Technology Reports | 5G | NR | Radio Performance/Management Specifications

Special Articles on Release 15 Standardization
—Advancements in the Completed Initial 5G and LTE/LTE-Advanced Specifications—

5G Radio Performance and Radio Resource Management Specifications

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3GPP has made specifications for a new radio technology called NR, which satisfies the requirements for a 5G RAN. In addition to the frequency bands below 6 GHz already used by LTE/LTE-Advanced, NR is able to use sub-millimeter and millimeter wave frequencies, realizing high throughput with wideband communication. This article discusses frequency trends for 5G and describes specifications for base station and terminal RF performance and radio resource management.

1. Introduction

The 3rd Generation Partnership Project (3GPP) has studied a New Radio (NR) communication technology satisfying the requirements for a 5G Radio Access Network (RAN)*1 [1], and has made specifications for it as the Release 15 specifications. The RAN Working Group 4 (RAN4), which has responsibility for making specifications for base station and terminal Radio Frequency (RF)*2 performance and radio resource management, established the new specifications not only for the frequency bands below 6 GHz already used by LTE/LTE-Advanced but also for sub-millimeter*3 and millimeter*4 wave frequency bands, which have not been used for commercial cellular systems previously.

Specifically, RAN4 defined new frequency bands with consideration for the frequency allocation plans

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*1 RAN: The network consisting of radio base stations and radio-circuit control equipment situated between the core network and mobile terminals.

*2 RF: Referring to the radio frequency analog circuit.

*3 Sub-millimeter wave: Radio signals of frequencies in the millimeter wave range, from approximately 10 to 30 GHz.

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

for 5G in various countries, and specified base station and terminal RF performance specifications for each frequency band. Radio Resource Management specifications, such as the specifications for terminals to measure the cell quality in the current cell and neighboring cells, were also specified mainly to ensure mobility performance of terminals.

This article describes these new frequency bands and specifications for RF performance and radio resource management.

2. New Frequency Bands for NR

In Japan, the new frequencies being considered for initial 5G deployment are the 3.7 GHz band (3.6-4.2 GHz), the 4.5 GHz band (4.4-4.9 GHz), and the 28 GHz band (27.0-29.5 GHz) [2]. As shown in **Figure 1**, parts of these ranges overlap with 5G frequency bands being considered in other countries. RF modules are manufactured and incorporated in terminals by frequency band (or groups of adjacent frequency bands), so terminal manufacturing costs can be reduced by harmonizing frequencies—defining bands that include the bands several countries—so that terminals for different countries can share RF modules. However, as the bandwidth of an RF module is increased, the fractional bandwidth (bandwidth divided by center frequency*5) increases and it becomes necessary to adjust power (impedance matching) over a wide frequency range, generally making it more difficult to design. As such, bands must be defined considering both their effect in harmonizing frequencies and feasibility of RF devices. The frequency bands defined and specified in Release 15 are described below.

Note that in the NR frequency band specifications, band names are prefixed with an "n" to distinguish them from existing LTE bands. The

