Technology Reports | Connected Car | Cellular V2X | Safe Driving Support

Special Articles on Next-generation Mobility Services

NTT DOCOMO Initiatives for the Connected Car Era

5G Laboratories Junichi Abe Shohei Yoshioka
Connected Car Business Office Shinpei Yasukawa
Corporate Sales and Marketing Department Kantaro Shinma

The automotive industry is entering an era of innovation that is being expressed with the word "CASE," referring to four elements: Connected, Autonomous, Shared & Services, and Electric. Technologies related to these elements are currently being studied actively. Of the four, the "Connected" technologies contribute to advancing the other three, and there is considerable anticipation for use of 5G and LTE in this area. This article focuses on the "Connected" aspect of CASE, giving an overview of safe-driving assistance, for which cellular communication is expected to be effective, and describing initiatives at NTT DOCOMO in this area.

1. Introduction

Recently, there are increasing expectations that the automotive ecosystem will be enhanced to provide smart mobility. In 2016, Daimler proposed that the automobile industry would be revolutionized by four elements: Connected, Autonomous, Shared & Services, and Electric; represented by the word "CASE."

Of these, the "Connected" element contributes to advancing the other three. For example, sensor information obtained using radar or cameras installed in vehicles or over roadways could be shared using wireless communication, for mutual benefit or to analyze traffic conditions. Results of such analysis could be used to notify of hazards that could cause accidents, or to distribute information that could help traffic flow through intersections, helping to realize safe and efficient autonomous driving.

"Public-Private ITS Initiative/Roadmaps 2019" [1] has outlined a vision of building a society with "safest, smoothly-operating roadway and traffic systems in the world." To contribute to this vision as a telecommunication operator, NTT DOCOMO is focusing on the "connected" aspect of CASE, and is promoting initiatives utilizing cellular communication.

This article gives an overview of safe driving assistance utilizing cellular communication and describes various initiatives by NTT DOCOMO in this area.

2. Overview of Safe Driving Assistance Using Cellular Communication

2.1 Role of Communication in Safe Driving Assistance

Advanced Driver Assistance Systems (ADAS)*1 are becoming more common. They use cameras and other sensors mounted in vehicles to recognize people and other objects near the vehicle, to detect potential accidents, and perform actions such as applying emergency braking, contributing to safer driving. On the other hand, technologies are also being studied that use radio communication to gather and distribute information that is difficult to detect with the vehicle's sensors, such as hazards that are hidden or out of visual range, or that covers a wider area, such as traffic or congestion information. These are being implemented as Intelligent Transportation Systems (ITS)*2 such as Vehicle Information and Communication System (VICS)®*3 and ITS Connect®*4 [2] [3].

As an example of detection using sensors and collection and distribution of data, an overview of dynamic maps is shown in **Figure 1**. Dynamic maps are expected to be used for autonomous driving, and use 3D maps and results from onboard sensors to accurately comprehend the position of the autonomously driving vehicle and to map information detected using sensors and distributed through wireless communication in real time, to understand the traffic conditions along the driving route.

Dynamic maps define four layers of information according the frequency of updates. They are: static information, semi-static information, semi-dynamic information, and dynamic information.

The static through semi-dynamic information layers provide information regarding the traffic environment that changes over time. It is being considered for use with wireless communication, for autonomous driving systems, and also for safe driving assistance while driving manually.

Dynamic information includes information regarding traffic signals and surrounding vehicles and pedestrians. This information is expected to be updated every second or less, and neglecting to do so could result directly in an accident. Information from the onboard sensors fits this category, but wireless communication is also being considered for information that cannot be detected with sensors or is outside of visual range.

2.2 Overview of Cellular V2X

Vehicle to Everything (V2X) technology is being

*1 ADAS: Systems that use cameras and other sensors in a vehicle to improve safety in operating the vehicle. Operation of a vehicle involves three elements, "Perception," "Decision," and "Operation," and a mistake in any of these can result in accident or dangerous operation. ADAS can provide assistance to any of these three elements by using sensors and other means to detect surrounding conditions.

*2 ITS: An overall term for transportation systems using communication technology to improve vehicle management, traffic flow and other issues.

