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Status of Investigations on Physical-layer Elemental Technologies and High-frequency-band Utilization

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Aiming to promptly introduce "fifth-generation mobile communications systems" ("5G" for short), as a member of the 3GPP, we have vigorously investigated key technologies for wireless interfaces that satisfy the technical requirements for 5G and completed these basic investigations (on "Study Items", SIs) in March 2017. In this article, the details and results concerning those SIs are presented, and key technologies concerning the physical layer, candidate frequencies, and specifications and performance requirements are discussed in terms of predicted future work on specification development.

1. Introduction

As for fifth-generation mobile communication systems (5G), it is highly anticipated that 5G will support various usage scenarios such as "enhanced Mobile BroadBand" (eMBB), "massive-Machine-Type Communications" (mMTC[*1]), and "Ultra-Reliable Low-Latency Communications" (URLLC).

In the 3rd Generation Partnership Project (3GPP), a new wireless-communication system without backward compatibility with LTE-Advanced wireless-communication systems, called "New Radio" (NR),

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[*1] MTC: A general term used in the 3GPP for machine-based communications using no intermediate human operations.

was approved as a "Study Item" (SI)*2, and investigations on that SI began at an assembly held in March 2016. As for the work involved in establishing the specifications for NR, considering the above-mentioned utilization scenarios, we assume that the high-frequency band up to 100 GHz—as well as the existing frequency band used by LTE—will be utilized, and we aim to develop specifications that achieve flexible wireless interfaces and that assure wireless performance in that high-frequency band. As for a technical field differing considerably from that of conventional LTE-based wireless interfaces, this article focuses on scalable frame structures compatible with various uses cases and frequency bands, initial-access technology and multi-antenna technology compatible with various frequency bands and base-station designs*3, and channel coding technology for covering a wide range of data sizes and delay requirements. In particular, it overviews the details of investigations on SIs and discusses items forecasted as future works on formulating specifications, i.e., "Work Items" (WIs)*4, namely, key technologies for the physical layer*5, candidate frequencies, and required specifications concerning performance requirements.

2. Elemental Technologies for Physical Layer

2.1 Radio Frame

For NR, radio frame is defined such that Orthogonal Frequency Division Multiplexing (OFDM)*6 with various sub-carrier*7 spacings (namely, at the least, 15, 30, 60, or 120 kHz) are supported. It is well known that narrower sub-carrier spacing is more suitable for wide-area coverage, the low-carrier-frequency band, and severe multipath*8 channel environments; on the other hand, wider sub-carrier spacing is more effective for high-speed movement, the high-carrier-frequency band, and latency reduction. By supporting multiple OFDM sub-carrier spacings in the unified framework of the radio frame, NR can support a wide range of frequencies—namely, from the existing cellular frequency band to the millimeter band—and provide multiple services—ranging from eMBB to URLLC—by a single framework.

In order to realize those features, the NR radio frame is specified as below (**Figure 1**):

- Radio frame is in units of 10 ms (i.e., it does not depend on OFDM sub-carrier spacing used).
- Sub-frames*9 are defined in units of 1 ms (i.e., they do not depend on OFDM sub-carrier spacing used).
- Slots*10 are defined as 14 OFDM symbols*11, and their time interval depends on sub-carrier spacing.

As for OFDM in general, a "Cyclic Prefix" (CP)*12 is attached to each OFDM symbol to assure multipath tolerance. As for NR, it is agreed that the overhead ratio of CPs among OFDM signals with different sub-carrier spacing, is fixed. In other words, in the case that OFDM signals have double the sub-carrier spacing, both OFDM-symbol

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*2 **SI**: Work that involves investigating feasibility and roughly identifying all functions that should be specified.

*3 **Base-station design**: Scenarios in which requirements of each operator (such as traffic) are considered and base stations are designed and developed.

*4 **WI**: Work that involves determining all functions needing specifying and formulating detailed specifications for those functions.

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

*6 **OFDM**: A high-efficiency multi-carrier transmission method that uses orthogonal narrowband sub-carriers. This method has been adopted for LTE because of its high tolerance with multipaths.

*7 **Sub-carrier**: Individual carrier for transmitting signals with multi-carrier transmission such as OFDM.

*8 **Multipath**: A phenomenon that results in a radio signal transmitted by a transmitter reaching the receiver by multiple paths due to propagation phenomenon such as reflection, diffraction, etc.

*9 **Sub-frame**: A unit of radio resources in the time domain consisting of multiple (generally 14) OFDM symbols (see *11).

