Technology Reports (Special Articles) URLLC Vertical Network V2X

Special Articles on 3GPP Release 16 Standardization Activities

5G Advanced Technologies for Creating Industries and Co-creating Solutions

Core Network Development Department Kenichiro Aoyagi Atsushi Minokuchi
Radio Access Network Development Department Kohei Harada Tianyang Min
6G Laboratories Yuki Takahashi Shohei Yoshioka

The use of 5G technologies is now being envisioned in a variety of industrial fields beyond the mobile communications industry such as smart factories and connected cars now being promoted in various countries. There is also much expectation that 5G connections will not only improve system performance but also help create new industries and solve social problems. This article describes the background to various studies related to industry collaboration in 3GPP Rel-16 and discusses solutions targeting mainly collaborations with industry partners.

1. Introduction

Fifth-generation mobile communications system (5G) technologies are expected to become platform technologies that can support a variety of industries and society in general and provide new value without being limited to conventional mobile communication services. As described in the opening article [1] of these Special Articles, enhancements to use cases and services play an important role in the expansion of 5G technologies. For 3rd Generation Partnership Project (3GPP) Release 16 (hereinafter referred to as "Rel-16") specifications, technical studies were conducted on enhancing 5G keeping in mind collaboration with new partners and technology fusion particularly in fields such as smart factories and connected cars.

This article describes the background to 3GPP Rel-16 studies on solutions that mainly target industry collaboration (hereinafter referred to as "industry collaboration solutions") and the elemental technologies for achieving those solutions.

2. Background to Studies on Industry Collaboration Solutions

Industry collaboration solutions studied for 3GPP Rel-16 came out of the needs and technical requirements of a variety of industry groups that were studying the Smart Factory, Vehicle to Everything (V2X)*1, etc. The following summarizes three examples of industry collaboration solutions.

2.1 Smart Factory

The Smart Factory concept has been attracting attention as an industry collaboration solution. A "smart factory" means a factory that connects all sorts of equipment within the factory to a network, visualizes equipment operation and product quality, and automates equipment operation with the aim of achieving smooth manufacturing processes. The Smart Factory envisions Control-to-Control (C2C) communication between control equipment and motion control*2 systems all connected to a network and demands real-time and high-reliability communications for controlling all of these devices. One means of communication for satisfying such requirements is wired communications, but this approach hinders flexibility in making changes to a manufacturing line. Against this background, the use of 5G with its ultra-reliable and low-latency features has been attracting attention.

In addition, the 5G Alliance for Connected Industries and Automation (5G-ACIA) was established in 2018 as a business organization to study the application of 5G technologies to industrial use cases such as factory automation. About 60 companies from the communications industry and manufacturing industry have come to participate in this alliance as of 2020. At 5G-ACIA, studies are being conducted on requirements for latency and data rate deemed necessary for industrial use cases applying 5G technologies such as factory automation, on how to connect a network operated by a communications operator to a network specialized for industrial use, etc. A white paper compiling a number of results from these technical studies has already been released [2].

2.2 V2X

V2X, or the use of wireless communications in the automobile industry, is another example of an industry collaboration solution. In V2X, sensor data shared between vehicles and all sorts of things can be useful in achieving services related to safe and efficient automobile operation. Amid this recent interest in V2X services, verification trials have been progressing through cooperation between the automobile industry and wireless communications industry [3]. In 2016, the 5G Automotive Association

*1 V2X: A generic name for Vehicle-to-Vehicle (V2V) direct communications between cars, Vehicle-to-Infrastructure (V2I) direct communications between a car and roadside devices (radio communications equipment installed along a road), Vehicle-to-Pedestrian (V2P) direct communications between vehicles and pedestrians, and Vehicle-to-Network (V2N) wide-area communications via base stations in a cellular network such as LTE or 5G.

*2 Motion control: In the automation of production processes, the high-precision moving and rotating of production equipment parts by a specific control method. Frequently used in positioning control and multi-axis robot control in automated factories.

(5GAA)*3 was established as a business organization to promote discussions and collaboration between both industries. As of 2020, more than 130 enterprises have come to participate in this organization.

5GAA consists of seven Working Groups (WGs). For example, WG1 discusses use cases and requirements, and as a result of this work, 5GAA has compiled a white paper on requirements for self-driving cars such as turning right or left when the car crosses into an oncoming lane [4]. 5GAA also submits opinions to 3GPP on such use cases and requirements [5].

Based on such information and opinions, 3GPP has been specifying a V2X standard that is expected to be a radio technology for achieving V2X services (**Figure 1**). (V2X is also called "Cellular V2X" outside of 3GPP to distinguish it from other V2X technologies. This term will be used below.) Cellular V2X can be divided into two types: Vehicular-to-Network (V2N), or base station – terminal communications, and sidelink, or terminal – terminal communications. Here, the Long Term Evolution (LTE)/New Radio (NR)*4 standard specified up to Rel-15 can be used for V2N while the LTE standard specified in Rel-14 and Rel-15 can be used for sidelink communications. In NR Rel-16, technologies for achieving use cases requiring even higher communication performance were studied and specified.

2.3 Local 5G

Various types of requirements for local 5G in Japan are not being directly reflected in 3GPP studies, but in this article, we take them up since

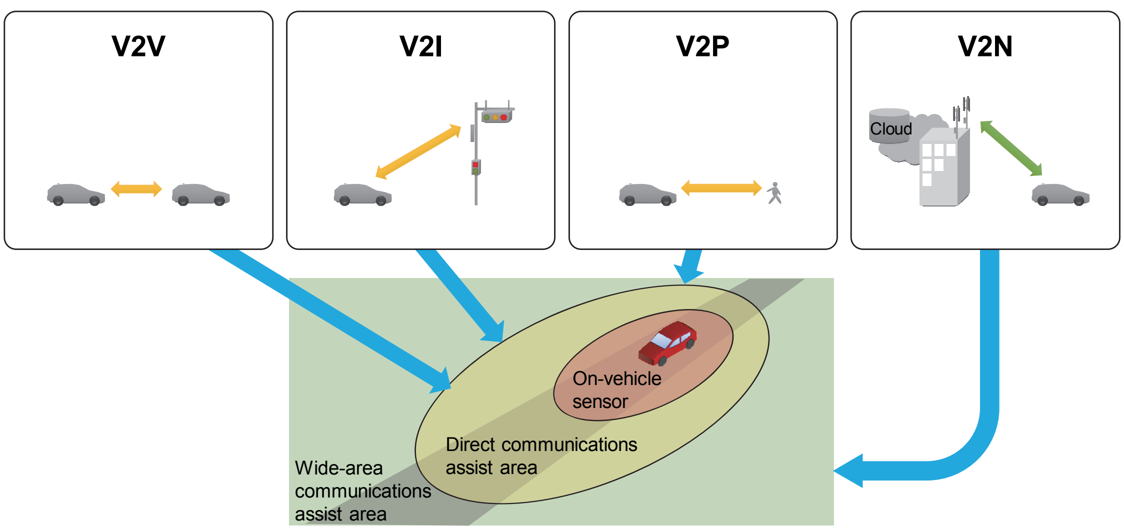

Figure 1 Cellular V2X concept

*3 5GAA: An association founded by automotive and telecommunications players to study and promote connected car services using 5G.