*3 VICS®: A trademark or registered trademark of the Vehicle Information and Communication System (VICS) Center.

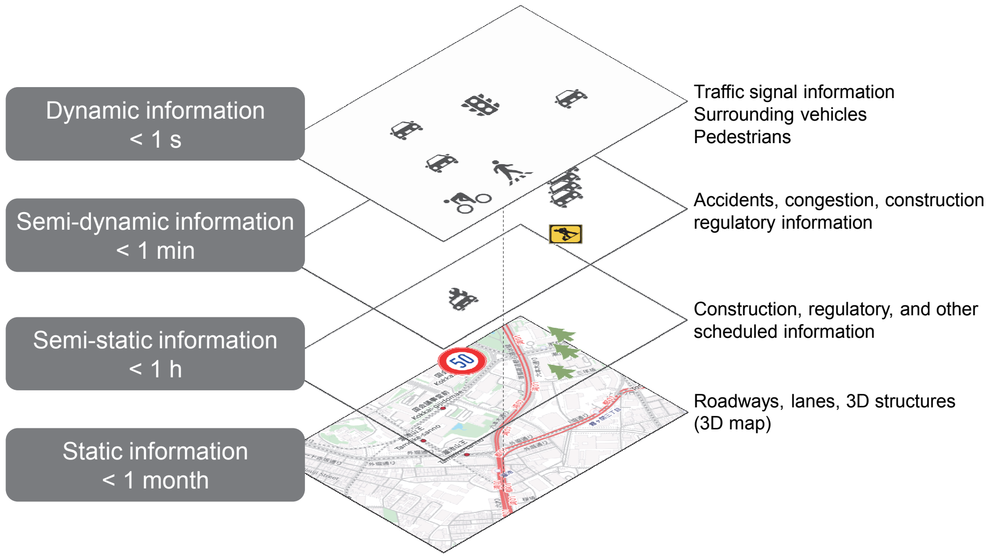

Figure 1　Dynamic map overview

studied as a means of connecting vehicles to all kinds of objects using wireless communication and sharing information. It includes direct communication Vehicle-to-Vehicle (V2V), direct communication Vehicle-to-Infrastructure (V2I: wireless communication between vehicles and equipment installed along roadways), direct communication Vehicle-to-Pedestrian (V2P), and wide-area communication via LTE and 5G cellular network base stations, called Vehicle-to-Network (V2N) communication.

The 3rd Generation Partnership Project (3GPP), which creates standards for mobile communication systems, is standardizing a V2X technology called cellular V2X, based on cellular communication technology. Technical study and testing for cellular V2X is in progress. The scope of application for cellular V2X is shown in **Figure 2**.

V2V, V2I and V2P (hereinafter "direct-communication V2X") use direct communication to gather information in the area near the vehicle but beyond the range of the onboard sensors. This area is called the "direct-communication assistance area" Direct-communication V2X use a radio interface called PC5, which is capable of low-latency communication. As an example, a use-case for this technology is to broadcast notification of sudden breaking to surrounding vehicles, to help following vehicles navigate intersections safely. Most information in this direct-communication assistance area corresponds to "dynamic information" within the dynamic maps described earlier.

V2N uses the wide-area aspect of cellular networks, mainly to cover the range beyond the direct-communication assistance area. A use case example anticipated for this technology is congestion information, which is not directly related to detecting emergency conditions, but contributes to smooth operation. Note that V2N can provide

*4　ITS Connect®: A driving assistance system with vehicle to roadside and vehicle to vehicle communication using dedicated frequencies in the 760 MHz band. A trademark or registered trademark of Kazuya Enya.

