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Advanced 5G Radio Technologies in 3GPP Release 16

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In June 2018, 3GPP issued its Rel-15 specifications, including specifications for the new radio access technology for 5G, called NR, and for advances to LTE technologies. In March 2020, commercial 5G services using NR were started in Japan. Further enhancements for NR and LTE have continued at 3GPP after Rel-15 was finalized, and the Rel-16 specifications were completed in June 2020. This article gives an overview of the NR and LTE specifications completed in Rel-16.

1. Introduction

Release 15 (hereinafter referred to as "Rel-15") of the 3rd Generation Partnership Project (3GPP) specifications for fifth-generation mobile communications systems (5G), including New Radio (NR) and Long Term Evolution (LTE), emphasized radio technologies for enhanced Mobile Broad-Band (eMBB). In addition to further advances for eMBB, Rel-16 advanced Ultra-Reliable and Low Latency Communication (URLLC), and specified enhancements that will promote Industrial Internet of Things (IoT), which will be used in creation of new businesses. This article describes the main technology enhancements specified in Rel-16 and gives background considered when studying them.

2. Directions for 5G Radio in the Rel-16 Specifications

Figure 1 shows the NR and LTE functions specified in 3GPP Rel-16, classified by the main usage scenarios for 5G, which are eMBB, URLLC, and massive Machine-Type Communications (mMTC).

As in Rel-15, Rel-16 has many functions for eMBB, and these are divided into functions for improving quality and performance, and functions to expand usage scenarios. NR as specified in Rel-15 focused on basic functionality to realize non-standalone[*1] and standalone operations, and functionality for improving quality and performance was left for further study. As such, several of those functions were specified in Rel-16 based on experience gained creating the LTE specifications. At the same time, functions for expanding usage scenarios and markets were specified, such as utilization of unlicensed bands (described below) and extensions for more flexible base station deployment.

Enhancements for URLLC and mMTC are mainly for developing new industries, and there are functional enhancements for realizing various Industrial IoT usage scenarios. The main Rel-16 functionalities for each usage scenario are described below.