*4 NR: Radio system standard formulated for 5G. Compared with 4G, NR enables high data rate using high frequency bands (e.g. sub-6 GHz bands and 28 GHz band) and low-latency and high-reliability communications for achieving advanced IoT.

they can be treated as technologies related to the practical use of some of the industry collaboration solutions described here. Local 5G in Japan can be positioned as 5G systems constructed and operated according to the environment and needs of specific local governments, factories, research facilities, etc. For example, local 5G can be used to construct a network that appropriates the inter-user network and radio resources*5 in a limited space or area to meet specific requirements such as ultra-low latency. It can also be used to provide flexible 5G environments to secure emergency communications at the time of a crisis or to deal with a variety of regional characteristics and environments such as an aging population and other demographics. In this way, local 5G is expected to bring innovative changes to the social infrastructure, create new business fields, and solve a variety of social problems (**Figure 2**).

3. Elemental Technologies for Industry Collaboration Solutions

Each of the three industry collaboration solutions described above consists of various technical requirements (**Table 1**).

However, in addition to these requirements, even more diverse and complex requirements can

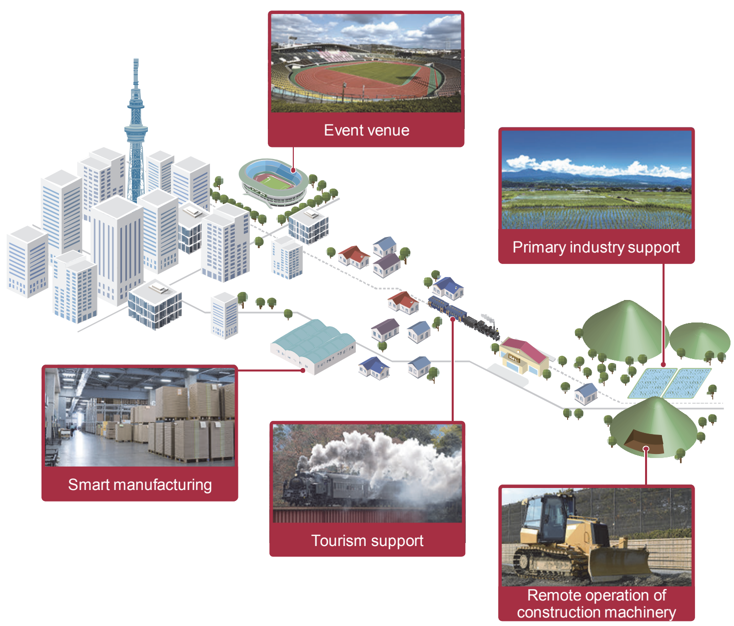

Figure 2 Local 5G concept

*5 **Radio resources:** General term for radiocommunication resources (radio transmission power, allocated frequency, etc.).

Table 1 Rel-16 technologies applied to industry collaboration solutions (examples)

	Smart Factory	V2X	Local 5G
URLLC	○	○	
TSN	○		
NPN	○		○
D2D (sidelink)		○	
5G-LAN Type Service	○		
Private Slice		○	○
Predictive QoS		○	

○ Main application example

be anticipated such as those for smart grid*6 systems. Thus, in Rel-16, the following functional enhancements and advancements were made as elemental technologies for achieving industry collaboration solutions in addition to NR and platform technologies of the 5G system. This was done to satisfy diverse technical requirements taking into account special environments such as closed areas.

3.1 URLLC

At 3GPP, the main features of 5G are taken to be (1) enhanced Mobile BroadBand (eMBB), (2) massive Machine Type Communications (mMTC), and (3) Ultra-Reliable and Low Latency Communications (URLLC). Among these, technologies for achieving high reliability and low latency have been made into specifications for achieving the industry collaboration solutions described above. At 3GPP, requirements for NR Rel-16 URLLC are defined for individual use cases. For example, the target values for factory automatic motion control*7 are "latency of 2 ms or less and reliability of 99.9999 or greater when sending a 20-byte packet." The following describes NR Rel-16 URLLC that has been made into specifications for satisfying these requirements.

1) Technical Enhancements for Low Latency Communications

(a) Intra-UE uplink prioritization

When data and signals with different latency and reliability requirements are sent from User Equipment (UE) in uplink communications toward control devices in a factory, cases can be envisioned in which collisions occur and critical control data arrive late. For example, in the event that an in-factory robot has left its designated area, it would be necessary for a monitoring sensor to send data on that situation to the control center so that it can shut down the robot immediately. The requirements for transmitting such a control signal at the time of an emergency are more stringent than those of an ordinary control signal in terms of latency

*6 Smart grid: A power distribution network that incorporates radio sensors in the power system to autonomously monitor, control, and optimize the supply side and demand side in real time.

*7 Factory automatic motion control: An automatic control system for strictly controlling the operation (movement, rotation, etc.) of production machines in a factory in specific cycles. This system can be incorporated, for example, in large printing machines and packaging machines.

and reliability, so that data must be sent on a priority basis. For this reason, the operations to be performed when multiple uplink transmissions having different levels of priority within the UE are about to collide have been specified for the physical layer*8 and higher layers*9.

- Prioritization on the physical layer

  Functions were specified on the physical layer for assigning levels of priority to uplink channels and signals such as the Physical Uplink Control Channel (PUCCH)*10, Physical Uplink Shared Channel (PUSCH)*11, and Sounding Reference Signal (SRS)*12 and for prioritizing the uplink transmissions with high priority. Specifically, two levels of priority—high priority and low priority—are supported here, and the priority level of PUCCH and PUSCH are set by dynamic indication based on Downlink Control Information (DCI)*13 and by higher-layer signaling*14. The priority level of SRS, meanwhile, is always set to low priority. In the case that high-priority and low-priority uplink transmissions have been scheduled in the same Orthogonal Frequency Division Multiplexing (OFDM) symbols*15, the low-priority uplink transmission will be dropped and only the high-priority uplink transmission will be performed.

- Prioritization on higher layers

  A new function called "intra-UE overlapping resource prioritization" was introduced in the upper layers as well. In the event that a configured grant*16 transmission collides with a dynamic grant*17 transmission or another configured grant transmission, this function compares the level of priority of the associated logic channels*18 and prioritizes the logic channel having transmission data with the highest level of priority. For a transmission given a low-priority status by the above process, the UE can save it if a Media Access Control Protocol Data Unit (MAC PDU)*19 has already been created and schedule it for retransmission to the base station. However, if a transmission set to low priority happens to be a configured grant, the base station cannot recognize the MAC PDU saved by the UE and cannot therefore schedule a retransmission. For this reason, a new function called "autonomous transmission" was introduced for autonomously resending the MAC PDU saved by the UE.

(b) Inter-UE uplink prioritization

In a factory, it can be assumed that multiple control terminals may simultaneously try to send data having different latency and reliability requirements. It is therefore necessary at such a time to prioritize the communications of a control terminal that is sending data with stringent latency and reliability requirements to prevent those data from arriving late. For this reason, uplink

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*8 Physical layer: First layer of the OSI reference model; for example, "physical-layer specification" expresses the wireless interface specification concerning bit propagation.

*9 Higher layers: All layers positioned above the physical layer such as MAC, PDCP, Radio Link Control (RLC), S1 Adaptation Protocol (S1AP), and X2 Adaptation Protocol (X2AP).