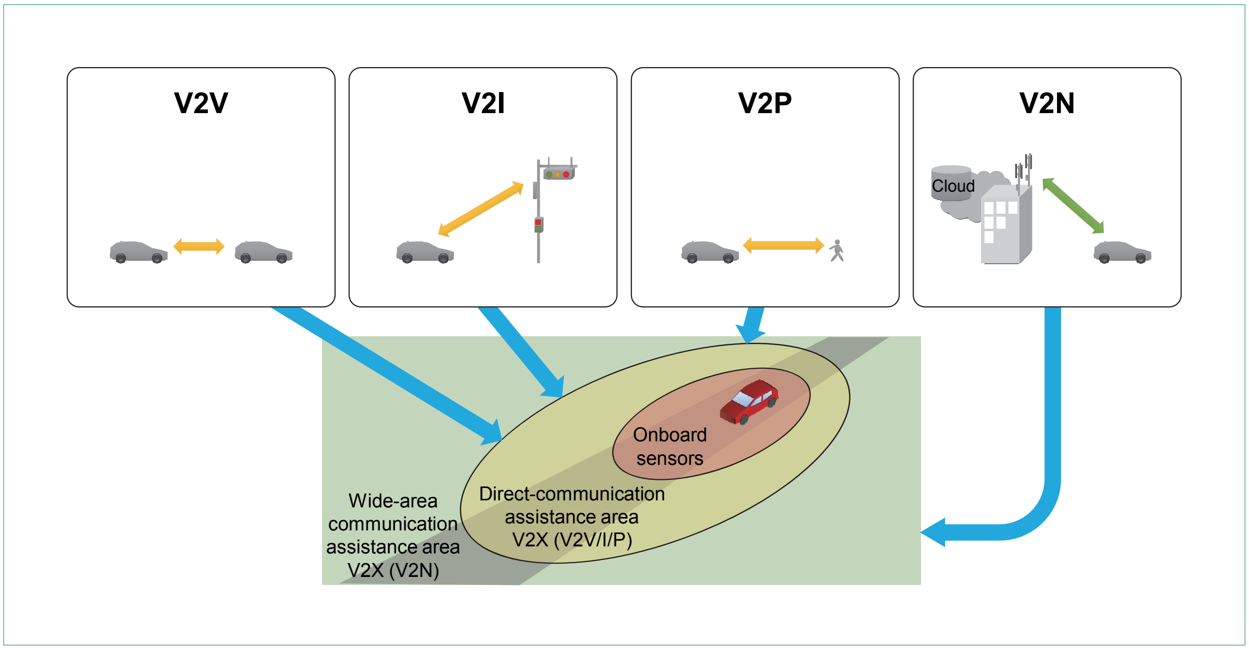

Figure 2 Range of application for cellular V2X

communication with other vehicles, roadside equipment and pedestrians through network base stations. This is called Vehicle to Network to Everything (V2N2X) communication. The wide-area communication assistance area corresponds mainly with "static" to "semi-dynamic" information within the dynamic maps described earlier.

2.3 Trends in Cellular V2X standardization

In standardization of cellular V2X, 3GPP Service and System Aspects (3GPP SA)*5 has decided use cases, requirements, architectures, security and other aspects. Based on these, wireless interfaces for V2N and direct-communication V2X have been studied in the 3GPP Radio Access Network (RAN)*6. In its deliberation, 3GPP is also exchanging information with the 5G Automotive Association (5GAA), an association in the automotive industry that discusses connected car services using cellular V2X.

1) Direct-Communication V2X

For direct communication V2X, LTE Release 14, 15 have been specified as updates from 3GPP Rel. 12, 13, for communication between terminals. LTE Rel. 14, 15 provide higher mobility support, communication range expansion, and transmission resource control by base-station or autonomous resource selection based on frequency sensing at terminals. Rel. 14 covers basic applications for safe-driving assistance, where the specification is optimized for periodic broadcast transmission of small packets with several hundred bytes. The frequency band for ITS operation (5,855 to 5,925 MHz) is generally assumed for the specification. Rel. 15 further provides increased data rates through carrier aggregation*7 and higher-order modulation functions.

For the New Radio (NR) Rel. 16 specification,

*5 3GPP SA: The 3GPP group handling standardization of service requirements, architectures, security, codecs, and network administration.