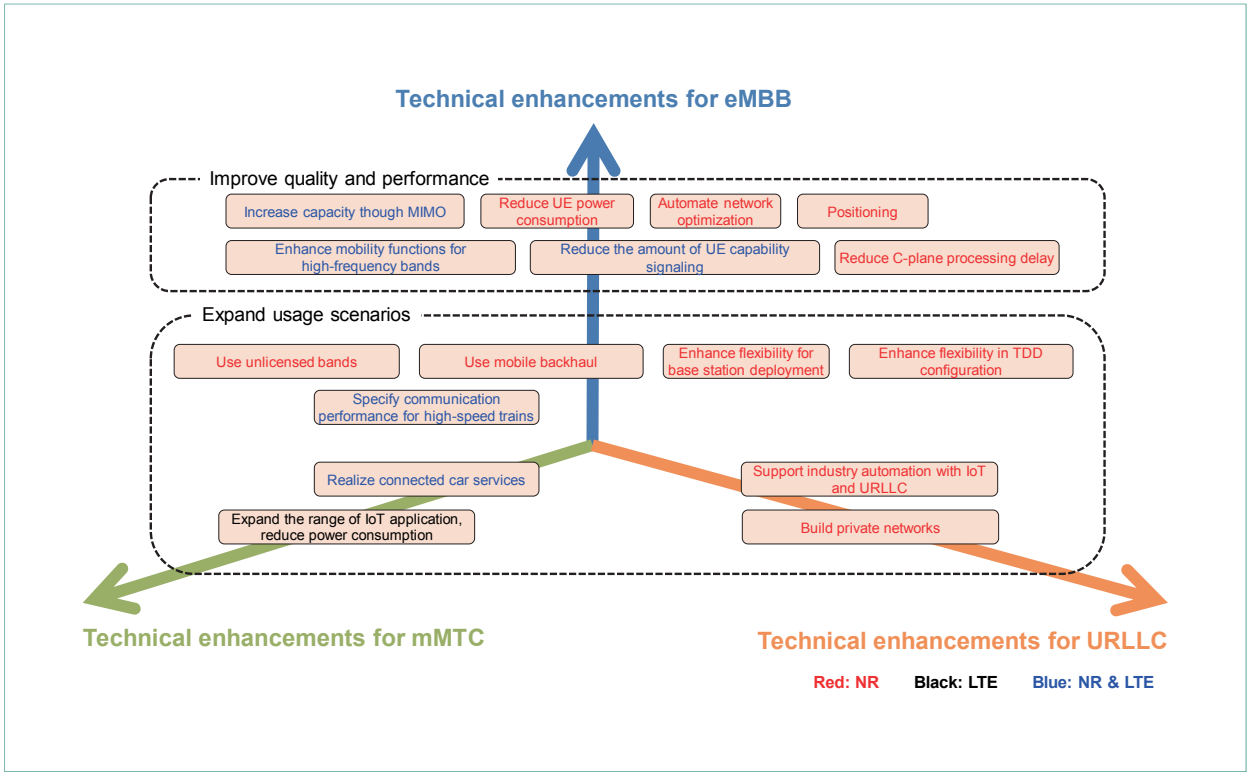

Figure 1 Major functionality specified in Rel-16 for NR and LTE

*1 Non-standalone: An operation format that provides services through a combination of NR and LTE areas. In this format, a service area cannot be provided by NR alone.

2.1 Technical Enhancements for eMBB

As shown in Fig. 1, functions are specified for seven objectives to improve quality and performance of eMBB. Functions have also been specified to satisfy five objectives for expanding the usage scenarios for eMBB.

1) Improving Quality and Performance

(a) Increase capacity through Multiple Input Multiple Output (MIMO)*2

Rel-15 specified several new MIMO functions for NR, such as antenna arrays*3 composed of multiple antenna panels, and multi-beam operation in high-frequency bands with analog beam forming*4, but these were enhanced further in Rel-16. For example, with Rel-15, there was no way to notify a UE of the configuration being used for communication at the base station, so it was not practical to apply distributed MIMO*5 communication using multiple antenna panels or transceiver points that are geographically separate. In Rel-16, a mechanism is specified for the UE to know when there are multiple antenna panels or transceiver points at the base station, and for configuring and communicating with each of them simultaneously, so high-ranked distributed MIMO communication can be used to increase speed and reliability.

(b) Enhance mobility functions for high-frequency bands

Basic mobility functions such as handover*6 were specified in Rel-15 NR, but there were still issues with mobility functions using analog beam forming in the high frequency bands, such as low reliability due to beam-sweep*7 delay. To realize stable, continuous communication, interruption time due to processing for handover and switching the Secondary Cell Group (SCG)*8 needed to be reduced, so in Rel-16, functional enhancements were made for handover on the same frequency and between different frequencies, and for switching the SCG. Specifically, the handover failure rate is reduced by enabling the UE to configure multiple handover candidate base stations rather than only one previously, and the communication interruption time is reduced by enabling the UE to communicate with both the handover source and target base stations simultaneously.

(c) Reduce UE power consumption

Improving UE battery life is an important aspect of raising user satisfaction, and features were specified in Rel-15 NR to reduce UE power consumption, including Discontinuous Reception (DRX)*9, which was also supported by LTE, and a new BandWidth Part (BWP) adaptation*10 function.

Some effective ways to further reduce power consumption include finding more opportunities for the UE to enter a sleep state by suspending operations such as Physical Downlink Control CHannel (PDCCH)*11 monitoring at finer granularity, and avoiding simultaneous performance of multiple processes. However, reducing power consumption with these sorts of operations can

*2 MIMO: A signal transmission technology that uses multiple antennas for transmission and reception to improve communications quality and spectral efficiency.

*3 Antenna array: An arrangement of multiple antenna elements or panels forming an antenna group.

*4 Beam forming: A technology that gives directionality to a transmitted signal, increasing or decreasing the signal power in a particular direction. Analog beam forming works by controlling the phase in multiple antenna elements (RF devices) to create directionality, while digital beam forming controls phase in the baseband module.

*5 Distributed MIMO: A MIMO transmission technology that transmits different MIMO streams from multiple base stations to a single UE.

*6 Handover: The process of switching the base station connected to the UE.

*7 Beam sweep: A technology that switches through the beams that a base station can use in order, with the same signal, covering the entire area.