*10 PUCCH: Physical channel used for sending and receiving control signals in the uplink.

*11 PUSCH: Physical channel used for sending and receiving data packets in the uplink.

*12 SRS: Uplink reference signal for measuring channel quality and reception timing etc. with the base station.

*13 DCI: Control information transmitted on the downlink that includes scheduling information needed by each user to demodulate data and information on data modulation and channel coding rate.

*14 Signaling: Control signals used for communication between terminals and base stations.

cancellation and uplink transmission power control were specified to perform inter-UE prioritization of uplink channels.

Uplink cancellation is a function that cancels a low-priority uplink transmission previously scheduled for a certain UE if a high-priority uplink transmission then comes to be scheduled for another UE using the same resources. In this process, a UE will be indicated via DCI of resources targeted for cancellation and the transmission of PUSCH or SRS scheduled to use those resources will be dropped. The level of priority that can become a target for cancellation can be set through higher-layer signaling.

Uplink transmission power control, meanwhile, is a function that performs prioritization by increasing the transmission power of UE transmitting high-priority PUSCH. Here, the target transmission power for a high-priority PUSCH will be indicated by DCI format 0_1 or 0_2.

The uplink-cancellation function described above increases the load on UE for which low-priority uplink transmission was previously scheduled. On the other hand, uplink transmission power control increases the load of UE for which high-priority uplink transmission has been scheduled.

(c) PDCCH enhancements

A control terminal in a factory that seeks to send or receive data having stringent requirements with respect to latency must receive scheduling information from the base station in a short interval. An enhancement for receiving the Physical Downlink Control Channel (PDCCH)[*20] in a short interval was therefore made. In NR Rel-15, the interval in which UE can receive the PDCCH is defined in terms of slot[*21] units. In NR Rel-16, on the other hand, one slot is divided into multiple spans (each a combination of multiple OFDM symbols) making it possible to receive PDCCH in each span. A span may consist of a combination of two OFDM symbols, four OFDM symbols, or seven OFDM symbols. This capability is supported only for an OFDM subcarrier[*22] of 15 kHz or 30 kHz. For example, given a subcarrier interval of 15 kHz and a span consisting of two OFDM symbols, the UE can receive PDCCH at seven times the frequency compared with the PDCCH receiving interval in NR Rel-15. PDCCH is used in the scheduling of the Physical Downlink Shared Channel (PDSCH)[*23] to the UE and the scheduling of PUSCH and PUCCH, so in NR Rel-16, it can be sent and received in shorter intervals than that of NR Rel-15, which should make for low latency.

(d) PUCCH enhancements

When a control terminal in a factory receives PDSCH from the base station, it is desirable that a Hybrid Automatic Repeat reQuest-ACKnowledgement (HARQ-ACK)[*24] be transmitted in a more flexible and faster manner to ensure high reliability and low latency. In NR Rel-15, HARQ-ACK indicating

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*15 OFDM symbols: A multi-carrier modulation format where information signals are modulated with orthogonal subcarriers. A type of digital modulation scheme where information is split across multiple orthogonal carriers and transmitted in parallel. It can transmit data with high spectral efficiency.

*16 Configured grant: A mechanism for allocating PUSCH resources beforehand from the base station on a user-by-user basis so that UE can transmit PUSCH by those resources if uplink data is generated without having to transmit a Scheduling Request (SR).

*17 Dynamic grant: A mechanism for allocating transmission resources for uplink data after a UE requests scheduling and receives DCI from the base station.

*18 Logic channels: Channels that divide transmission information by application.

*19 MAC PDU: A protocol data unit on the MAC layer. PDU expresses protocol data including the header and payload (see *47).

*20 PDCCH: Control channel for the physical layer in the downlink.

transmission in a certain slot is grouped together as a HARQ-ACK Codebook (CB)*25. In addition, one PUCCH resource from among eight PUCCH-resource candidates is selected and transmitted in slot units.

In NR Rel-16, in contrast, a certain slot can be divided into multiple OFDM symbol units enabling HARQ-ACK CB to be transmitted within such a unit. For example, when dividing a slot into seven OFDM symbol units, a maximum of two HARQ-ACK CB can be transmitted in one slot (14 OFDM symbols). Here, eight PUCCH-resource candidates can be set for each symbol unit after division. This approach improves flexibility in specifying PUCCH resources to be used in transmitting HARQ-ACK CB and promotes low latency.

(e) PUSCH enhancements

A control terminal in a factory that seeks to perform uplink communications must first receive scheduling information from the base station. However, to improve the reliability of communications in the air interface, it can be assumed that a control terminal will transmit the same data multiple times. Transmitting scheduling information multiple times for the same data, however, creates overhead*26 that can increase latency over the entire system. For this reason, NR Rel-15 supported a function for transmitting PUSCH repeatedly with the same channel configuration across multiple slots based on the scheduling obtained from a single PDCCH. With this scheme, however, continuous transmission may not be possible depending on the channel configuration, and latency may increase as a result. The number of repeated transmissions here can be set through higher-layer signaling.

Now, in NR Rel-16, this function has been upgraded to enable repeated transmission of consecutive OFDM symbols. In the case that a certain transmission here is scheduled across the boundary between slots, that transmission will be divided in a slot-by-slot manner. In this way, PUSCH can be transmitted with low latency while improving reliability. Moreover, in addition to static setting of the number of repeated transmissions by higher-layer signaling, dynamic indication of the number of repeated transmissions by DCI has been introduced thereby enabling repeated transmission of PUSCH in a flexible manner.

(f) Scheduling enhancements

Scheduling enhancements were made to reduce conflicts between diverse URLLC traffic periods and configured-grant/Semi-Persistent-Scheduling (SPS) configuration*27 periods by enabling multiple configured grants (maximum 12 grants) and SPS (maximum 8 instances) to be set in one cell. Additionally, to reduce signaling overhead, collective deactivation*28 of multiple previously set configured grant type2*29/SPS configurations by PDCCH was enabled. Furthermore, to support the scheduling of URLLC traffic having

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*21 Slot: A unit for scheduling data consisting of multiple OFDM symbols.

*22 Subcarrier: Individual carrier for transmitting signals with multi-carrier transmission such as OFDM.

*23 PDSCH: Physical channel for sending/receiving data packets in the downlink.

*24 HARQ-ACK: A receive acknowledgment signal whereby a receiving node can tell the sending node whether or not the data was successfully received (decoded).

*25 HARQ-ACK CB: A set of bits when transmitting multiple HARQ-ACK bits on a single uplink channel.

*26 Overhead: Control information needed for transmitting/receiving user data, plus radio resources used for other than transmitting user data such as reference signals for measuring received quality, as well as redundant transmission of such control information and reference signals.

*27 SPS configuration: A scheduling technique for performing semi-persistent resource allocation.

*28 Deactivation: The act of deactivating transmission by radio resources set by RRC.

extremely short periods (for example, the control traffic period generated by a packaging machine*30 is under 1 ms), the NR Rel-16 SPS shortest transmission period was set to 0.125 ms as an enhancement over the 10 ms shortest transmission period of NR Rel-15.