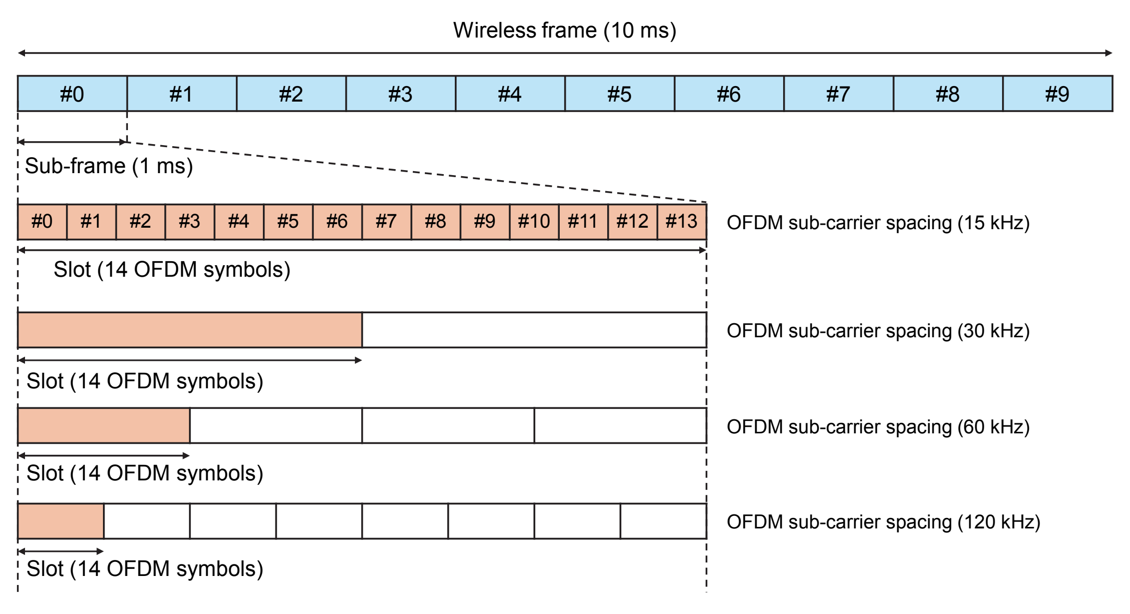

Figure 1 Prescribed configuration of wireless frame (in case of 14 OFDM symbols per slot)

length and CP length are halved.

2.2 Initial Access

As for initial access to an NR cell, the same method as used for general LTE, i.e., detecting synchronization signals*13, acquiring broadcast system information*14, and establishing a connection by random access*15, is used. However, as for the configuration of signals and channels, transmission methods, and so on, NR and LTE are significantly different.

1) NR Synchronization Signals

As in the case of LTE, synchronization signals are composed of two parts, namely, a Primary Synchronization Signal (PSS)*16 and a Secondary Synchronization Signal (SSS)*17. However, in the case of NR, the number of "Physical Cell IDentifiers" (PCIDs)*18 expressed by the synchronous signals is doubled in comparison with that for LTE since a deployment scenario potentially with extremely high density is supposed. In addition, the sequence length of the synchronous signals and the method for generating those sequences are also changed. Since it is preferable that blind detection*19 of OFDM sub-carrier spacing applied for synchronization signals is not required when a mobile terminal makes initial access, a single default OFDM sub-carrier spacing will be defined for each frequency band. In NR, the periodicity and timing of synchronization signals transmission

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*10 **Slot:** A unit for scheduling data consisting of multiple OFDM symbols (see *11).

*11 **Symbol:** A unit of data for transmission. In OFDM, it comprises multiple sub-carriers. Multiple bits (2 bits in the case of Quadrature Phase Shift Keying (QPSK)) map to each sub-carrier.

*12 **CP:** A guard time (also called "guard interval") inserted between symbols in OFDM signals to minimize interference between prior and subsequent symbols caused by multipath effects. Usually, this part of the signal is copied from the part of the latter-half symbols.

*13 **Synchronization signal:** A physical signal enabling the mobile terminal to detect cell frequency, reception timing, and cell ID in order to begin communications, e.g., when a mobile terminal powers up.

