-1-4, a-2, and a-3, which require interaction, would be hard to achieve with 700 MHz band ITS alone, these use cases were organized in terms of basic messages and advanced messages. We proposed achieving SIP-UC a-1-3, a-1-4, a-2, and a-3, which require interaction, with the following approach: the 700 MHz band ITS, which uses the distant reach of radio waves to gather information from a wide range, would cover basic messages, which use broadcasting to provide basic information, while a new communication method would cover advanced messages that use two-way communication to exchange information necessary for interaction.

We indicated standardization of message sets to make the system practical and the need to consider security as issues and future action for social implementation. We also suggested that it is necessary to formulate RSU slot allocation rules (guidelines).

We found that responding during hard braking (emergencies) in the use case g-1 (Unmanned platooning of following vehicles by electronic towbar) is an issue. As for future actions, the ARIB STD-T109 standard needs to be changed or requirements need to be revised after deep examination of use cases.

6.2. Future prospects

(1) Promote verification testing and social implementation of 700 MHz band ITS, which can be utilized over the long term

In this R&D, we verified the feasibility of “cooperative driving automation use cases” with 700 MHz band ITS by desk study and simulation. The basic information such as vehicle location, speed, direction, etc., handled in most use cases other than those use cases that require interaction (a-1-3, a-1-4, a-2, a-3) is the same as that of the ITS Connect service currently in use. In addition, the ability of the 700 MHz band to reach far and travel around obstacles is said to be extremely advantageous for Japan’s road conditions, which include poor visibility, and for vehicle antenna design, etc. Therefore, we believe it is important to maximize the use of the 700 MHz band ITS for cooperative driving automation, while still taking international trends into consideration. To do that, the following need to be done.

- For each SIP-UC, fully define more detailed service requirements and the communication requirements that derive from them, taking account of various situations such as road conditions.
- In line with the use case roadmap, give priority to services that are essential for automated vehicles to operate and steadily implement these services in society while making communications more advanced.

We believe it is important to continue discussions on ways to achieve utilization of the 700 MHz band ITS as a form of communication for cooperative driving automation.

(2) For SIP-UC in which interaction is necessary, consider new communication methods based on the assumed timing of their realization

Since SIP-UC a-1-3, a-1-4, a-2, and a-3, which require interaction, cannot be handled by the 700 MHz band ITS, which is a broadcast based on the assumption of one-way sending of information, it is necessary to use new communication methods that enable two-way communication to achieve interaction. However, the communication sequence to achieve interaction is complex, as described in the section on issues and future actions in Part 5, and many issues remain, so further study is needed.

As this study continues, it will be important to discuss new communication methods, including proposals incorporating the idea that the 700 MHz band ITS is responsible for basic messages that broadcast basic information, while new communication methods are responsible for advanced messages that exchange information necessary for interaction through two-way communication. It will be necessary to do future study after gaining an understanding of the current situation.