*8 SCG: With dual connectivity, the serving cell group used to communicate with the second of the two base stations connected to the UE.

increase communication delay and reduce achievable throughput.

As such, Rel-16 introduced functionality such as a mechanism to appropriately skip operations, such as periodic reception during DRX or measurements, based on instructions from the base station so that sleep can continue, and a function whereby the base station sends instructions to reduce the maximum number of MIMO layers*12 when high throughput is not required, enabling the UE to turn off some of its circuits. These functions enable flexible adaptation to requirements that differ depending on the UE or services being provided.

(d) Positioning

Positioning functions are an important application, but in Rel-15 NR they had limitations such as being reported based only on the cell ID*13. Rel-16 specifies dedicated functions for location and positioning with NR. In particular, a Positioning Reference Signal*14 on the downlink is specified for positioning, and various other positioning methods on the downlink and the uplink are specified, based on reference signal timing differences, on reference signal received power*15, on angle of arrival*16, and on the Rx-Tx time difference. Operators can use these positioning methods as appropriate, depending on the base-station deployment scenario, the frequencies being used, the positioning accuracy required and other factors. Support for NR positioning functions also enables implementation of more accurate positioning than LTE by utilizing NR features such as wide bandwidth and Massive MIMO*17.

(e) Reduce the amount of UE capability signalling

To meet the diverse demands for 5G, a wide range of functions have been specified for NR, and with them, the amount of signaling to indicate functions supported by UE (UE capabilities) has increased. Past 3GPP Releases have also introduced measures to reduce this signaling, within a scope that could be handled by radio protocols, but in practical terms, the amount of signaling was approaching the maximum bytes in a single data unit transmittable by radio, so a more drastic measure to reduce signaling in the entire system, including core network*18, was needed. The drastic measure that was taken is to register UE capabilities in a database and to assign an identifier to the UE capabilities in the database, as a mechanism to identify features supported by the UE.

(f) Reduce C-plane*19 processing delay

Rel-16 also includes functional enhancements to further reduce C-plane delay. For example, in Rel-15 NR, the Random Access CHannel (RACH)*20 procedure generally has four steps, so an exchange of four messages is required to establish communication. Rel-16 NR specifies a two-step RACH that reduces the procedure to two steps, reducing C-plane delay. This function was investigated in Rel-16 for scenarios with unlicensed

*9 DRX: Intermittent reception control used to reduce power consumption in UE.
*10 BWP adaptation: A technology in NR for dynamically switching communication settings such as bandwidth or subcarrier intervals between the UE and serving cell. It can be used to reduce power consumption by, for example, reducing bandwidth when high-speed communication is not needed.
*11 PDCCH: Control channel for the physical layer in the downlink.
*12 MIMO layers: In MIMO, the number of multiplexed layers when multiplexing different signals on the same radio resources using spatial multiplexing with different antennas.
*13 Cell ID: Identifying information assigned to each cell.
*14 Reference signal: A known signal from base stations, configured in UE.
*15 Reference signal received power: Received power of a reference signal measured at the UE.
*16 Angle of arrival: The angle of arrival of the radio signal from the transmitter, as seen by the receiver. Generally measured by the difference in arrival times at two or more antennas.

bands using Listen Before Talk (LBT)[*21], where overhead[*22] due to multi-step message exchange is a concern, but it was also found to be useful in scenarios using licensed bands, so the specifications allow it to be used in all NR usage scenarios.

(g) Automate network optimization

The Minimization of Drive Test (MDT)[*23] and Self Organizing Networks (SON)[*24] functions were specified to automate optimization of area quality in LTE networks by having UE report observations of radio quality to the network, and then collecting this quality data from the UE and analyzing it on the network side. Operators can use the MDT and SON functions to improve quality while limiting the manual labor involved. These functions were not supported in the NR Rel-15 specifications, but there was demand for such functionality in Rel-16, which was anticipated for full commercial deployment of NR services, so specifications for new NR functions similar to MDT and SON were included in Rel-16. These new specification also support collection of quality data for each beam in multi-beam operation, which is a feature of NR, and acquisition of quality data when in non-standalone operation.