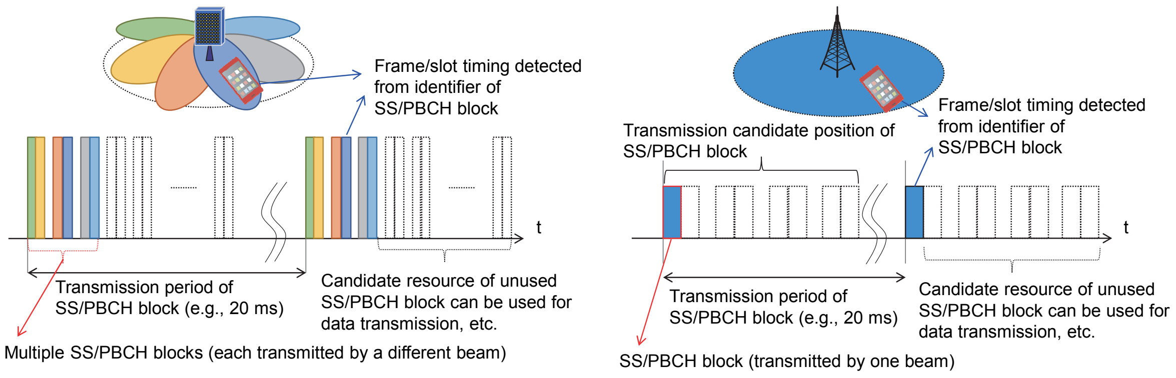
*14 **Broadcast system information:** Essential system information (including cell access information required for executing the procedure for connecting mobile terminals to cells, random-access channel information and so on) to be broadcasted within a cell.

*15 **Random access:** A procedure executed by mobile terminals and base stations for connecting uplink signals and synchronizing their transmission timing.

are configurable by network, and mobile terminals can be notified about them accordingly. Moreover, the default transmission periodicity supposed by a mobile terminal making initial access before the notification is defined as 20 ms, which is longer than the transmission periodicity of synchronization signals in LTE (i.e., 5 ms) so that "always on" signals transmission is reduced as much as possible. Also, to reduce the burden on mobile terminals for NR cell access, a scheme for expanding the frequency raster[20] in comparison with that in LTE and reducing the number of candidate positions is investigated.

2) Beam-sweeping Transmission of Synchronization Signals and Broadcast Channels

In the case of the high-frequency band above 6 GHz, it is considered that beamforming[21] is applied, e.g., to transmission on the base-station side, to assure communication distance between a base station and a mobile terminal and the area covered by the base station. By applying beamforming, on the one hand, it is possible to extend transmission distance (by concentrating transmit signal power in a specified direction); on the other hand, the range of direction in which signals can be received with sufficient signal strength is narrowed due to beamforming. Since Synchronization Signals (SS) and Physical Broadcast CHannel (PBCH)[22] need to reach all mobile terminals within a cell, "beam sweeping" transmission (where a base station transmits signals while switching beam direction sequentially to cover a whole cell area) is supported for multi-beam operation and is applied to transmission of an SS/PBCH block, which is defined as an unit of beam sweeping (i.e., different transmission beams are applied to different SS/PBCH blocks) (**Figure 2** (a)). In addition,



(a) Example of high-frequency-band/multi-beam operation

(b) Example of low-frequency-band/single-beam operation

Figure 2 Notification of SS block index when single or multi-beams are used

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[16] **PSS:** A signal used by mobile terminals for achieving time/frequency synchronization with a received symbol of a downlink signal from a base station. One of three different PSS signals is used by a cell as a part of PCID (see *18).

[17] **SSS:** A signal used by mobile terminals for detecting PCID (see *18) of a base station, and one of 336 signals is used by a cell as a remaining part of PCID.

[18] **PCID:** An identifier for a physical cell. In case of LTE, 504 PCIDs are available and used, but in case of NR, 1008 PCIDs are used.

[19] **Blind detection:** A process performed to identify specific signal or parameter from multiple candidates (e.g., based on hypothesis testing).

[20] **Raster:** A frequency-carrier position used by mobile terminals for finding presence or absence of synchronous signals, e.g., when a mobile terminal powers up.

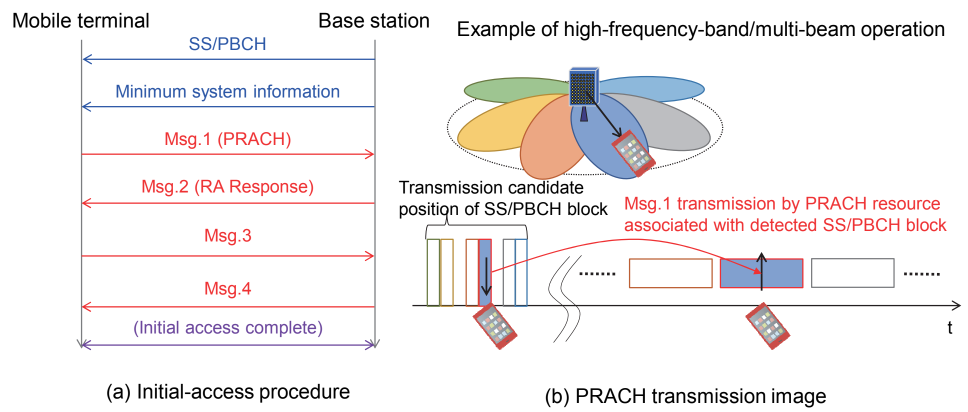
[21] **Beamforming:** Technology for generating a directional pattern for transmission and/or reception by using multiple antennas (by means of controlling amplitude and phase of each of multiple antennas) and increasing or decreasing antenna gain in regard to specific directions.