*6 3GPP RAN: The group that handles standardization of the segment between terminal devices and base stations within 3GPP, an organization that standardizes 3G and later mobile communication systems. There are several working groups (WG) within 3GPP RAN such as WG1, which studies Layer 1 radio specifications; WG2, which studies Layer 2/3 radio specifications; and WG4, which studies radio performance. Details of each of these technologies are studied separately in each group.

which is scheduled to be completed in March 2020, aperiodic data communication and unicast/groupcast communication are being studied in addition to periodic broadcast communication. It also provides retransmission control using feedback information, and Quality of Service (QoS)*8 control with higher accuracy and efficiency. Rel. 16 assumes a wide range of frequencies below 6 GHz including ITS frequencies and millimeter-wave*9 frequencies from 24.25 GHz to 52.6 GHz, where it is expected to co-exist with UpLink and DownLink (UL/DL) communication in the same frequency bands.

2) V2N

It is assumed that both unicast communication (between a base station and a specific vehicle) and multicast communication (between a base station and multiple vehicles) will be used for V2N. Existing LTE standards as completed in Rel. 13 can be used for V2N, and the first release of the NR format for 5G (Rel. 15), which was completed in June 2018, can also be used. Work on specifications for Ultra-Reliable and Low Latency Communications (URLLC)*10, with latencies of 0.5 to 1 ms on the radio segment and maximum packet error rates of 10^{-6}, is also in progress for Rel. 16.

3. Initiatives at NTT DOCOMO

3.1 Overview

NTT DOCOMO is collaborating with the Ministry of Internal Affairs and Communications (MIC) and partner enterprises to implement safe driving assistance with connected cars, evaluating performance of direct-communication V2X, studying conditions of interference with existing systems, and performing demonstrations of cellular V2X. We are also mapping information transmitted through V2X and testing distribution of dynamic maps using cellular networks. These will be described below.

3.2 Evaluation of Direct V2X Communication Performance and Investigation of Interference with Existing Systems

In FY2018, NTT DOCOMO was entrusted with technical examination services*11 as part of the MIC process for allocating frequencies [4], as a preliminary study for the introduction of V2X.

These technical examination services included evaluation of basic communication performance with respect to requirements of two use cases for direct communication specified in 3GPP Rel. 14 (**Figure 3** (1)), study of interference conditions with existing systems (Fig. 3 (2)), and study of technologies to prevent interference (Fig. 3 (3)). The direct communication use cases were "Highway merging and lane changing assist" and "Emergency hazard notification" for autonomous driving and safe-driving assistance. The existing system examined for interference was 5.8 GHz Dedicated Short Range Communications (DSRC), specified in Association of Radio Industries and Businesses (ARIB)*12 STD-T75 [5], which is an ITS radio system in operation in Japan as the Electronic Toll Collection System (ETC/ETC2.0).

In evaluation of communication performance, we were able to confirm inter-vehicle communication distances of 830 to 1,000 m and vehicle-roadway distances of 400 to 620 m for conditions with a line-of-sight environment and no screening objects, no interference from within the system or adjacent channels, and packet error rates of 10^{-2} or less.

In the study of interference conditions, we

*7 Carrier aggregation: A technology for increasing bandwidth and transmission speed, while maintaining backward compatibility, by simultaneously transmitting and receiving multiple carriers.

*8 QoS: Techniques for securing optimal bandwidth according to the purpose of communication and guaranteeing the quality required by that type of communication.

*9 Millimeter wave: Radio signals of frequencies in the range from 30 GHz to 300 GHz.

*10 URLLC: Generic terminology for communication requiring low delay and high reliability.