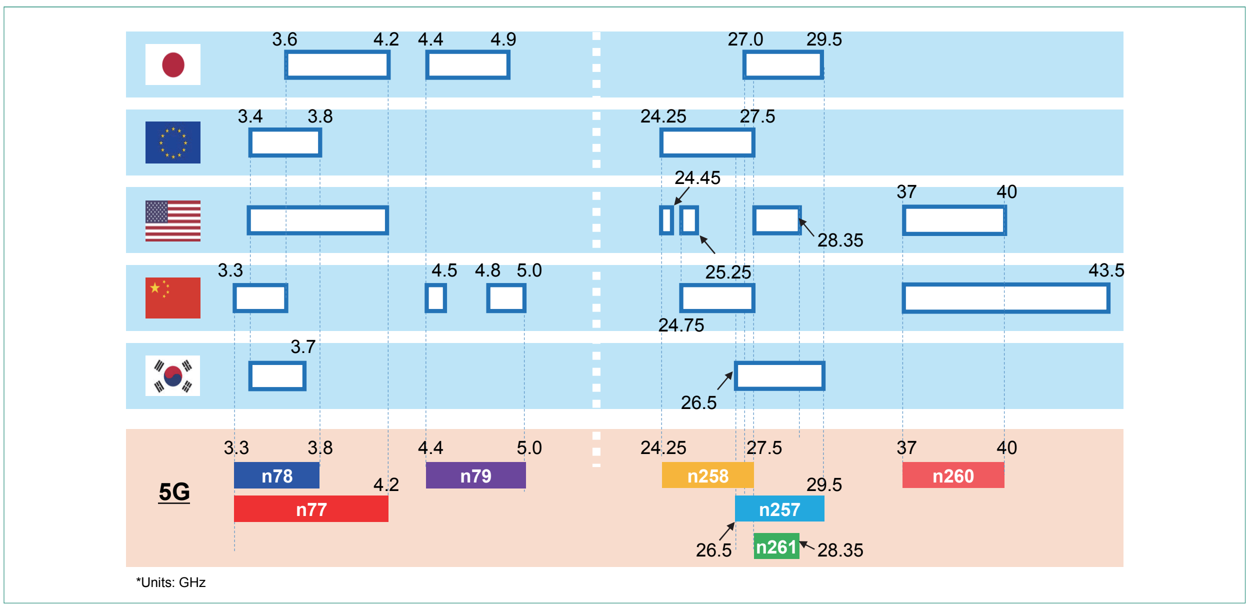

Figure 1 5G candidate frequencies in Japan and other countries

*5 Center frequency: The frequency within a frequency band at the center of the range used for communication.

frequency bands are also grouped into two ranges in Release 15, as follows.

- Frequency Range 1 (FR1): 450 to 6,000 MHz
- Frequency Range 2 (FR2): 24,250 to 52,600 MHz

2.1 3.7 GHz Bands (Bands n77 and n78)

It would be desirable to define a range from 3.3 to 4.2 GHz, to harmonize the bands used in Europe, the USA, China, and South Korea. However, this range has a fractional bandwidth 4.2 times that of Band 42 (3.4 to3.6 GHz) in the 3.5 GHz band, which was introduced with LTE/LTE-Advanced. This raises issues, particularly regarding power amplifier efficiency. As a result, two bands were defined: n77 (3.3 to 4.2 GHz), which will harmonize frequencies including Japan, and n78 (3.3 to 3.8 GHz), which is a narrower band encompassing frequencies used in Europe, the USA, China, and South Korea.

2.2 4.5 GHz Band (Band n79)

In November 2017, China indicated plans to use the 4.8 to 5.0 GHz band for 5G and that they are studying use of the 4.4 to 4.5 GHz band. The 4.4 to 4.9 GHz band is also a candidate in Japan, so Band n79 (4.4 to 5.0 GHz) was defined to include these ranges and harmonize with China.

2.3 28 GHz Band (Bands n257, n258, and n261)

The 27.0 to 29.5 GHz band is a candidate in Japan, so it is desirable to harmonize this band with the USA and South Korea. RF devices supporting a wide bandwidth of 5.25 GHz would be required to include this range of 5G candidate frequencies from all regions (24.25 to 29.5 GHz), hence for practical considerations, two bands were defined: band n257 (26.5 to 29.5 GHz) for Japan, North America (USA, Canada, etc.), and South Korea, and n258 (24.25 to 27.5 GHz) for Europe and China. The narrower n261 band (27.5 to 28.35 GHz) was also defined for operators in North America because the RF modules needed to support both the 28 GHz (n257) and 39 GHz (n260) bands at the same time, while maintaining RF performance, could be larger than desired.

2.4 Other Frequency Bands

The USA and China are also considering the 39 GHz band (n260: 37 to 40 GHz), as shown in Fig. 1. Note that besides the above, frequency bands used by existing LTE systems can also be used with NR. These are called LTE-refarming bands and for Japan, the 700 MHz (n28), 800 MHz (n5), 900 MHz (n8), 1.5 GHz (n74), 1.7 GHz (n3), 2 GHz (n1), and 2.5 GHz (n41) bands have been specified. See references [3] and [4] regarding other bands regulated in Release 15.

3. NR Radio Parameters

As mentioned above, NR is capable of using a wide range of frequencies from existing LTE bands to sub-millimeter and millimeter-wave frequencies. However, radio characteristics significantly vary depending on frequency range and band, so it is desirable to be able to configure radio parameters, such as subcarrier*6 spacing, channel bandwidth, and effective communication bandwidth in Orthogonal Frequency Division Multiplexing (OFDM)*7, according to the configured frequency band.

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

*7 OFDM: A digital modulation system developed to improve resistance to multi-path interference. It converts a signal with a high data rate to multiple low-speed narrow-band signals and transmits those signals in parallel along the frequency axis. OFDM enables signal transmission with high spectral efficiency.

3.1 Subcarrier Spacing

In FR1, the subcarrier spacings that can be used for data signals are 15, 30, and 60 kHz. In FR2, they are 60 and 120 kHz. All terminals must support all of these except 60 kHz in FR1. In NR, the Cyclic Prefix (CP)*8 insertion ratio (the CP length relative to the OFDM symbol*9 length) is the same for all available subcarrier spacings. As such, as the subcarrier spacing increases, the absolute CP length decreases and resistance to multi-path signal delay decreases. This can result in reduced coverage for each base station. On the other hand, use of wider subcarriers can increase resistance to frequency shift, e.g., due to Doppler shift*10. FR2 is also quite susceptible to phase noise*11 due to oscillator error*12 in terminals and base stations, but there are components that can generally be mitigated by setting a wider subcarrier spacing.