[22] **PBCH:** A channel for broadcasting essential wireless parameters for receiving control channel and corresponding shared channel (such as system frame number, control channel configuration including sub-carrier spacing and so on).

it is also possible to adopt a configuration in which only one SS/PBCH block is periodically transmitted (i.e., single-beam operation) by a single beam pattern without applying beam sweeping e.g., for the low-frequency band (Fig. 2 (b)). NR will define multiple candidate positions of SS/PBCH blocks within a radio frame and base station can practically transmit SS/PBCH block(s) at one or more candidate position(s) according to the number of beams to be used for transmitting SS/PBCH blocks. However, due to multiple candidate positions of SS/PBCH block within a radio frame, unless a mobile terminal could identify which SS/PBCH block (i.e., position) is actually detected, it is impossible to recognize radio-frame timing and slot timing. Consequently, a mechanism to identify the index of the SS/PBCH block by using the PBCH and reference signal, called "PBCH DeModulation Reference Signal" (PBCH-DMRS), included in the SS/PBCH block is investigated.

3) Random Access after acquisition of Broadcast System Information

After broadcast system information is acquired, mobile terminals use the four-step random access procedure used in LTE (**Figure 3** (a)). For the Physical Random-Access CHannel (PRACH)[*23] transmitted as Msg.1, in addition to some formats using the same sequence length and OFDM sub-carrier spacing as LTE PRACH formats, PRACH formats using wide OFDM sub-carrier spacing and shorter sequence length are introduced mainly for the high-frequency band. In the case that transmission beamforming is applied to the SS/PBCH block to extend the cell coverage, it is necessary to apply



(a) Initial-access procedure

(b) PRACH transmission image

Figure 3 Initial-access procedure and image of PRACH transmission

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[*23] PRACH: A physical channel used by mobile terminals as an initial transmitted signal in the random-access procedure.

equivalent reception beamforming at base station for receiving the PRACH preamble from the mobile terminal. Consequently, the mobile terminal transmits the PRACH preamble on the resource which is associated with the detected SS/PBCH block so that base station can apply appropriate reception beamforming for receiving PRACH preamble on the resource (Fig. 3 (b)).

4) Cell and Beam-quality Measurements

To measure a reception quality in a cell for, e.g., handover, the reference signals included in the SS/PBCH block (i.e., SSS and PBCH-DMRS) are used. In the case of multi-beam operation applying transmission beamforming for SS/PBCH blocks, mobile terminals can be configured to measure and report the reception quality of each SS/PBCH block as the quality of each base-station beam. It is also possible to configure Channel State Information - Reference Signal (CSI-RS)*24 resources for the measurement so that more flexible measurement, e.g., on each base station and/or each beam, can be performed and reported.

2.3 Multi-antenna Technology

As for NR, the transmission and reception of signals from multiple antennas in the uplink and downlink can be performed by using 3D beam control. Particularly in the case of the high-frequency band, it is vital to create high beam gain with multiple antennas in order to compensate influence of radio attenuation. For example, as for the 30-GHz band, base stations and mobile terminals are equipped with maximums of 256 and 32 antenna elements, respectively. Here, the antenna elements are divided into several groups and digital signal processing is performed with a control unit called "antenna ports."

1) Examples of Equipped Multi-antenna Circuitry and Equipment

Examples of multi-antenna circuitry are shown in **Figure 4**. Digital beamforming is usually applied for the low-frequency band, and multi-antenna technology of LTE is prescribed on the basis of this example. In this example, a transmission-and-reception beam is formed by varying phase and amplitude of a digital signal. In the meantime, as for systems for transmitting broadband signals in the high-frequency band, it is becoming more difficult to achieve beamforming in the digital domain due to influences such as implementation cost. As a result, phase and amplitude of analog signals are varied, and configurations based on analog beamforming and hybrid beamforming are generally applied. As for beamforming in the analog domain, beams cannot be controlled in units of "sub-bands*25" under certain device configurations of analog circuitry; accordingly, beamforming is generally achieved by wideband beam control.