2) Technical Enhancements for Improving Communications Reliability

In NR Rel-15, packet duplication transmission control on the Packet Data Convergence Protocol (PDCP)*31 layer was introduced as technology for improving communications reliability in the radio interface [6]. Then, to further improve communications reliability in the radio interface, PDCP-layer packet duplication transmission control was enhanced in NR Rel-16. Differences in PDCP-layer packet duplication transmission control between NR Rel-15 and NR Rel-16 are shown in **Figure 3**. As shown, NR Rel-15 PDCP-layer packet duplication transmission control enables duplicate transmission by setting two carriers by Radio Resource Control (RRC)*32. On the other hand, NR Rel-16 PDCP-layer packet duplication transmission control

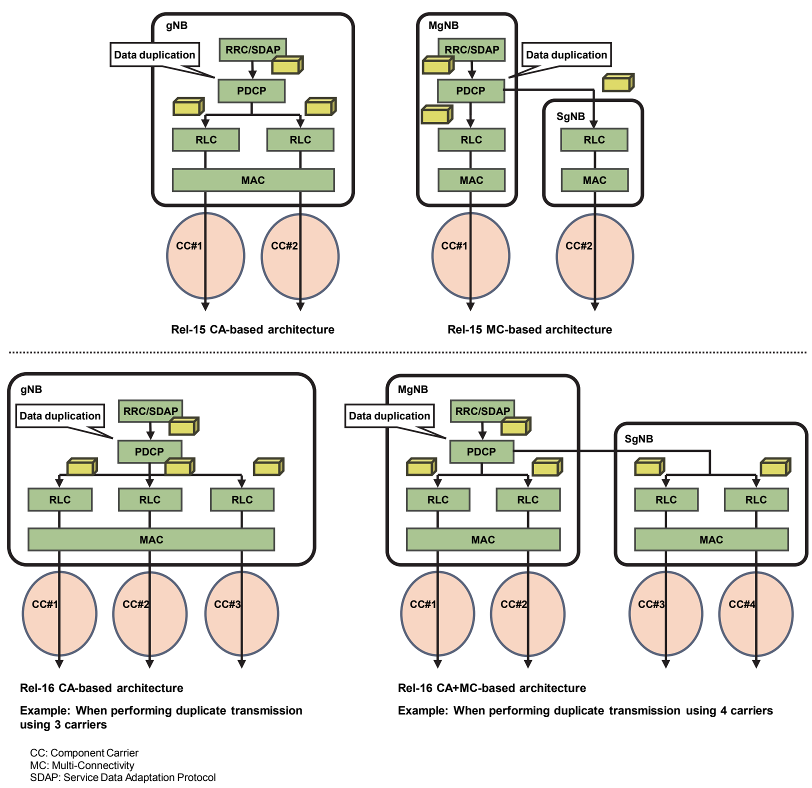

Figure 3 Differences in duplicate transmission between Rel-15 and Rel-16

*29 Configured grant type2: A transmission method that allocates PUSCH resources beforehand (periodically) from a base station and that activates a PUSCH transmission by PDCCH using those resources at any time.

*30 Packaging machine: A machine that automatically performs packaging operations. Packaging processes include filling, sealing, labeling, and wrapping of a product.

*31 PDCP: A sublayer of Layer 2 and protocol that performs ciphering, integrity check, reordering, header compression, etc.

*32 RRC: Layer 3 protocol that controls radio resources in the radio network.

enables duplicate transmission by setting a maximum of four carriers from among Master gNB (MgNB)*33 and Secondary gNB (SgNB)*34 carriers by RRC. Since a maximum of four carriers can be set here, duplicate transmission becomes possible by selecting, for example, only three carriers as shown at the bottom left of the figure or all four carriers as shown at the bottom right of the figure. Moreover, given that the condition of the radio interface in which the UE is communicating can change dynamically due to radio quality, congestion, etc., the ability to control the carriers to be used for duplicate transmission in a dynamic manner as needed was specified the same as in NR Rel-15. For the case in which some carriers are not needed for duplicate transmission, this type of control can turn duplicate transmission in a certain carrier OFF to prevent a drop in resource usage efficiency.

Functional enhancements were also specified in Rel-16 on the core network*35 side in relation to URLLC communications. To improve reliability on the U-plane*36, the reliability of the data path can be guaranteed through flexible setting of redundant paths*37 according to various requirements such as network configuration (**Figure 4**). Enhancements were also made for the case of terminal mobility such as improvements in latency in relation to handover*38 and a function for monitoring Quality of Service (QoS).

3.2 TSN

Time Sensitive Network (TSN) is technology for achieving time synchronization in real-time communications between communications equipment as in Internet of Things (IoT) systems and for achieving low-jitter communications. IEEE TSN is the TSN standard in IEEE 802*39 composed of a variety of

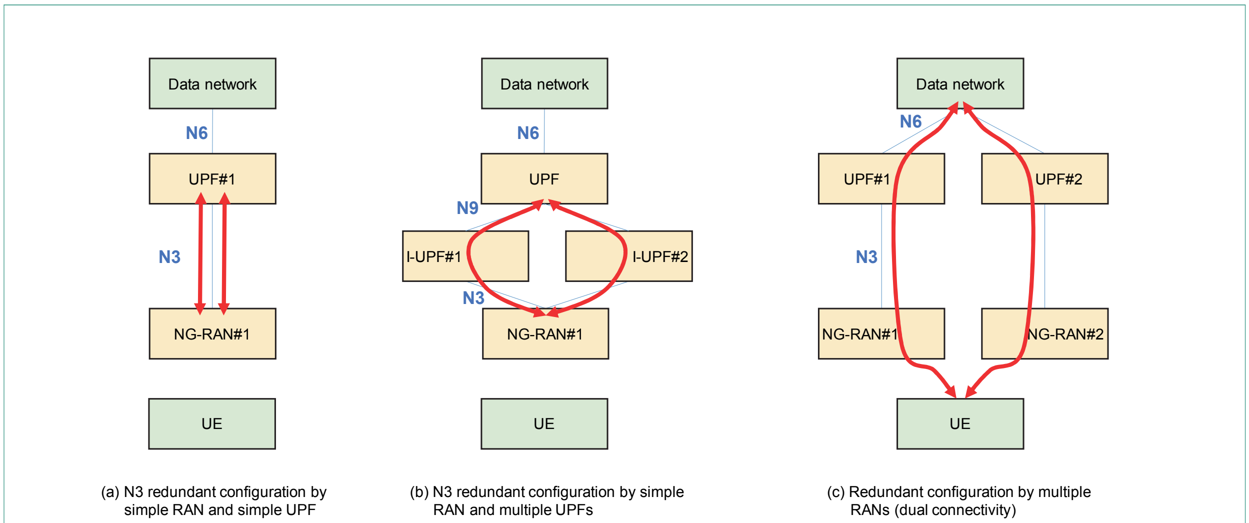

Figure 4　Redundant paths in URLLC

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*33 **MgNB:** The gNB that serves as master node in Dual Connectivity (DC).

*34 **SgNB:** The gNB that serves as secondary node in DC.

*35 **Core network:** A network comprising switching equipment, subscriber information management equipment, etc. A mobile terminal communicates with the core network via a radio access network.

*36 **U-plane:** The part of the signal sent and received in communications, which contains the data sent and received by the user.