Subcarrier spacing is configured by the network using higher layer*13 signals. The optimal subcarrier spacing can be applied according to the deployment scenario and considering the trade-offs described above.

3.2 Channel Bandwidth

1) Channel Bandwidth in LTE

In LTE (Release 8), channel bandwidth can be set in the range of 1.4 to 20 MHz. In LTE-Advanced (Release 10), Carrier Aggregation (CA)*14 technology was introduced, realizing wide bandwidths up to 100 MHz by using up to five LTE carriers, called Component Carriers (CC)*15 at the same time [5]. In Release 13, the number of CCs that can be used with CA was expanded to a maximum of 32, for a maximum bandwidth of 640 MHz [6].

2) Channel Bandwidth in NR

CA is also supported in NR, and Release 15 supports intra-band contiguous and non-contiguous CA, inter-band CA, and combinations of these (**Figure 2**). It also supports Dual Connectivity (DC)*16, communicating on both NR carriers (including CA) and LTE carriers simultaneously.

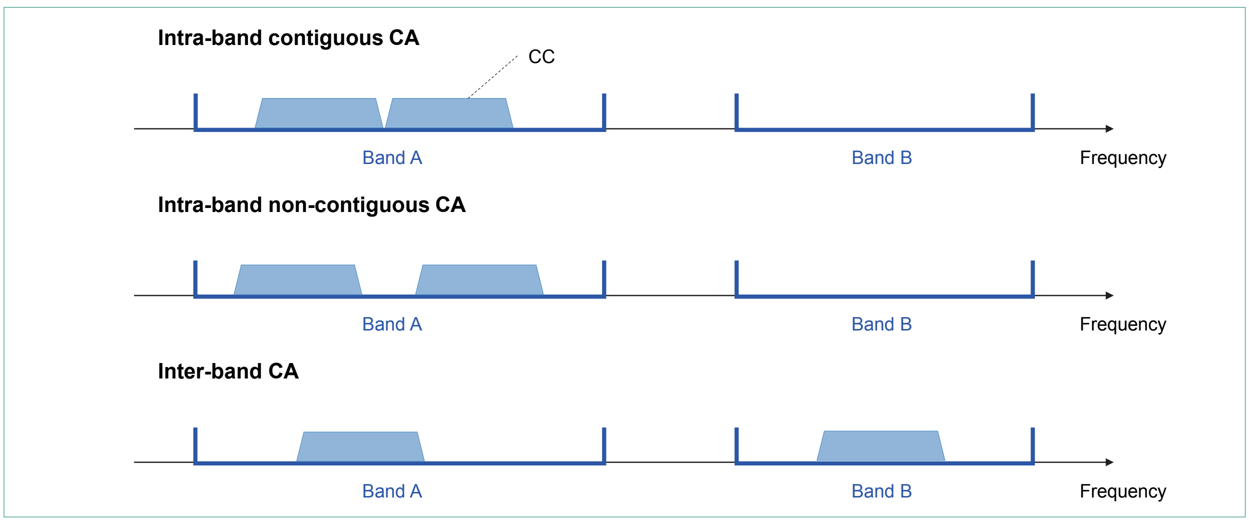

Figure 2　CA supported in Release 15

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

*9　**OFDM symbol**: The unit data of transmission, consisting of multiple subcarriers for OFDM. A CP is inserted at the front of each symbol.

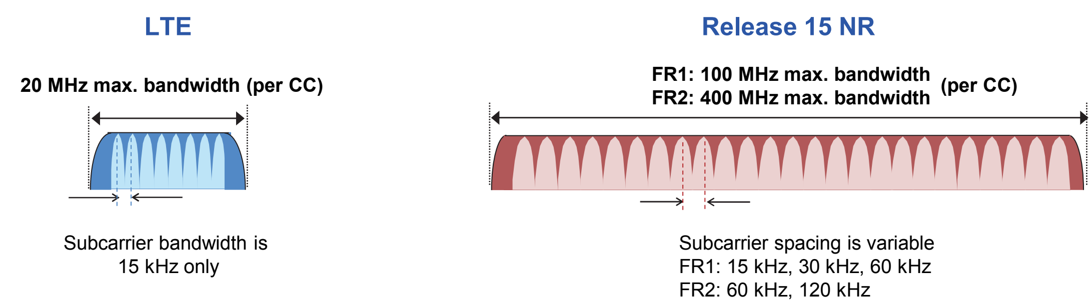
*10　**Doppler shift**: Shift in carrier-wave frequency due to the Doppler effect.