2) Beam Control Regarding Layers 1 and 2

Beam control regarding Layer 1*26 and Layer 2*27 is broadly classified as beam management and Channel-State Information (CSI)*28 acquisition. Beam management is particularly effective at high frequencies, and under the aim of acquiring and maintaining beam pairs for base station and mobile terminals at Layer-1 and Layer-2 levels, it is

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*24 **CSI-RS**: A downlink reference signal used by mobile terminals to measure the state of the radio channel.

*25 **Sub-band**: A partial band composed of a part of a system bandwidth.

*26 **Layer 1**: The first layer (physical layer) in the OSI reference model.

*27 **Layer 2**: The second layer (data link layer) in the OSI reference model.

*28 **CSI**: Information describing the state of the radio channel traversed by the received signal.

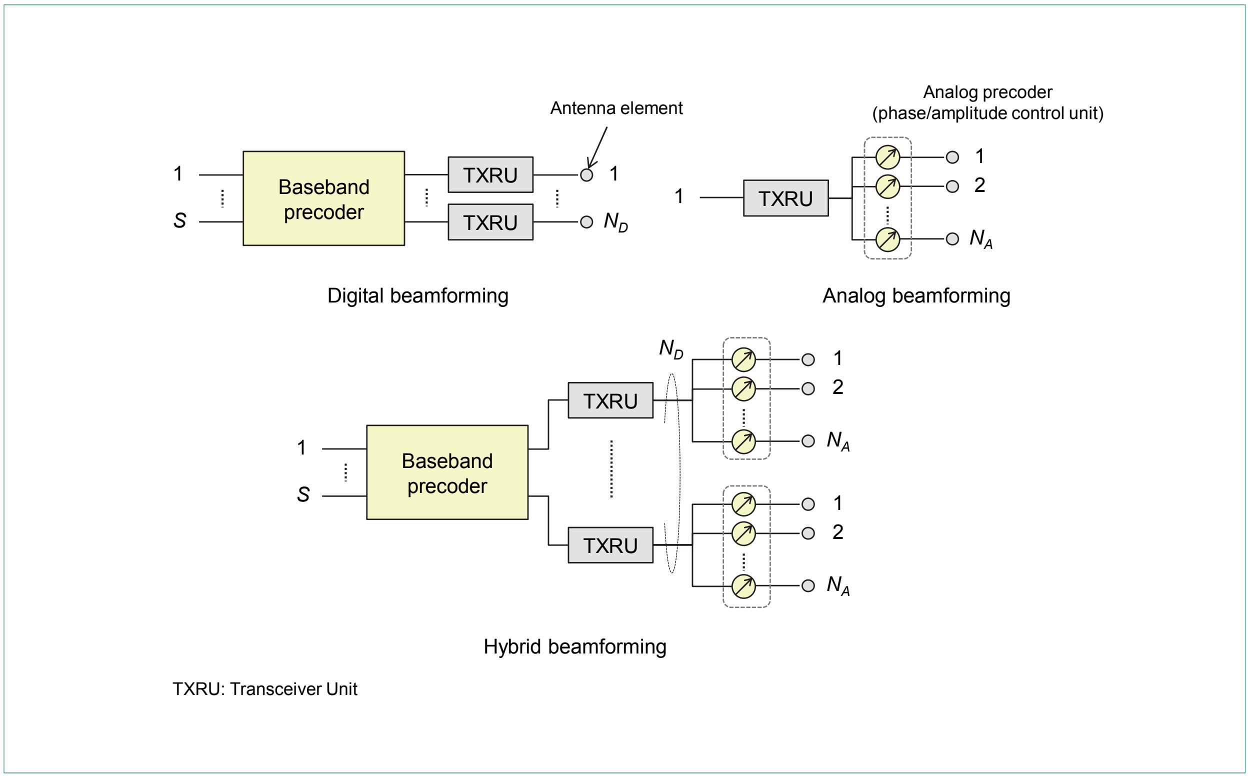

Figure 4 Implementation examples of multi-antenna circuitry for achieving beamforming

supposed that beam post-processing is performed in a longer cycle than that of CSI acquisition on the basis of Reference-Signal Received Power (RSRP)*29. In addition, a technology called "beam failure recovery," which detects mismatching of beam pairs on the terminal side and sending to the base station a request to switch to another beam pair, is supported. Furthermore, CSI acquisition is used for determining the precoder and Modulation and Coding Scheme (MCS)*30 in order to form sharper beams and higher data rate, and it is supposed that the beam is controlled in a relatively short cycle. It is agreed that CSI-RS at least (namely, a downlink reference signal) and a Sounding RS (SRS)*31 (namely, an uplink reference signal) will be used for the techniques described above, and it is planned to formulate technical specifications by applying a simple framework.