2) Expanding Usage Scenarios

(a) Use unlicensed bands

Since Rel-13, 3GPP has included specifications for Licensed Assisted Access (LAA)[*25] for LTE to meet the demand for increased network capacity, enabling carrier aggregation to be used to bundle and use frequency bands licensed to operators (licensed bands) together with frequency bands not requiring licensing (unlicensed bands). In addition to LAA for NR, Rel-16 adds support for scenarios that were not supported for LTE, such as using unlicensed bands with NR alone, and Dual Connectivity (DC) using both licensed and unlicensed bands. Using DC rather than carrier aggregation enables operators to deploy base stations using unlicensed bands, independently of base stations using licensed bands. This mechanism that enables unlicensed bands to be used independently allows operators that do not have licensed bands to provide communication services. Note that supported unlicensed band frequencies include the 5 GHz band supported by LTE as well as the 6 GHz band.

(b) Use mobile backhaul

Normally, to expand and increase the density of the NR radio access network[*26] requires increasing the density of base station deployment and similarly, expanding and increasing the density of the mobile backhaul network[*27], which connects base stations to the core network. Rel-16 defines specifications for Integrated Access and Backhaul (IAB), which enables networks to be expanded and the density increased using wireless backhaul links based on NR, rather than requiring wired backhaul links. IAB nodes are relay nodes that use NR communication for both the backhaul and access

*17 Massive MIMO: A generic term for MIMO transmission technologies using very large numbers of antennas.

*18 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.

*19 C-plane: Control plane. A protocol used to transmit control signals for establishing or terminating communication and other operations.

*20 RACH: A common uplink channel that is used for transmitting control data and user data. It is shared by multiple users and is independently and randomly transmitted by users.

*21 LBT: A mechanism that enables a device to check whether another device is transmitting data before transmitting by radio.

*22 Overhead: Control information needed for transmitting/receiving user data, and radio resources used for purposes other than transmitting user data, such as reference signals for measuring received quality.

*23 MDT: A technology standardized by the 3GPP for gathering QoE information. Terminals send information to the network regarding incidents such as interruption of communication or failed handover as they occur, such as location and cause of the incident.

links. As parent nodes, they connect wireless backhaul links to other IAB nodes and also to base stations with functionality to accommodate IAB nodes, and they can accommodate UE as well as other IAB nodes [1]. A feature of IAB nodes is that they can provide wireless backhaul (X2*28 and Xn*29 interfaces) between base stations when operating NR in standalone and also in non-standalone using DC [2]. IAB nodes are also able to implement network synchronization between nodes that satisfies the requirements of Time Division Duplex (TDD)*30 systems, based on downlink signals and assist information received from parent nodes.

(c) Enhance flexibility for base station deployment

In addition to E-UTRA-NR DC (EN-DC)*31, NR standalone, and NR-E-UTRA DC (NE-DC) operating modes, Rel-15 NR specified a NR-NR DC (NR-DC) operating mode, although in limited form. Rel-16 specifies support for asynchronous NR-DC with a Master Cell Group (MCG) and SCG, which was not specified in Rel-15. For example, NR-DC using a Frequency Division Duplex (FDD)*32 band and a TDD band can be implemented without requiring synchronization between bands. Carrier aggregation function enhancements not specified in Rel-15 were also added, such as cross-carrier scheduling*33 between carriers with different sub-carrier*34 spacing and aperiodic Channel State Information-Reference Signal (CSI-RS) triggers*35. These enable high-frequency-band aspects such as data transmission and beam measurements to be controlled using the low-frequency band, which has higher reliability, when performing carrier aggregation with a low frequency band and a high-frequency band.

(d) Specify communication performance for high-speed trains

In LTE and NR specifications until Rel-15, communication performance was maintained for UE traveling at speeds under 300 km/h. However, we can expect increasing demand for stable communication in mobile environments traveling at speeds exceeding 300 km/h in Japan and other countries. Accordingly, Rel-16 specifies performance supporting speeds up to 500 km/h.