*37 **Redundant paths:** The setting of multiple transmission paths for transmitting and receiving the same data to improve the reliability of communications.

*38 **Handover:** A technology for switching base stations without interrupting a call in progress when a terminal moves from the coverage area of one base station to another.

*39 **IEEE 802:** IEEE Committee that defines standards related to LAN and Metropolitan Area Network (MAN). Commonly known as LAN/MAN Standards Committee (LMSC).

enhanced communication standards based on Ethernet.

A smart factory requires high-accuracy time synchronization. For example, the requirement for end-to-end synchronization accuracy in motion control is under 1 μs. In Rel-16, functional enhancements were made to apply feature technologies of the NR/5G system to TSN and to achieve Time Sensitive Communication (TSC) that performs precise time synchronization and low-jitter communications in a 5G system.

First, as a configuration for achieving TSN in an NR/5G system, the entire NR/5G system is taken to act as a bridge in TSN and the Central Network Controller (CNC)*40 in TSN adopts a fully centralized model*41 to control inter-port communications (**Figure 5**). This bridge adopts some of the techniques in IEEE 802.1Q*42 for inter-port traffic scheduling. Communication paths are set via this bridge between each unit of terminating equipment (such as IoT terminals) and the TSN Grand Master (GM) that performs integrated management of TSN system time. Here, the bridge takes on some of the burden of time synchronization control and supports some parts of IEEE802.1 AS*43.

In other words, a variety of network control technologies in an NR/5G system such as high-speed and large-capacity NR plus URLLC, QoS, security, etc. can be applied within this TSN bridge. A high-quality, high-reliability TSN that applies 5G feature technologies can therefore be constructed while achieving flexible equipment layout even in a complex environment such as a factory (**Figure 6**).

Additionally, to achieve high-accuracy time synchronization between UE and gNB, a function was specified to enable the base station to broadcast/unicast high-accuracy 5G system reference timing (time granularity: 10 ns) to a UE as a solution on

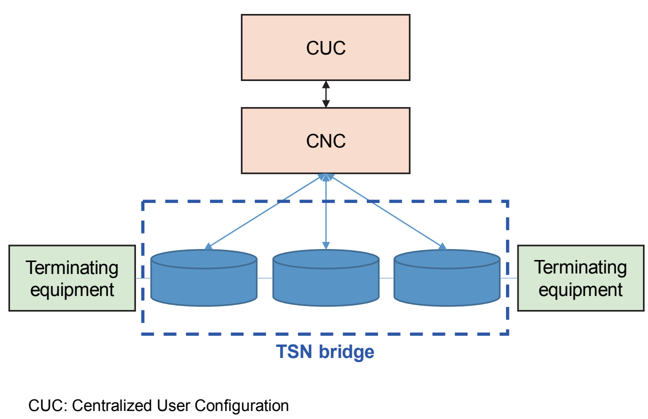

Figure 5　TSN fully centralized model

*40 CNC: A component that controls a TSN bridge in TSN.

*41 Fully centralized model: A TSN model. A model for managing terminating equipment and applications in an integrated manner in a Centralized User Configuration (CUC).

*42 IEEE 802.1Q: A standard related to a network based on bridges and bridge configurations in a Local and Metropolitan Area Network.

*43 IEEE802.1 AS: A standard related to time synchronization control in a Local and Metropolitan Area Network.

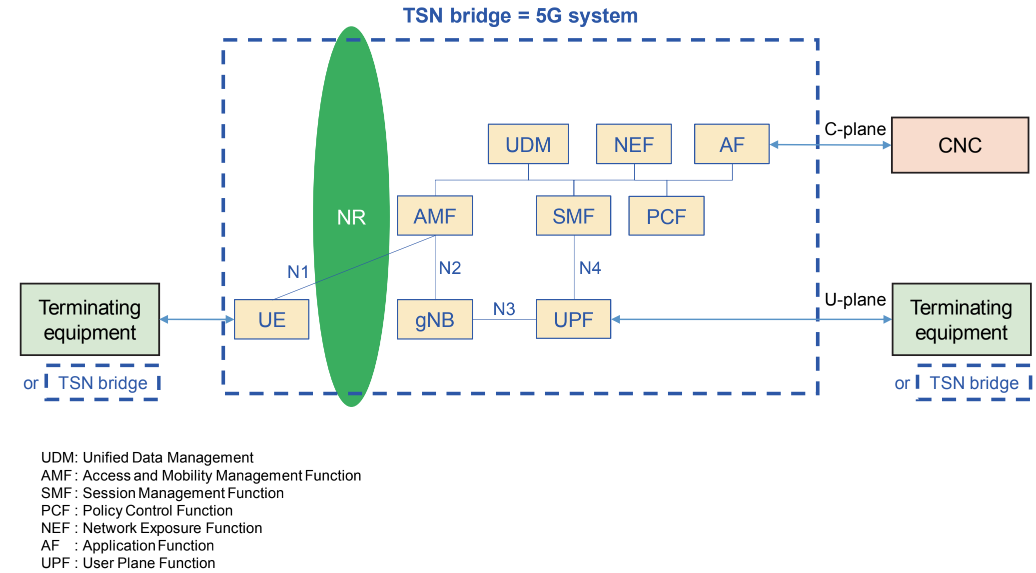

Figure 6 Example of a configuration applying a 5G system to a TSN bridge

the Radio Access Network (RAN)*44 side. A function has also been introduced on the UE side for making autonomous requests to the base station for 5G system reference timing to deal with synchronization offsets within the terminal. The base station, meanwhile, can obtain traffic-related Time Sensitive Communication Assistance Information (TSCAI) from the core network at QoS flow*45 setup and handover time. TSCAI includes arrival times and periodicity information for traffic having stringent latency requirements, which makes it useful for achieving efficient base station scheduling.

IEEE TSN uses the Ethernet frame*46 format, so it can be assumed that Ethernet frames will be transferred between UE and gNB when a 5G system plays the role of a TSN Bridge. It is also assumed here that the payload*47 size of such an Ethernet frame is small compared with header size. To therefore reduce overhead, an Ethernet Header Compression (EHC)*48 function in the PDCP sublayer has been specified in NR Rel-16. The principle of header compression, as in the case of Robust Header Compression (RoHC)*49, is to have the receive side save header elements whose contents do not change and associated Context ID (CID)*50 in memory so that the transmission of those saved elements can be omitted and to have decompression performed on the receive side. Please see a 2014 article in this journal [7] for details on RoHC control. The procedural flow of EHC is shown in **Figure 7**. Referring to steps (a) – (c) in the figure, header compression is performed in the following way.

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*44 **RAN:** A network consisting of radio base stations and radio-circuit control equipment situated between the CN (see*35) and mobile terminals.

*45 **QoS flow:** An IP flow unit that differentiates between QoS classes (communication service quality (allowed latency, packet loss rate, etc.)) in a Protocol Data Unit (PDU) session tunnel set up between a base station and the core network.

*46 **Ethernet frame:** Data format used for Ethernet LAN communications.

*47 **Payload:** The part of the transmitted data that needs to be sent, excluding headers and other overhead.

*48 **EHC:** A PDCP sublayer function for compressing the header of an Ethernet frame transmitted between UE – gNB. Compresses, in particular, the transmit MAC address, receive MAC address, payload type, Q-Tag (option) in the header part of an Ethernet frame. Any Ethernet frame length can be compressed.