3) Data Transmission

As for data transmission, beam control and spatial multiplexing are possible by using the propagation-path information acquired by the above-described techniques. As for NR, it is agreed that single-user Multiple-Input Multiple Output (MIMO)*32 and multi-user MIMO*33 will be supported; in particular, for the downlink, single-user MIMO with a

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*29 **RSRP**: Received power of a signal measured at a receiver. RSRP is used as an indicator of receiver sensitivity of a mobile terminal.

*30 **MCS**: A predetermined combination of data modulation and channel coding rate when performing Adaptive Modulation and Coding (AMC).

*31 **SRS**: Uplink reference signal for measuring uplink channel quality and reception timing, etc. at a base station.

*32 **Single-user MIMO**: Technology that uses MIMO transmission at identical temporal frequencies for a single user.

*33 **Multi-user MIMO**: Technology that uses MIMO transmission at identical temporal frequencies for multiple users.

maximum of eight streams and multi-user MIMO with a twelve streams will be supported, and for the uplink, single-user MIMO with at least four streams will be supported.

2.4 Channel-coding Technology

As for LTE, Tail-Biting Convolutional Coding (TBCC)*34 and turbo coding*35 are applied as error-correction coding. As for NR, in addition to those coding methods, Low-Density Parity-Check (LDPC) coding and polar coding have been investigated. While LDPC coding can shorten delay in decoding processing by using parallel processing, and polar coding can reduce decoding-calculation load in comparison to that in the case of TBCC, together they exhibit an outstanding property in terms of being asymptotic in relation to the Shannon limit*36. Accordingly, LDPC coding was applied to data channels, and polar coding was applied to control channels.

3. High-frequency-band Utilization

As for SIs regarding NR, usage of frequency bands, specification of wireless characteristics for each frequency band, and test methods have been investigated as part of investigations related to frequency.

3.1 Frequency Band Used for NR

As one step towards achieving eMBB (namely, one use case of 5G), in regard to NR, technologies that utilize more-continuous frequencies than those used for LTE for broadband communication have been investigated. Although the first SIs started with investigations targeting frequencies up to 100 GHz, in consideration of the necessity of promptly formulating specifications, candidate frequencies in each region were investigated. The results of that investigation revealed that, as shown in **Figure 5**, in the millimeter range, frequencies from around 30 to around 40 GHz are expected to be mainly utilized.

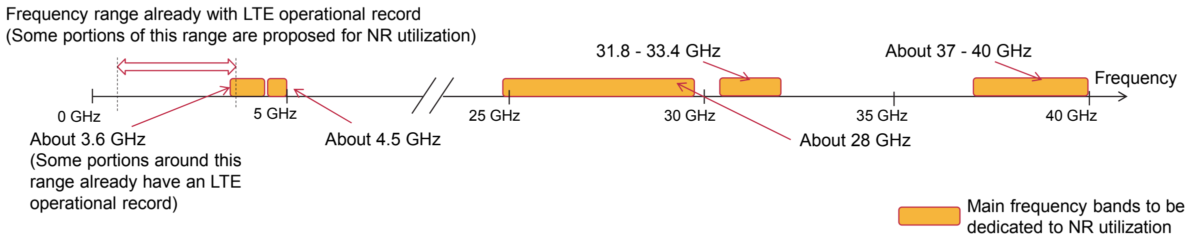

Figure 5 Candidate frequencies expected to be mainly utilized for NR in each region

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*34 **TBCC:** A type of error-correcting code; namely, a coding scheme that generates codewords by using convolution calculation. TBCC has already been practically applied in 3G mobile-communications systems.

*35 **Turbo coding:** A type of error-correcting code proposed by Berrou et al. in 1993. Together with Low-Density Parity-Check (LDPC) code, it is known to produce characteristics that are closest to the Shannon limit (see *36), and it has already been implemented in systems (including 3G mobile communications).

*36 **Shannon limit (also known as "Shannon communication-channel capacity"):** Theoretically derived from bandwidth and Signal-to-Noise (SN) ratio, the maximum amount of information that can be transmitted.

The frequencies that have been conventionally specified for LTE range up to a maximum of about 6 GHz. Radio-characteristics specifications in regard to the millimeter band (including frequencies from 30 to 40 GHz) have not been investigated by the 3GPP. In addition, since utilization success in regard to the mobile telephony in the millimeter band has not been reported, it is necessary to newly investigate such utilization from the viewpoint of manufacturing technology. Accordingly, from that viewpoint, investigations focused on the millimeter band in particular have been performed.