*11　**Phase noise**: Any fluctuation in phase that is not needed for communication, originating in the RF devices due to oscillator error and other causes. Can result in interference between subcarriers or common phase error, degrading the quality of communication.

CA is an important technology for realizing wideband communication, but as mentioned above, NR defines frequency bands that are much wider than LTE. With an LTE-equivalent channel bandwidth of 20 MHz (per CC), a huge number of CCs would be needed for CA. This has led to concern for the complexity of controlling the CCs, and resulting increased terminal manufacturing costs, and increasing control-signal overhead. For NR, the channel bandwidth per CC is increased to a maximum of 100 MHz in FR1 (when a subcarrier spacing of 30 or 60 kHz is used), and 400 MHz in FR2 (when a subcarrier spacing of 120 kHz is used). Note that supporting 400 MHz in FR2 is an optional feature, and terminals are only required to support up to 200 MHz. Specific channel bandwidths that can be configured in each frequency band are shown in **Figure 3**.

3.3 Effective Bandwidth During Communication

With LTE, only the central 90% of the channel bandwidth is used for data communication, to protect adjoining frequencies. For example, a channel



Frequency range	Frequency band		Subcarrier spacing (kHz)	CC width (MHz)*1														
	Band no.	Frequency band		5	10	15	20	25	30	40	50	60	70	80	90*2	100	200	400*2
FR1	n77/n78	3.7 GHz band	15		O	O	O			O	O						–	–
			30		O	O	O			O	O	O		O	O	O	–	–
			60		O	O	O			O	O	O		O	O	O	–	–
	n79	4.5 GHz band	15							O	O						–	–
			30							O	O	O		O		O	–	–
			60							O	O	O		O		O	–	–
FR2	n257	28 GHz band	60	–	–	–	–	–	–	–	O	–	–	–	–	O	O	
			120	–	–	–	–	–	–	–	O	–	–	–	–	O	O	O

*1 "O" indicates configurable.
*2 Optional function

Figure 3 NR channel bandwidths

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*12 **Oscillator error:** The difference in frequencies produced by oscillators on the base station and the terminal. An oscillator is an RF device that produces a particular frequency and is used to convert the baseband signal to be transmitted to a signal in the carrier frequency band, or vice versa.

*13 **Higher layer:** Refers to any layer positioned above the physical layer, namely, layers such as Medium Access Layer (MAC), Radio Link Control (RLC), Packet Data Convergence Protocol (PDCP), and Application Protocols (e.g.: S1AP, X2AP, etc.).

*14 **CA:** A technology for increasing bandwidth and data rate by simultaneously transmitting and receiving signals for one user using multiple carriers.

*15 **CC:** Term denoting each of the carriers used in CA.

*16 **DC:** A technology that achieves wider bandwidths by connecting two base stations in a master/slave relationship and performing transmission and reception using multiple CCs supported by those base stations.

with 20 MHz bandwidth would have an effective bandwidth of 18 MHz, excluding the 1 MHz guard bands*17 at each end. The guard bands at each end are inserted to reduce interference on other frequencies, but NR also applies preprocessing to normal OFDM signals, as shown in **Figure 4**, to reduce interference on other frequencies (such as in [7]). Accordingly, ways to increase the effective bandwidth have also been studied. As a result, except for some of the narrower bandwidths (e.g.: 5, 10 MHz), greater than 90% of the bandwidth can be used for communication (up to 98%, depending on the channel bandwidth), further increasing spectrum efficiency*18. Note that the width of the guard bands has been reduced, but this assumes the preprocessing to reduce interference as mentioned above, and values specified regarding interference on neighboring frequencies (leakage power, etc.) remain the same as for LTE.

4. Base Station and Terminal RF Performance Specifications

RF configurations and RF performance specifications for base stations and terminals specified for NR by frequency band are described below.

4.1 Base Stations

1) Base Station RF Configurations

The configurations specified for NR base station equipment are shown in **Table 1**. These include configurations specified earlier for LTE, which are BS type 1-C, having the base station and antennas connected by coaxial cable*19, and BS type 1-H, having an integrated Active Antenna System (AAS)*20 with radio transceivers connected to antennas using a Transceiver Array Boundary (TAB) connector*21. In addition to these, a new configuration called BS type 1-O/2-O is defined with a connector-less AAS