*49 **RoHC:** A technique for compressing the RTP/IP/UDP header specified in RFC documents.

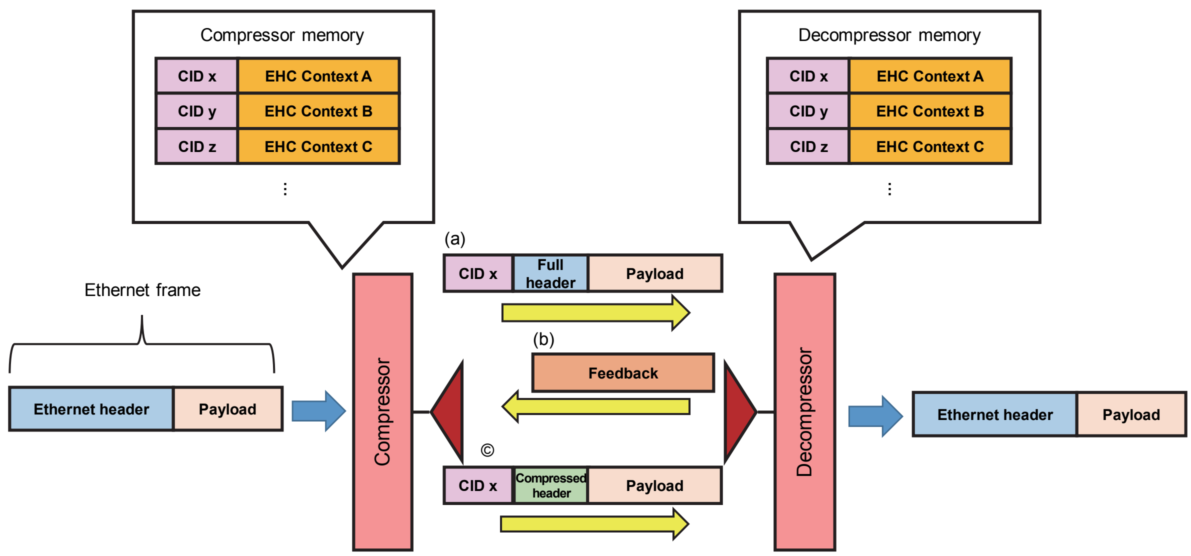


Figure 7　EHC compression/decompression procedure

(a) The transmit side sends the full header*51 of a certain packet and CID associated with that full header to the receive side.

(b) To notify the transmit side that it has saved that context*52 in memory, the receive side sends it feedback on saved context.

(c) After receiving the feedback, the transmit side considers that the receive side has saved that context and proceeds to compress the header and to send the data.

Ethernet header compression can be applied in either the downlink or uplink direction, so for a downlink, the transmit side would be evolved NodeB (eNB)*53 or gNB while the receive side would be a UE.

3.3 NPN

In contrast to a Public Network (PN) provided by a telecom operator for universal use by the general public, a Non Public Network (NPN) refers to technology for configuring a closed network that appropriates radio resources such as frequency as well as base stations and network resources and limits access to specific users or groups. In addition, the appropriation of radio/network resources in this way contributes to improved performance in terms of high-speed, large-capacity, and ultra-low-latency communications compared with a PN. In Rel-16, two NPN architecture formats are specified: Public Network Integrated NPN (PNI-NPN) that constructs dedicated-network base stations as a part of an operator's 5G PN and Standalone NPN

*50 CID: An ID assigned to identify context (see *52). The receive side restores a header based on the received CID, uncompressed header elements, and context corresponding to that CID stored in local memory.

*51 Full header: The header part of an Ethernet frame before compression in the PDCP entity. It consists of the transmit MAC address, receive MAC address, Ethernet frame length or Ethernet payload type, and Q-Tag (option).

*52 Context: The content of Ethernet header elements stored in receive-side memory. An ID is assigned to each context.

*53 eNB: A base station for the LTE radio access system.

(SNPN) that constructs a network independent of the operator's network (**Figure 8**).

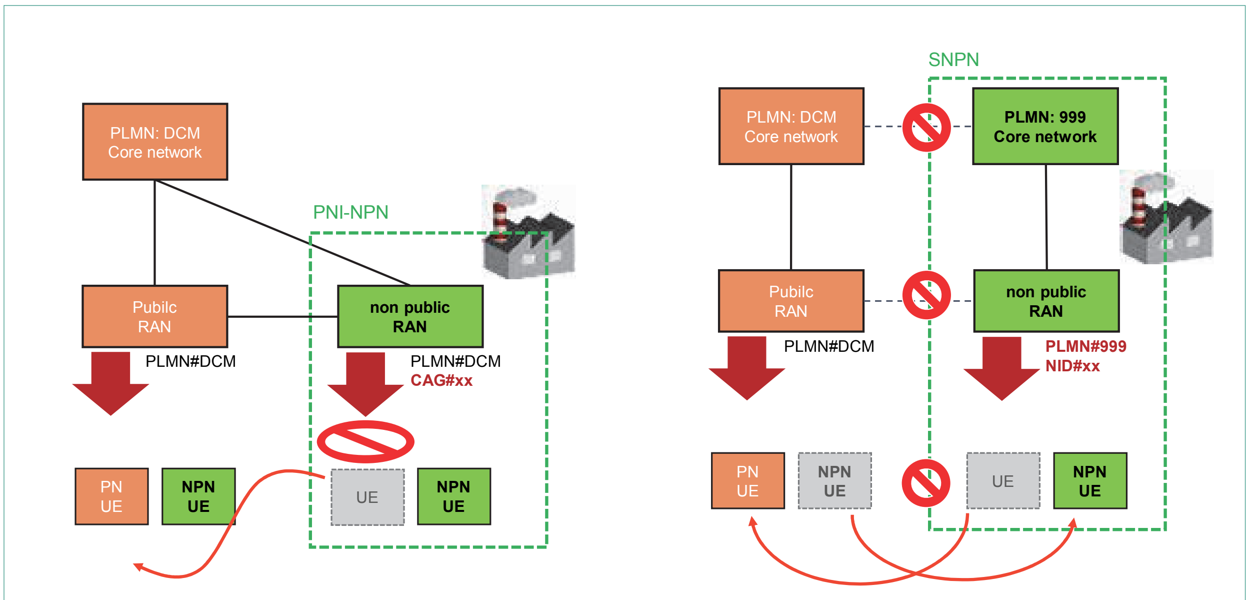
1) PNI-NPN

PNI-NPN is network architecture that accommodates an NPN within a network the same as a 5G Core Network (5GC) that accommodates a PN (Fig. 8 (a)). This format applies Closed Access Group (CAG) as access control. Here, UE tries to access an upper cell that judges access rights by cross-checking the CAG ID sent from that cell through broadcast system information*54 against a list of CAG IDs that are accessible on the UE side for setting and saving. However, UE with no CAG ID settings is "cell barred" meaning that it cannot access that cell and cannot be a target of cell selection processing. At the same time, NPNUE residing in the PNI-NPN is allowed to access the PN by setting an operator code (Public Land Mobile Network (PLMN)*55 ID), the same as in a PN.