3.2 Radio-characteristics Specification

As a matter that should be considered when investigating specifications for the millimeter band, the viewpoint under which specifications presuppose transmission and reception by beamforming, utilization of the frequencies continuing over a width of several hundred megahertz, and necessity of specification based on measurement by Over-The-Air technology (OTA)*37 (described in Section 3.3) is cited.

1) Coexistence Investigations Presupposing Transmission and Reception by Beamforming

In the 3GPP, in the case that Adjacent Channel Leakage Ratio (ACLR)*38 (i.e., a basic parameter concerning wireless characteristics) and Adjacent Channel Selectivity (ACS)*39 are discussed, interference effects between mobile terminals or wireless base-station equipment using adjacent frequencies are investigated by simulation (namely, "coexistence investigations") with the consideration of requirements in terms of system performance.

Although similar coexistence investigations are performed in regard to the millimeter band, in the case a frequency channel used by the current cell is beamformed, the influence on adjacent frequencies is a key point to be considered. In concrete terms, it is necessary to consider points such as base-station expansion supposing the millimeter band depends greatly on beamforming gain, and the extent of the interference effect between adjacent frequencies depends on beamforming gain at the above-mentioned frequencies and surrounding frequencies. In consideration of such points, investigations on base-station expansion supposing the millimeter band and evaluations of mobile terminals wireless equipment that presuppose transmission and reception by beamforming have begun in the 3GPP. Moreover, when those evaluations are performed, new radiowave-propagation characteristic models corresponding to the millimeter band are used. On top of that, in regard to setting required values for definitive ACLR/ACS, in addition to evaluation results of the coexistence investigations from the above-mentioned viewpoint of system performance, implementation verification from the viewpoint of fabrication technology was considered, when initial results of investigations as SIs were summarized. Moreover, basic parameters concerning wireless characteristics such as transmission power, spectrum mask*40, and spurious emission*41 were investigated, and the results of those investigations were reported, alongside those on ACLR/ACS, at the International Telecommunication

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*37 OTA: A method for setting specified points and measurement points in a radiowave-propagation space, specifying wireless performance (including antenna emission and reception characteristics), and measuring those parameters.

*38 ACLR: In modulated signal transmission, the ratio between the transmitted signal band power and undesired power generated in the adjacent channels.

*39 ACS: The ability to correctly select and receive (i.e., filtering) the desired wave even under the condition that signal-power ratios of the desired wave and an interfering wave adjacent to the desired wave are prescribed.

*40 Spectrum mask: An unwanted wave (excluding spurious emission*41) emitted in the frequency range adjacent to the primary signal when that signal is transmitted.

*41 Spurious emission: An unwanted wave emitted at a wavelength outside the channel bandwidth of the main signal when that signal is transmitted.

Union - Radio Communication Sector (ITU-R).

2) Feasibility from the Viewpoint of Implementing Equipment for Broadband Transmission

Aiming to make it possible to utilize a continuous frequency band spanning a width of several hundred megahertz, in addition to discussions on conditions required from the viewpoint of system performance, investigations considering implementation of equipment from the aspects of BaseBand (BB)*42 components and Radio-Frequency (RF)*43 components of base station and mobile terminals were performed. For example, from the viewpoint of implementation of the BB, in the case that a certain OFDM sub-carrier spacing is used, as the frequency bandwidth used for communication gets wider, information-bit number theoretically usable for transmission and reception by one slot increases in proportion to channel bandwidth; even so, it is necessary to implement Fast Fourier Transform (FFT) functional units*44 with even higher processing power. Moreover, from the viewpoint of RF, as the frequency band used gets higher, the effect of phase noise*45 gets more prominent, and communication using a multi-value modulation scheme and a multiple number of streams becomes difficult. As for solving that problem, it is necessary to implement high-accuracy RF devices with, for example, Phase-Locked-Loop (PLL)*46 circuits, and it is also necessary to apply even bigger OFDM sub-carrier spacing. In either case, it is necessary to consider costs and feasibility.

Conclusions drawn from the results of investigation on SIs concerning maximum channel bandwidth, OFDM sub-carrier spacing, and FFT processing capacity are listed in **Table 1**. As for WIs, on the basis of demands such as each specified band, it is planned to discuss optimum maximum channel bandwidth and size of OFDM sub-carrier spacing.

3.3 Specification Presupposing OTA and Related Issues

1) Necessity of Specifications Presupposing OTA

As for wireless-characteristics specifications for LTE, except in the case of some specifications*, as shown in **Figure 6**, physical connectors of the

Table 1 Conclusions of SIs about maximum channel bandwidth, sub-carrier spacing, and FFT size

	LTE	NR	
		Less than 6 GHz	Greater than 6 GHz
Maximum channel bandwidth	20 MHz*1	100 – 200 MHz*2	100 MHz – 1 GHz*2
Sub-carrier spacing	15 kHz	15 kHz, 30 kHz, 60 kHz	60 kHz, 120 kHz, 240 kHz, (480 kHz)
FFT size	2,048	4,096, (8,192)	

*1 In the case Carrier Aggregation is used, radio characteristics up to 100 MHz have been specified.