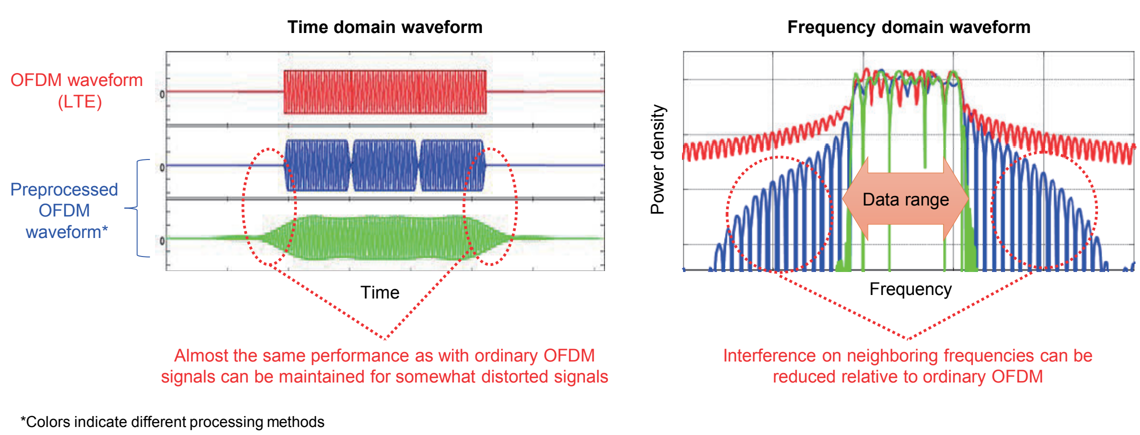


Figure 4 OFDM signal preprocessing

*17 **Guard band:** A frequency band set between the bands allocated to different wireless systems to prevent interference between the RF signals of those systems.

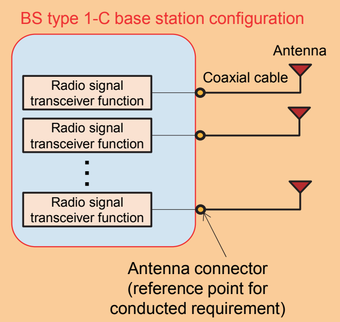
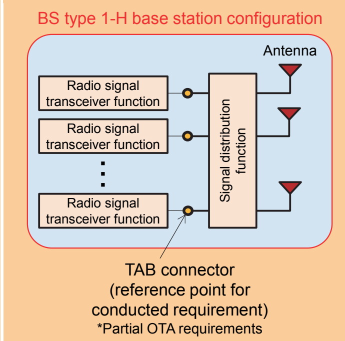
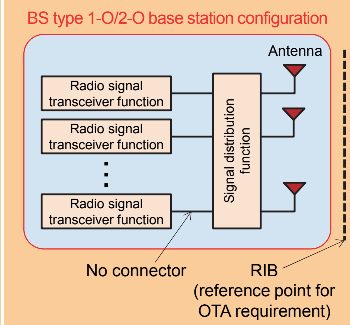
*18 **Spectrum efficiency:** The number of data bits that can be transmitted per unit time per unit frequency.

*19 **Coaxial cable:** A type of cable with an outer shielding layer, used mainly for transmitting high frequency signals. Used to transmit signals between antennas and the base station.

*20 **AAS:** A system that integrates antenna elements and RF circuits that have traditionally been separated thereby providing a more efficient system.

*21 **TAB connector:** Used in BS type 1-H NR base stations and a reference point used for radio characteristics.

Table 1 Base station configurations specified for NR

BS type	BS type 1-C (equivalent to earlier base stations)	BS type 1-H (equivalent to AAS in LTE-Advanced Release 13)	BS type 1-O/2-O (newly introduced AAS from NR)
Frequency range	FR1	FR1	FR1/FR2
Base station configuration			

for each frequency range [8].

(a) FR1 RF configuration

One of the RF configurations for FR1 does not require connectors between radio signal transceivers and antennas according to BS type 1-O specifications, so smaller equipment size and improved power efficiency can be expected, compared with AAS in LTE Advanced Release 13 [9].

(b) FR2 RF configuration

FR2 has the advantages of wideband communication in high-frequency bands, but in terms of RF configuration, the shorter wavelengths result in higher power losses in connectors and cables; and higher radio propagation losses and reduced coverage due to lower power density over the wider frequency band. High antenna gain[*22] is necessary to maintain coverage, but it will be difficult to implement the radio signal transceivers and antennas with high density in a limited space for FR2 if conventional RF configurations with connectors are used. For this reason, only the BS type 2-O RF configuration with no connectors is defined. With the specification for BS type 2-O, it should be possible to implement beam forming[*23] over a wide band and maintain coverage while achieving high-speed communication.