The core network manages a CAG list accessible to UEs based on contract information, etc. and "CAG only" information that determines whether access to the PN described above is allowed and provides this information to the UE. Furthermore, by notifying base stations of the CAG list described above and "CAG only" settings, a base station can use that information in access control to a CAG cell for the UE in connected mode, e.g., by handover.

2) SNPN

In contrast to PNI-NPN that is accommodated in the core network of a PN, SNPN is accommodated in a core network configured in a standalone



(a) PNI-NPN (b) SNPN

Figure 8 NPN configurations

*54 **Broadcast system information:** Various types of information broadcast simultaneously to each cell, such as the location code required for judging whether location registration is needed for a mobile terminal, information on surrounding cells and radio wave quality required for services in those cells, and information for restricting and controlling outgoing calls.

*55 **PLMN:** An operator that provides services using a mobile communications system.

manner independent of the PN (Fig. 8 (b)). In a SNPN, a Network ID (NID) is set separately from a PLMN ID, and a UE set with that NID proceeds to select that NID in operator selection processing activated when terminal power is turned on. In other words, an NPNUE residing in a SNPN differs from an NPNUE residing in a PNI-NPN and cannot move to a PN set with a different PLMN ID. An SNPN cell can be identified by a combination of a PLMN ID and NID provided by system information. In addition, authentication processing in a SNPN is carried out independent of the PN. Here, Extensible Authentication Protocol Transport Layer Security (EAP-TLS)*56 that uses an authentication key obtained from the terminal can be applied to the authentication system. In this case, the terminal can reside in the network without using a Universal Subscriber Identity Module (USIM)*57, which enhances the flexibility of compact terminals used in IoT and similar systems and makes it easy for a vendor or other enterprise to construct a proprietary network.

3.4 V2X

1) V2X Architecture

In anticipation of applying 3GPP mobile radio systems to connected cars and other systems, V2X system architecture using NR/5G systems has been specified in NR Rel-16. The use of network slicing*58, a feature technology of 5GC, is also expected, and a value indicating a V2X application has been newly specified in the Slice/Service Type (SST) value, which is an information element that selects a network slice.

2) V2X Lower-layer Specifications

Among communications in cellular V2X, all specifications prescribed up to NR Rel-16 can be used for V2N. The abovementioned standard for URLLC, in particular, has been discussed and specified assuming connected cars as one of the targeted use cases. Meanwhile, for sidelink communications, the following has been specified based on a NR Rel-15 base station – terminal communications system [8] and a LTE sidelink communications system.

(a) Feature functions of NR sidelink communications

NR sidelink communications has been studied as a means of satisfying high performance requirements for communication speed, reliability, and latency, and new structures and functions have been adopted relative to LTE sidelink communications.

- Radio frame*59 structure: Multiple OFDM subcarrier intervals (15 kHz, 30 kHz, 60 kHz, 120 kHz) can be applied. This is the same as base station – terminal communications in NR Rel-15 in which a wide subcarrier interval is effective in tracking high-speed movement and reducing latency.
- Communication types: Three types of communication are specified on the physical layer: broadcast, groupcast, and unicast. LTE sidelink communications specified only the broadcast type, which made it necessary to set overly safe values for communication parameters to ensure

*56 EAP-TLS: An authentication protocol specified by IETF that issues a digital certificate on both the client side and server side to enable mutual authentication.

*57 USIM: An IC card used to store information such as the phone number contracted with a mobile operator. A subscriber identity module used for mobile communications in 3GPP W-CDMA/LTE and 5G applications.

*58 Network slicing: A network format provided in 5GC. Technology that logically or physically divides network equipment and network resources according to service requirements such as use cases, business models, etc.

*59 Radio frame: The smallest unit used for signal processing (encoding, decoding). A single radio frame is composed of multiple slots (or subframes) along the time axis, and each slot is composed of multiple symbols along the time axis.

communication quality. However, newly specified groupcast and unicast types enable appropriate communications based on the channel state with limited communication targets, which leads to better resource utilization efficiency while maintaining communication quality. These new communication types are also effective in avoiding unnecessary decoding processing in UEs other than the communication targets. One example of applying a newly specified communication type would be the use of groupcast in vehicles platooning. This would enable efficient communications among the vehicles making up a platoon.

- Traffic types: Various elemental technologies have been specified assuming periodic and aperiodic traffic. In the case of unpredictable and highly urgent data, they enable transmission that satisfies high performance requirements for reliability and latency. For example, if the possibility arises that an automobile accident is imminent, immediate communications among nearby vehicles could prevent that accident from occurring. In this regard, LTE sidelink communications have been specified assuming only periodic traffic.
- Retransmission function: Retransmission has been specified based on feedback (HARQ feedback) on the physical layer. Improved performance in terms of reliability and latency is expected with each data transmission, and from a system point of view, avoiding retransmission beyond what is necessary leads to improved system performance overall. This function is specified in addition to blind retransmission adopted in LTE sidelink communications.
- Multiple Input Multiple Output (MIMO)*60, higher order modulation: NR sidelink communications can perform up to two layers of transmission. Additionally, as a data modulation scheme*61, 256 Quadrature Amplitude Modulation (256QAM)*62 has been specified. 256QAM increases the amount of data that can be transmitted in a certain time-frequency resource, which improves data rate. In NR Rel-16 specifications, the sharing of video between vehicles is envisioned as a use case. MIMO/256QAM is expected to be one of the functions making such a use case possible.

(b) Inter-terminal synchronization

Inter-terminal synchronization is necessary for achieving sidelink communications using the above structures and functions. This synchronization is performed using the same structure and procedure as LTE sidelink communications. That is to say, signals are transmitted and received based on the timing of a Global Navigation Satellite System (GNSS)*63, eNB/gNB, or UE (vehicle, etc.) synchronization signal*64. The UE synchronization signal is specified with the structure

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*60 MIMO: A signal transmission technology that improves communications quality and spectral efficiency by using multiple transmitter and receiver antennas to transmit signals at the same time and same frequency.

*61 Data modulation scheme: Technology for transmitting and receiving multiple signals at the same time using certain time/frequency/space resources. In 256QAM (see *62), there are 256 combinations of amplitude and phase and transmitting one of those combinations enables 8 bits to be transmitted together.

*62 256QAM: A type of modulation scheme. 256QAM modulates data bits through 256 different amplitude and phase signal points. A single modulation can transmit 8 bits of data.

*63 GNSS: Generic name for satellite positioning systems such as GPS and Quasi-Zenith Satellite System (QZSS).

*64 Synchronization signal: A physical signal that enables detection of the synchronization source identifier, and frequency and reception timing required by the mobile terminal to start communications.

shown in **Figure 9**.

(c) Resource allocation

In a state in which inter-terminal synchronization has been established, the UE transmitting data uses the resources determined by either of two resource allocation techniques (Mode 1, Mode 2) to transmit that data.

In Mode 1, the UE uses the resources provided by the gNB, which can indicate either periodic or aperiodic resources.

In Mode 2, in contrast, the UE autonomously selects the resources that it needs. Specifically, it receives resource reservation information from other UEs and selects available resources based on the information. Resource reservation can be applied to either periodic or aperiodic resources. Also specified is a function for reevaluating whether previously selected resources can indeed be used immediately before attempting to use them and a function for reselecting resources if previously reserved resources are reserved by another UE. These functions are effective in avoiding collisions in transmitted or received signals between terminals, which suggests that required communication quality can be satisfied even in the case that resources are autonomously selected by each UE.