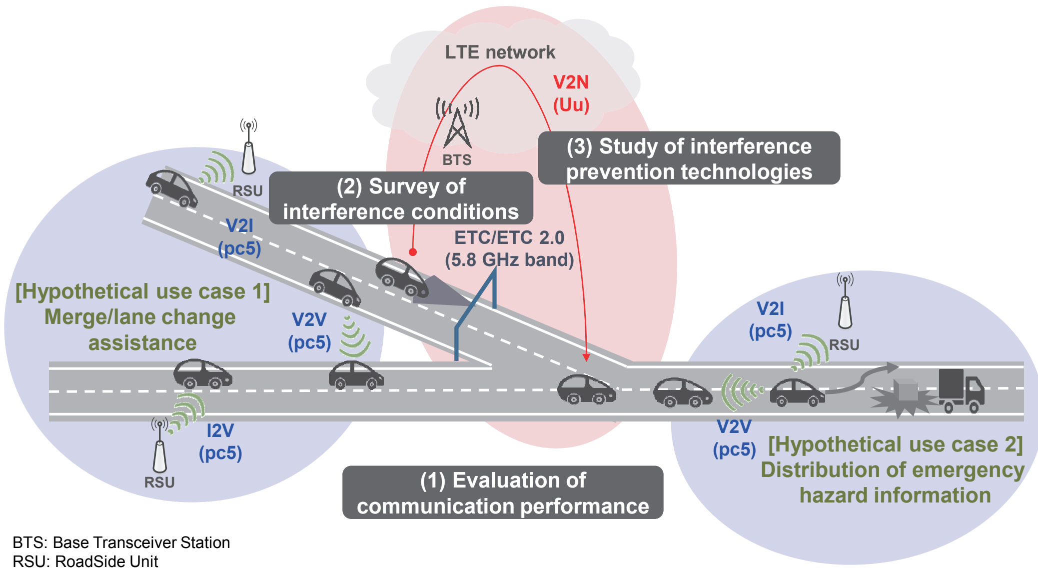

Figure 3 Technology testing for implementing a connected-car society

determined that for ETC, separation distances of 0 to 23.5 m were required for frequency separation of occupied bands for carriers of 20 MHz or greater, and for ETC 2.0, separation distances of 23.5 to 349.5 m were required. We also studied a technology for preventing interference, which builds a geofence*13 using pre-determined locations of ETC/ETC 2.0 base stations and considering separation distances. It then stops direct-communication V2X transmissions in areas of concern, switching to V2N communication.

3.3 Cellular V2X Testing

In cooperation with Continental Automotive Japan Inc, Ericsson Corp., Nissan Automotive, and Oki Electric Industry Co., Ltd., and Qualcomm Technologies, Inc., NTT DOCOMO has successfully conducted the first test of cellular V2X in Japan [6]. NTT DOCOMO developed a system to evaluate V2N (V2N2X) using our commercial LTE network to collect location and other information from each vehicle and distribute safe driving assistance messages, and we conducted driving tests with the system.

The V2N (V2N2X) evaluation system used in the tests periodically collected information from each vehicle on an ITS server using a closed network connection*14 to the commercial LTE network, as shown in **Figure 4**. The ITS server analyzed the information, determined accident risk, and distributed safe driving assistance messages. These included broken-down vehicles or other obstacles in the roadway, risk of collision when passing intersections with poor visibility, and the risk of an approaching vehicle when passing another vehicle (**Figure 5**).

*11 Technical examination service: A project established by the MIC to perform technical studies on highly practical technologies for efficient spectrum use, to promote the early introduction of those technologies.

*12 ARIB: An organization subordinate to the MIC that sets standards for systems that use the radio spectrum in the fields of communication and broadcasting in Japan.

*13 Geofence: A virtual boundary established on the ground. By coordinating with location data, it can be used to regulate terminal behavior or other aspects when the boundary is crossed.