2) Base Station RF Performance Requirements

The RF performance specifications for BS type 1-C/1-H are based on the LTE-Advanced specifications, applied to the NR radio parameters described above. However, BS type 1-O/2-O have integrated radio signal transceiver and antennas and there are no connectors to take measurements, so Over-The-Air (OTA)[*24] specifications have been extended so that in the overall RF performance specifications, a reference position in the radiated space (the Radiated Interface Boundary (RIB)[*25]) can be defined.

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*22 Antenna gain: Radiated power in the direction of maximum radiation usually expressed as the ratio of radiated power to that of an isotropic antenna.

*23 Beam forming: A technology that gives a 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.

*24 OTA: A method for measuring radio characteristics transmitted or received from a base station or terminal, by positioning it opposite to a measurement antenna. Configurations have been defined for NR base stations and terminals that have no antenna connectors, so this method has been established for regulating such devices.

(a) New TRP specifications in OTA requirements

In addition to the Equivalent Isotropic Radiated Power (EIRP)*26 and Equivalent Isotropic Sensitivity (EIS)*27 [8] including the antenna characteristics in the beam direction, which are defined in LTE-Advanced Release 13, the Total Radiated Power (TRP) is introduced as a new metric definition. Defining TRP makes it possible to specify OTA requirements for power related requirements, including base station output power, spurious emissions*28 and so on. The definitions for EIRP, EIS and TRP used in the OTA requirements are illustrated in **Figure 5**.

(b) Features of FR2 RF performance specifications

A comparison of the main base station RF performance specifications is given in **Table 2**. The RF performance specifications for FR1 are based on the LTE Advanced specifications, with the maximum channel bandwidth expanded to 100 MHz. For FR2, the specifications reflect wider bands, lower latency and fast response, with maximum channel bandwidth expanded to 400 MHz and transmitter transient period of 3 μs, which is the ON/OFF switching time for Time Domain Duplex (TDD)*29. The specifications also consider deterioration of RF device characteristics in the millimeter-wave bands, compensating for it using beam forming with high-gain antennas, and relax requirements for radio characteristics such as the Adjacent Channel Leakage Ratio (ACLR)*30 in the transmission characteristics and Noise Figure (NF)*31 in the reception circuits. This helps ensure feasibility in manufacturing. With OTA requirements, transmit power deviation*32 is regulated as TRP accuracy for

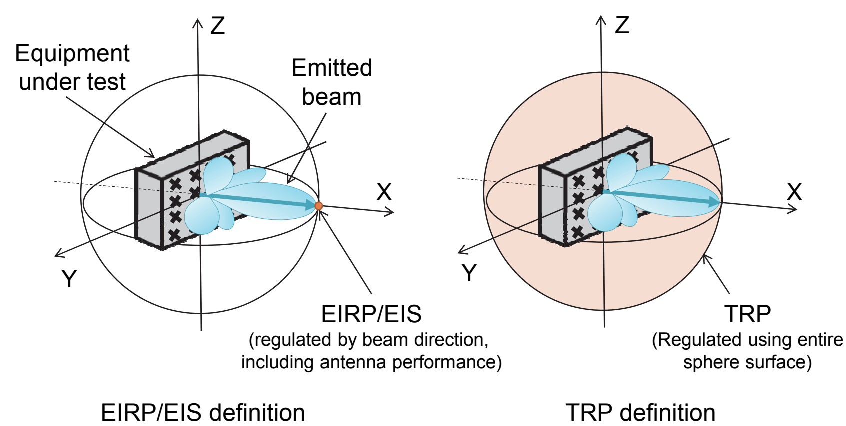

Figure 5 Definitions used for NR base station and mobile terminal RF requirements

*25 RIB: A standard point used for regulating OTA in base station RF performance specifications. This is the point where characteristics of radio emissions and reception space are measured.

*26 EIRP: The transmission power at the reference point in radio radiation space.

*27 EIS: The received power at the radiated requirement reference point in radio reception space.

*28 Spurious emissions: Unneeded radio emissions outside the desired band. Causing interference with neighboring frequencies.

*29 TDD: A bidirectional transmit/receive system. It achieves bidirectional communication by allocating different time slots to uplink and downlink transmissions that use the same frequency band.

*30 ACLR: When transmitting a modulated signal, the ratio between the transmitted signal band power and undesired power generated in the adjacent channels.

Table 2　Comparison of main base station RF performance specifications

	LTE	NR FR1 BS type 1-O	NR FR2 BS type 2-O
Max. channel bandwidth	20 MHz	100 MHz	400 MHz
Transmitter Transient period	< 17 μs	< 10 μs	< 3 μs
ACLR	45 dB	45 dB	28 dB*2
NF	5 dB*1	5 dB*1	10 dB
Transmit power deviation	+/- 2.0 dB	+/- 2.2 dB (EIRP accuracy)	+/- 3.4 dB (EIRP accuracy)
		+/- 2.0 dB (TRP accuracy)	+/- 3.0 dB (TRP accuracy)

*1　Specified values for wide-area base stations
*2　Specified values for 24.25 to 33.4 GHz

per-carrier total power deviation and EIRP accuracy, accounting for antenna performance.