(e) Enhance flexibility in TDD configuration

Conventionally with TDD, when neighboring cells used the same frequency, it was typical to use the same ratio when allocating time resources for uplink and downlink communication, to mitigate interference between neighboring cells. However, traffic characteristics on uplink and downlink differ depending on location. For example, there tends to be more uplink traffic at a sports stadium, as users upload more video and photographs than in other areas. As such, there is demand to configure the TDD uplink-downlink ratio differently for each area, according to traffic characteristics in that area. However, interference needs to be controlled between

*24 SON: A network installed with functions to self-configure and self-optimize its parameters.
*25 LAA: A generic name for radio access methods in which terminals obtain configuration information from an LTE carrier using a licensed band, and then use an unlicensed band for radio communication.
*26 Radio access network: The network consisting of radio base stations situated between the core network and mobile terminals to perform radio layer control.
*27 Backhaul network: Indicates the route connecting a wireless base station to the core network.
*28 X2: A reference point between eNB, defined by 3GPP.
*29 Xn: A reference point between gNB, defined by 3GPP.
*30 TDD: A bidirectional transmit/receive system. It achieves bidirectional communication by allocating different time slots to uplink and downlink transmissions on the same frequency band.
*31 EN-DC: An architecture for NR non-standalone operation. Performs Radio Resource Control connection with LTE wireless, and also uses NR as an additional wireless resource.

TDD cells with different uplink-downlink ratios, so a mechanism was specified for UE to measure interference between cells, to report it to the network, and for the network to control the interference. Note that functions for UE to measure and report interference between TDD cells have been specified, but how the network will control such interference is implementation dependent.

2.2 Technical Enhancements for URLLC

1) Support Industry Automation with IoT and URLLC

In Rel-15, basic URLLC functions are supported, including a Transmission Time Interval (TTI)*36 structure to reduce delay, a Channel Quality Indicator (CQI)*37 and a Modulation and Coding Scheme (MCS)*38 table for communications requiring higher reliability.

Rel-16 NR includes enhancements for Augmented Reality (AR) and Virtual Reality (VR), which were considered in Rel-15, as well as for URLLC and Industrial IoT, for use cases such as factory automation, which requires 99.999999% reliability and latency in the range of 0.5 to 1 ms or less. One example of an enhancement to further reduce delay is to specify settings and UE behavior that could transmit control signals with more flexibility within the slot*39. By doing so, control signals can now be sent in a shorter time interval than with Rel-15. Enhancements that improve reliability include the introduction of a downlink control information*40 format that reduces payload*41 size and increases reliability, and increasing the number of redundant carriers for Packet Data Convergence Protocol (PDCP)*42 layer packet duplicate transmission control. These have increased transmission reliability on the radio segment.

2) Build Private Networks

There is increasing demand to build networks in closed areas, for scenarios such as machinery in a factory, inside a train car, or for smart-city devices, so that only certain devices can connect within a closed area. To meet these demands, 3GPP has introduced a mechanism that will enable existing communications operators or new operators to build independent, private networks, separate from the public networks, which are for mobile telephones and smartphones.

2.3 Technical Enhancements for mMTC

1) Expand the Range of IoT Application, Reduce Power Consumption

Rel-16 LTE specifies functional enhancements related to mMTC, the operation scenario that enables connection of large numbers of devices, including enhanced Machine Type Communication (eMTC)*43 for LTE and Narrow Band Internet of Things (NB-IoT)*44.

Most of the enhancements to eMTC and NB-IoT functions in Rel-16 LTE are extensions to existing functions. For example, the Wake-Up Signal is a function introduced in Rel-15, to reduce UE power consumption by skipping detection of paging signals*45. This was enhanced by specifying the Group Wake-Up Signal, which can issue instructions more finely, to groups of UEs, and reduce power consumption more efficiently. Functional

*32 FDD: A bidirectional communications mode that uses different frequencies and frequency bands for uplink and downlink communications.
*33 Cross-carrier scheduling: A method for directing transmission of data on a carrier using a different carrier.
*34 Subcarrier: An individual carrier for transmitting signals in a multi-carrier transmission scheme such as Orthogonal Frequency Division Multiplexing (OFDM).
*35 Aperiodic CSI-RS trigger: A method whereby a reference signal used to measure radio channel conditions is transmitted when needed, rather than periodically.
*36 TTI: Transmission time per data item transmitted via a transport channel.
*37 CQI: An index of reception quality measured at the mobile station, expressing propagation conditions on the downlink.
*38 MCS: A predetermined combination of data modulation and channel coding rate when performing Adaptive Modulation and Coding (AMC).
*39 Slot: A unit for scheduling data consisting of multiple OFDM symbols.

enhancements were also specified for cell measurement, such as enabling the Resynchronization Signal (RSS)*46 to be used for cell measurements, and enabling more-accurate eMTC cell measurements. Enhancements to various other existing functions are also supported, such as reducing control channel overhead and expanding Coverage Enhancement (CE) mode*47 functions, enabling a wider range of IoT use cases to be supported.