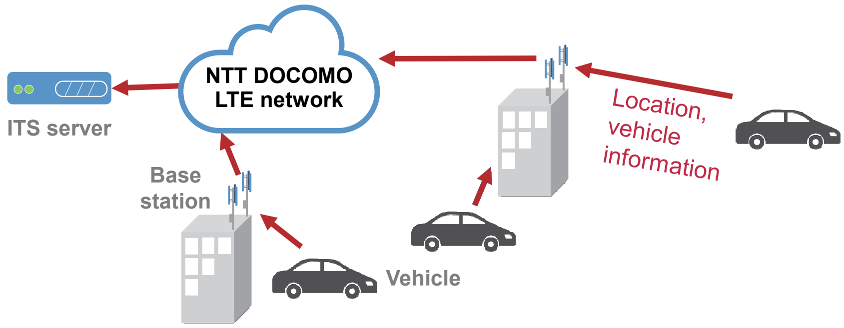

Figure 4　Overview of V2N (V2N2X) evaluation system

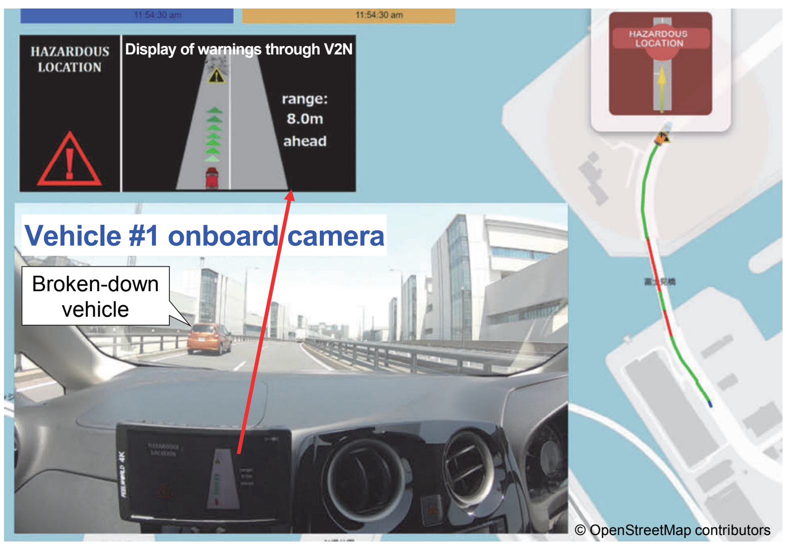

Figure 5　Broken-down vehicle notifications through V2N

In these tests, the median*15 LTE communication delay was less than 50 ms, and at the 95 percentile*16 level, messages were delivered in 60 ms or less. Note that for these results, all vehicles had already established a wireless connection, and results are reference values for the environmental conditions of the experiments.

Tests verified the latency for V2N (V2N2X) communication, but implementing a practical ITS server for collecting information and distributing safe-driving assistance information in real time will require further study of server scalability, overall

*14 Closed network connection: A direct connection to the LTE network that does not go through the Internet, provided by NTT DOCOMO as Access Premium LTE.

*15 Median: The value in the middle when countable data is ordered in increasing (or decreasing) size.

*16 Percentile: For a distribution of measured values, an indication of what proportion (percentage) of values are less than the specified value. For example, for a value at the 65 percentile level, 65% of the samples have a value that is less.

system availability, and how the costs of communication lines, the ITS server and other components should be handled.

3.4 Verification of Technology for Efficient Dynamic Map Distribution

If dynamic map data begins circulating frequently on networks as autonomous driving becomes practical and begins to spread, large increases in communication traffic and increased loads on cellular networks could exceed expectations. With an awareness of this issue, NTT DOCOMO accepted commissions from the MIC from FY2016 to FY2018 to research technologies for efficient distribution of dynamic map information.

It is anticipated that managing map data in a conventional cloud architecture would be too centralized, so this research dealt with technologies to distribute the data over mobile edge servers*17 located in each region within the cellular network; to partition and manage data in units of 125 m or 1 km square, each associated with an update version for partial and differential distribution; and for dynamically switching between cellular and wireless LAN communication, or using both simultaneously, depending on the state of an autonomously driving vehicle, the purpose or amount of the data being distributed and other factors (**Figure 6**).

Testing of these technologies was done by building a test environment that simulates a real environment at the Yokosuka Research Park. This included a communication environment with LTE test base stations, a core network*18 simulator and mobile edge servers; a dynamic map (measurements and mapping done using results from Strategic Innovation promotion Program (SIP)*19 studies); and