4.2 Terminals

1) Terminal RF Configuration

In contrast with the NR base stations described above, terminal implementations only apply beam forming for FR2, and the RF front end configuration for FR1 NR terminals is not significantly different from earlier LTE, except for the new 3.7 and 4.5 GHz band implementations.

When NR is first introduced, non-standalone operation linked with LTE is assumed, so terminals supporting it will need to have conventional LTE radio equipment as well as the NR radio equipment.

2) Terminal RF Performance Requirements

For FR1, RF performance is specified for new radio parameters such as maximum transmit power and receiver sensitivity, to support NR as described above. As with conventional LTE-Advanced, Conducted requirements[*33] for antenna connectors are applied.

On the other hand, for FR2, transceivers and antennas are integrated and measurements cannot be made at connectors, as with the base stations, so OTA requirements have been introduced. Requirements have been adopted for EIRP maximum transmit power in FR2 using cumulative distributions[*34] of each EIRP value obtained when performing beam forming in a full sphere with the terminal at the center (**Figure 6**). The purpose of introducing these requirements was to statistically guarantee that the beam could be aimed correctly in the intended direction (toward the communicating base station) and with the necessary range. The Min peak value is defined as the value that at least one of the measured EIRP values must exceed, and spherical coverage is defined as the value on the cumulative distribution at X%; in other words, the value that must be maintained on (100-X)% of the area of the surface of the sphere. The Max value is defined as the value that the maximum

*31 NF: The level of noise power generated inside a piece of equipment. It is defined as the ratio between the Signal-to-Noise (SN) ratio of input signals and the SN ratio of output signals.

*32 Deviation: Dispersion or fluctuation from standard values.

*33 Conducted requirements: A type of test requirement for base stations and terminals, or a method for conducting tests with wired connections to the terminal.

*34 Cumulative distribution: The probability that the property being evaluated will be at or below a particular value.

measured EIRP value must not exceed, and was decided with consideration for requirements in various countries and regions, by organizations like the Federal Communications Commission (FCC)*35. Besides smartphones and other mobile terminals, which are the main consideration, Release 15 also considers ways to increase communication distances and data rates for other types of terminals such as fixed wireless terminals*36. These types of terminals are categorized according to Power class in the standard specifications, and the four Power classes are specified below, distinguished by required transceiver power and differences in spherical coverage (**Table 3**).

- Power class 1

    This class conforms with transportable stations as defined by FCC 16 to 89. In contrast with Power class 3 described below for