*2 Whether accomplished by 1 CC (carrier component) is undetermined.

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*42 **BB:** The circuits or functional blocks that perform digital signal processing.

*43 **RF:** The radio frequency circuit.

*44 **FFT functional unit:** A functional unit for executing a fast FFT (or an Inverse FFT (IFFT)) required by the transmission and receival process.

*45 **Phase noise:** Random phase modulation due to a noise source modulating a transmitter.

*46 **PLL:** A circuit that synchronizes the output signal frequency with a standard frequency.

* In the case of LTE as well as NR, Release15 WI—called "enhancements of Base Station RF and EMC requirements for Active Antenna System" (eAAS)—has been prescribed as a specification based on OTA; however, target frequency band is below 6 GHz, and from the viewpoint that a specification stipulating wired connection is also possible, investigations on SIs regarding NR differ from those regarding LTE.

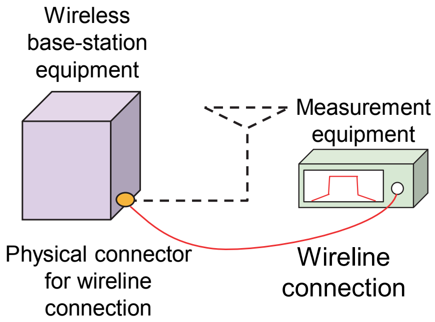

Figure 6 Example of wireline-connection specification based on physical connector

antennas of mobile terminals and wireless base stations are used as reference points for specifying and measuring requirements (wired-connection provision). On the contrary, in the case of a high-frequency band like that of millimeter waves, power attenuation within circuits becomes significant; consequently, devices such as amplifiers, filters, and antennas become more integrated (for achieving low loss), and physical connectors themselves cannot be installed. Furthermore, in the case that use of multiple amplifiers and antennas (such as massive MIMO*47) is supposed, even when frequencies below the 6-GHz band are used, measuring each physical connector is a point of demerit from the viewpoint of man-hours spent for testing. In consideration of those circumstances, as for SIs, the necessity and importance of OTA specifications for executing prescription and measurement under wireless-characteristics specifications for a certain propagation space were discussed. As a result of those discussions, as specifications to be discussed as future WIs, on the one hand, as for frequencies under 6 GHz, specifications presupposing wireline connection or OTA were targeted; on the other hand, as for millimeter waves, only specifications presupposing OTA were targeted.

2) Challenges Concerning Specification Presupposing OTA

In the case that tests using OTA are performed, in general, the scale of test facilities increases, and while time is required for measuring radio characteristics at spatial axis in addition to conventional frequency axis, inaccuracy of the measurements tends to become worse in comparison to that of wireline tests. As for formulating specifications, from the viewpoint of running tests and their costs, it is therefore extremely important to formulate specifications properly in consideration of spatial characteristics (since directional characteristics of power radiated from mobile terminals and wireless

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*47 **Massive MIMO:** MIMO systems transmit radio signals overlapping in space by using multiple antenna elements for transmission and reception. Massive MIMO systems aim to achieve high-speed data communications with greater numbers of simultaneous streaming transmissions while securing service areas. They achieve that aim by using antenna elements consisting of super multi-element arrays to create sharply formed radio beams to compensate for the radio propagation losses that accompany high-frequency band usage.

base-station equipment are generally not uniform). For example, at a certain measurement frequency, spurious emission is defined in terms of the sum of all energies emitted in a certain space. When spurious emission is measured, the space is divided up into several regions, and spatial measurements are performed for each region. In that case, if the divided regions are made smaller (or the number of divisions is increased), in general, measurement accuracy improves. However, that means that the number of points in space that must be measured increases, and it becomes a risk that all the points cannot be measured in a reasonable time. Accordingly, during the discussions on future WIs, it is important to formulate each wireless specification in consideration of the trade-off between measurement time and accuracy described above.

4. Conclusion

In this article, the contents of technical investigations (completed in March 2017) by 3GPP RAN on SIs were explained. In the phase of 5G WIs, key technologies and candidate frequencies studied as SIs, as well as wireless-performance requirement specifications and their effects, are being continually investigated. From now onwards, it is expected that the results of those investigations will be implemented as commercial products. NTT DOCOMO will push ahead with investigations on essential key technologies for implementing commercial 5G products.