We note here that for both resource allocation techniques, resources are allocated in units of slots the same as in LTE sidelink communications.

(d) Control-channel/shared-channel structure

Using the allocated resources, the UE

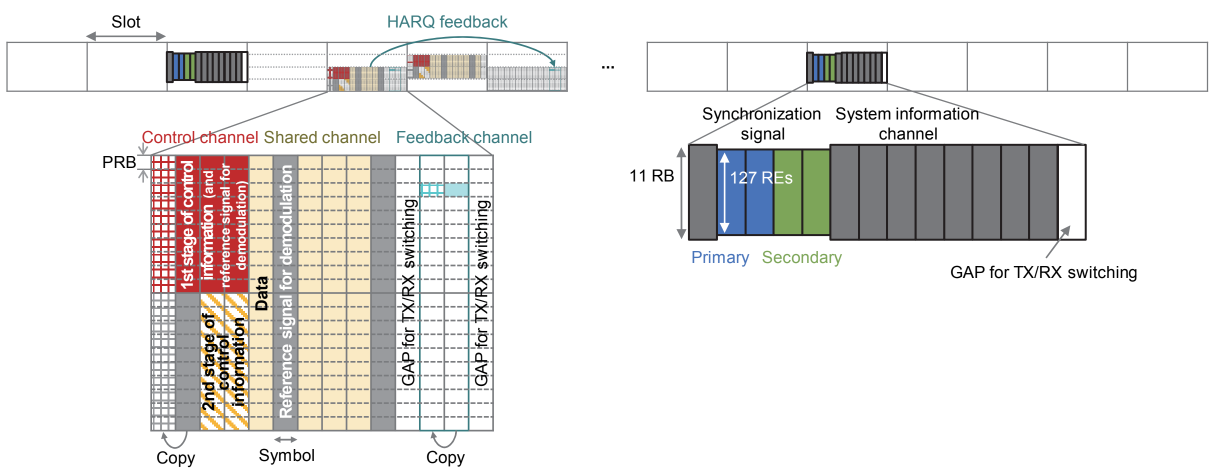

Figure 9　Example of a physical channel configuration for sidelink use

transmits data and associated control information to another UE. The physical channel*65 used here for transmitting information and data consists of the control channel and shared channel shown in Fig. 9, where the former contains the 1st stage of control information and the latter the 2nd stage of control information plus data.

The control channel is positioned at the front of the slot to reduce latency. The 1st stage of control information contains information indicating that other UEs will perform blind decoding*66, which is necessary to receive and decode the 2nd stage. The 2nd stage of control information contains various types of information including that necessary for the UE receiving the 1st stage to receive and decode the data. Resource reservation information described above is contained in the 1st stage of control information while communication type, destination information, etc. are contained in the 2nd stage. Dividing control information into two stages in this way enables flexible control of the resources used in transmitting each stage of control information based on channel state while improving resource usage efficiency and received quality. Furthermore, by enabling the 2nd stage format to be changed while treating the 1st stage format as common ensures forward compatibility.

(e) Retransmission based on feedback information on the physical layer

A UE receiving data addressed to itself via a groupcast or unicast can transmit feedback information to the originating UE. As shown in Fig. 9, HARQ feedback is performed on a dedicated physical channel and the resources available for the channel as shown are provided with a specific slot period. A resource for HARQ feedback with respect to certain received data is uniquely determined by the transmission resource for that data and by transmission source/destination information. This mechanism does not require UE blind decoding while avoiding feedback-channel collisions even for Mode 2 described above. Additionally, for Mode 1, HARQ feedback can be sent to the gNB from the originating UE transmitting the data. The gNB can then schedule retransmission based on the received feedback information.

(f) Other functions

Functions other than those described above have also been specified to satisfy various requirements. These include Channel State Information (CSI) feedback*67, power control based on downlink/sidelink path loss*68, and congestion control*69. Additionally, for V2N in which one side is either LTE or NR, a function has been specified for allocating sidelink resources to the other side.

3.5 Other Related Technologies

1) 5G-LAN Type Service

Functions for managing communications within a specific group, group management that defines a 5G Virtual Network (VN) group*70, User Plane

*65 **Physical channel:** A generic term for channels that are mapped onto physical resources such as frequency or time, and transmit control information and other higher layer data.

*66 **Blind decoding:** Receive-side UE processing that attempts to receive and decode a signal that may have been transmitted regardless of whether that transmission actually occurred.

*67 **CSI feedback:** In communications between two units of equipment, technology for transmitting a reference signal from one unit, receiving that signal and measuring channel quality from that signal on the other unit, and reporting that quality to the transmitting unit. The reported information can then be used to decide on various transmission parameters with the aim of improving communications quality and spectral efficiency.

*68 **Path loss:** Propagation path loss estimated from the difference between the transmitted power and received power.

Function (UPF) call back*71 that performs in-house communications, inter-UPF interface N19, etc. are being introduced within individual factories, offices, etc.

2) Private Slice

While the previously described PNI-NPN is ranked as technology that can achieve an appropriation/division of radio resources (base stations, frequencies), the use of network slicing is also envisioned as a means of achieving end-to-end resource division that includes the core network. 5GC Rel-16 specifies Network Slice Specific Authentication and Authorization (NSSAA) that enhances the network slicing function and independently applies authentication and authorization procedures within a specific network slice. For details on this technology, please see a separate article in this issue [9].

3) Predictive QoS

In autonomous driving and similar fields, there is a need for collecting and analyzing high-definition video data captured by on-vehicle cameras in real time. It is therefore important to be able to predict the quality of communications in the area corresponding to that vehicle's driving route and time period. In Rel-16, the Network Data Analytic Function (NWDAF)*72 specified for 5GC makes it possible to analyze various types of data accumulated within the network and to predict future communications quality. Processing for obtaining information such as analysis results from external servers and applications via the Network Exposure Function (NEF)*73 has also been specified. For details on this technology, please see a separate article in this issue [9].

4. Conclusion

This article described industry collaboration solutions under the NR/5G system specified in 3GPP Rel-16. Rel-17 and beyond is expected to provide for the use of big data and AI, drones, etc. in addition to adding functional enhancements to the various industry collaboration functions described in this article. As described in the opening article [1] of these Special Articles, enhancements to use cases and services with an eye to Beyond 5G and 6G can be viewed as an important element in the evolution of 5G technologies. Going forward, NTT DOCOMO aims to contribute to the further evolution of 5G.

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*69 Congestion control: Technology for prohibiting a certain UE from using an excessive amount of resources mainly for the case of UE autonomous selection of transmission resources. Judging whether transmission should be allowed or denied depends on channel availability and the UE's transmission conditions.

*70 5G VN group: A terminal group that provides virtual and private communications in 5G LAN-type services.

*71 UPF call back: In UPF that terminates the U-plane with a terminal, the setting of a communications path with another terminal without making an outside connection such as with the Internet.

*72 NWDAF: A network function specified in 5GC that returns the results of collecting and analyzing various types of data within the network.

*73 NEF: A network function specified in 5GC that provides an API to external servers and applications outside of 3GPP specifications.