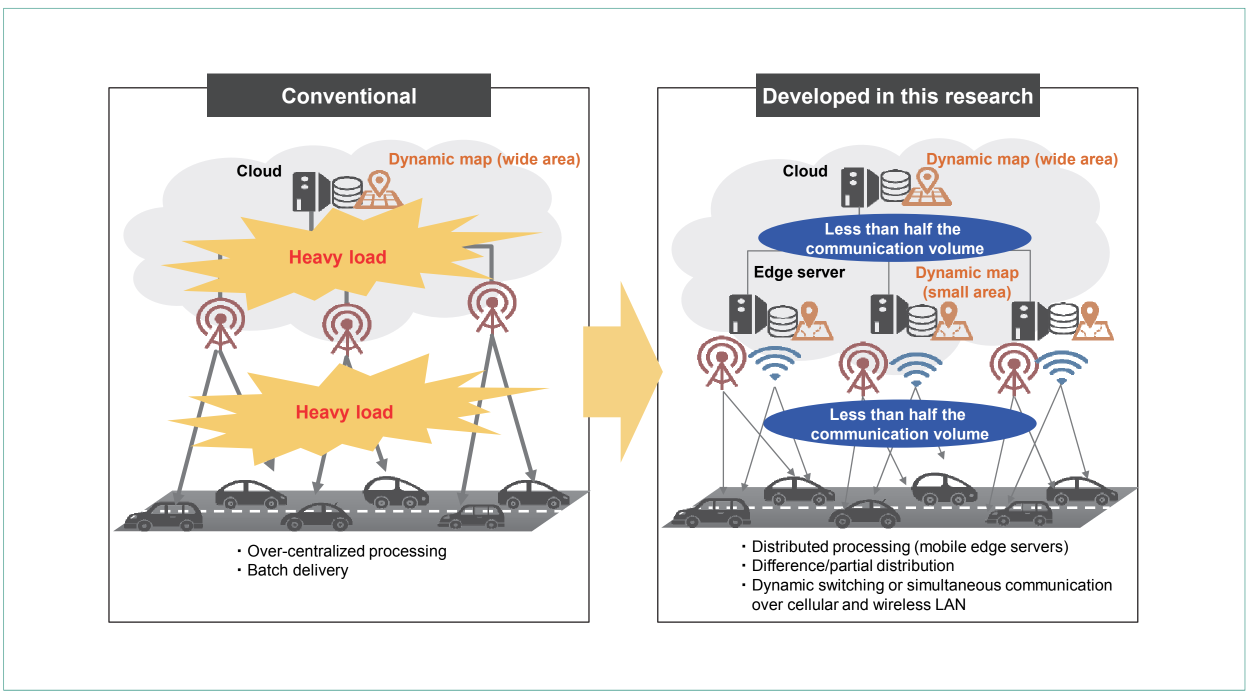

Figure 6 Overview of R&D on technology for efficient distribution of dynamic maps

*17 Mobile edge server: A server that provides service processing within the cellular network, relatively close to terminals and not on the Internet.

*18 Core network: A network consisting of switching entities and subscriber information management equipment, etc. Mobile terminals communicate with the core network via the radio access network.

autonomously driving vehicles (four vehicles prepared in collaboration with Doshisha University, Nagoya University, Kanazawa University, and the University of Tokyo). Testing showed that use of these technologies can reduce traffic on the wired and wireless sections of the cellular network by more than 50%, relative to previously. It also demonstrated that end-to-end service, from distribution of maps to autonomous driving of vehicles, is feasible. In particular, these technologies were used to distribute dynamic maps to four vehicles with different autonomous driving processes, and we showed that the four vehicles were able to receive them and to operate in a similar manner.

4. Conclusion

This article has given an overview of safe driving assistance technologies using cellular communication and introduced various testing efforts being conducted by NTT DOCOMO.

Cellular V2X will connect the many participants in transportation and provide safe driving assistance using cellular communication, but practical implementation will require further testing in various environments, with collaboration among related ministries and the automotive industry, to study its feasibility more deeply. NTT DOCOMO will continue to study sustainable ways to implement safe driving assistance using cellular communication, and contribute to implementing the "safest, smoothly-operating roadway and traffic systems in the world."

Note that this article has used, in part, results from the MIC Technical Examination on Connected Cars, and also MIC contracted research entitled, "Development and Experimental Proof of Autonomous Mobility System (Autonomous Driving Technology, Automatic Control Technology, etc.)," and "R&D of frequency effective utilization technology corresponding to various situations supporting a vast number of autonomous mobility systems."

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*19 SIP: A national project established by the Council for Science, Technology and Innovation within the Cabinet Office, to promote initiatives that span government department frameworks and examine everything from basic research to application and commercialization.