New functionality to be added in Rel-16 was also discussed, including scenarios where NR standalone operation, which is expected in the future, coexists with eMTC and NB-IoT. In particular, radio resource*48 scheduling functions were extended and functions were added to be aware of scenarios coexisting with NR, so that when NR standalone operation becomes more common in the future, eMTC and NB-IoT can operate with greater efficiency and flexibility. In addition to these enhancements to existing functions, new functions also continue to be added, such as Preconfigured Uplink Resources (PUR), which enable uplink data to be sent directly, while remaining in an IDLE state*49, so that devices spend most of the time in an IDLE state, reducing delay and power consumption for IoT device uplink data transmissions.

2) Realize Connected Car Services

Since Rel-14, 3GPP has specified Vehicle to Everything (V2X)*50 communication using sidelinks*51 based on LTE, and in Rel-15, new functions including carrier aggregation, multi-level modulation*52 and delay reductions were added. NR slidelinks were specified in Rel-16, not to replace the basic V2X services covered by LTE sidelinks, but to complement them by targeting advanced V2X services that require lower delay, higher reliability, high capacity or wide coverage. For Rel-16 NR sidelinks, various types of physical channel*53 and resource allocation were specified, as well as basic functions such as Hybrid Automatic Repeat reQuest (HARQ)*54 feedback, CSI feedback, and support for resource configuration functions for sidelinks that span Radio Access Technology (RAT) linking LTE and NR. Further enhancements to NR sidelink functions will be studied for Rel-17 and beyond, such as relay functions and location/positioning functions.

3. Conclusion

This article has described enhancements to 5G radio technologies as prescribed in 3GPP Rel-16 specifications. Some of the technical enhancements introduced here, for eMBB and for IoT and URLLC in support of industry automation, are described in more detail in other articles of this special feature (see [1] [3] [4]). In August 2020, 3GPP began work creating Rel-17, to further advance 5G radio. NTT DOCOMO will continue promoting 5G standardization, and contributing to further development of 5G standards.

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*40 Downlink control information: 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.

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

*42 PDCP: A sublayer of Layer 2 and protocol that performs encryption, integrity checks, reordering, header compression, etc.

*43 eMTC: An LTE communication specification for low data rate communication for IoT devices (sensors, etc.) using a narrow bandwidth.

*44 NB-IoT: An LTE communication specification for low data rate communication for IoT devices (sensors, etc.) using a narrower bandwidth than eMTC.

*45 Paging signal: A radio signal for notifying a mobile terminal that is in the standby state of an incoming call or network information update.

*46 RSS: A function that sends a cell resynchronization signal, separate from existing synchronization signals, to reduce the time and power needed to resynchronize UE and cell.

*47 CE mode: A UE state in which it receives a signal transmitted repeatedly to expand coverage.

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*48 Radio resource: Unit of time or frequency range allocated to each user for communication purposes.
*49 IDLE state: A state in which dedicated resources between the mobile terminal and the radio network are released.
*50 V2X: A generic name for direct Vehicle-to-Vehicle (V2V) communication, direct Vehicle-to-Infrastructure (V2I) communication between vehicle and roadside radio communication devices, direct Vehicle-to-Pedestrian (V2P) communication, and Vehicle-to-Network (V2N) wide-area communication via base stations in a cellular network such as LTE or 5G.
*51 Sidelink: A communication link for communication between UE, without passing through a base station.
*52 Multi-level modulation: A modulation system that includes two or more bits of information in one symbol.
*53 Physical channel: In a radio interface, channels that are separated in terms of a physical resource such as frequency or time.
*54 HARQ: A technology that combines Automatic Repeat reQuest (ARQ) and error correcting codes to improve error-correcting performance on transmission and reduce the number of retransmissions. A packet retransmission method that improves reception quality and achieves efficient transmission by combining the retransmitted data with previously received data.