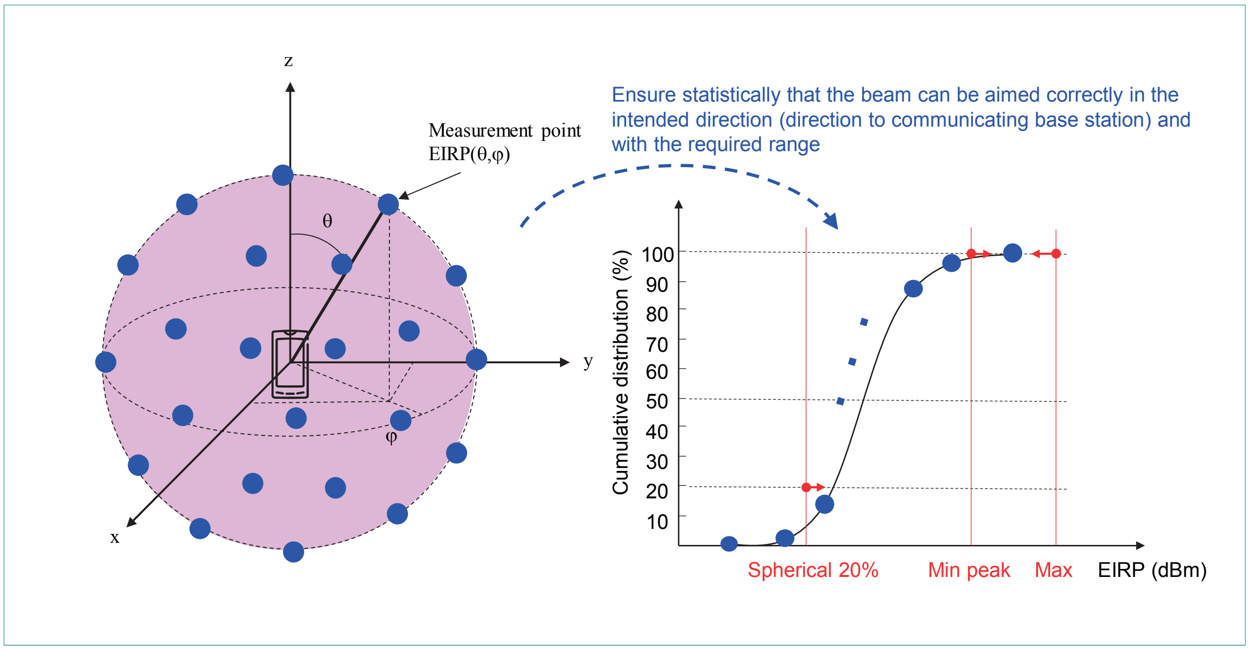

Figure 6 OTA EIRP evaluation using a cumulative distribution

Table 3 FR2 power class

FR2 power class	UE type example	EIRP (dBm)			TRP (dBm)
		Max	Min peak	Spherical	Max
1	Fixed wireless terminal	55	40	32 (85%)	35
2	Vehicle-mounted terminal	43	29	18 (60%)	23
3	Mobile terminal (Smartphone, etc.)	43	22.5	11.5 (50%)	23
4	Fixed wireless terminal	43	34	25 (20%)	23

*35 **FCC**: The Federal Communications Commission of the USA. Has the authority to approve and license industries including television, radio, telegraph and telephone.

*36 **Fixed wireless terminal**: A communication method in which both base station and terminal have a fixed location. Applications include use for backhaul communication between base stations.

handheld terminals, this Power class permits a maximum TRP of 35 dBm with maximum permitted TRP of 23 dBm*37. It assumes use cases with fixed equipment able to emit a strong signal with a narrow beam in a particular direction.

- Power class 2

  This class of terminals is intended mainly for use in vehicles. Its target for spherical coverage is 60% and maximum TRP is the same as Power class 3 for mobile terminals, but requires a higher EIRP characteristic.

- Power class 3

  This class is intended for smartphones and other mobile terminals. The orientation of the terminal with respect to the base station is random, so the target for spherical coverage is 50%.

- Power class 4

  This class requires wider spherical coverage (20%) and higher EIRP than Power class 2 described above. Since it can be installed without knowing the location of the NR base station, in contrast the narrow-beam Power class 1, it can be used more flexibly in use cases such as in vehicles or trains, and not only in fixed installations.

5. Radio Resource Management Specifications

Specifications regarding Radio Resource Management (RRM)*38, to ensure terminal mobility performance, are described below.

5.1 Measurements for Serving Cell and Neighbor Cell

For operations such as handover to a neighbor cell, or adding a new CC in the case of CA, it is desirable to measure cell quality, such as the Reference Signal Received Power (RSRP)*39 or Reference Signal Received Quality (RSRQ)*40, for neighbor cells. This enables these processes to be performed appropriately, maintaining radio link quality. With LTE, all base stations continually transmit a Cell-specific Reference Signal (CRS)*41, so it is easy for terminals to measure the cell quality from neighbor cells. However, NR has no reference signal like the CRS, to reduce resource overhead and interference to other cells in the case that traffic levels are low.

With NR, the cell quality is measured by using SS/PBCH Blocks (SSB)*42. These are composed of a Synchronization Signal (SS)*43 and the Physical Broadcast CHannel (PBCH)*44 which have a longer transmission periodicity than CRS (**Figure 7** (a)).

The SSB periodicity can be configured for each cell, in the range of 5, 10, 20, 40, 80, or 160 ms. However, terminals do not need to measure cell quality with the same periodicity as the SSB and the appropriate periodicity can be configured according to the channel condition. This is desirable and can help avoid unnecessary measurements and reduce power consumption on terminals.

As such, the new SSB-based RRM Measurement Timing Configuration window (SMTC window)*45 has been introduced to notify terminals of the periodicity and timing of SSBs that the terminals can use for measurements. As shown in Fig. 7, the SMTC window periodicity can be set in the

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*37 dBm: Power value [mW] expressed as 10log (P). The value relative to a 1 mW standard (1 mW = 0 dBm).

*38 RRM: A generic term for resource management including mobility operations such as handover or measurement of cell quality via reference signals in order to manage limited radio resources or connect between terminals and base stations smoothly, etc.

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

*40 RSRQ: The ratio of the power of the reference signal to total power within the receive bandwidth.

*41 CRS: Reference signal specific to each cell for measuring cell quality.

*42 SSB: Component including Synchronization signal and Physical Broadcast Channel, which is transmitted periodically. Terminals receive it for not only detecting cell ID and reception timing but also performing measurement the cell quality.

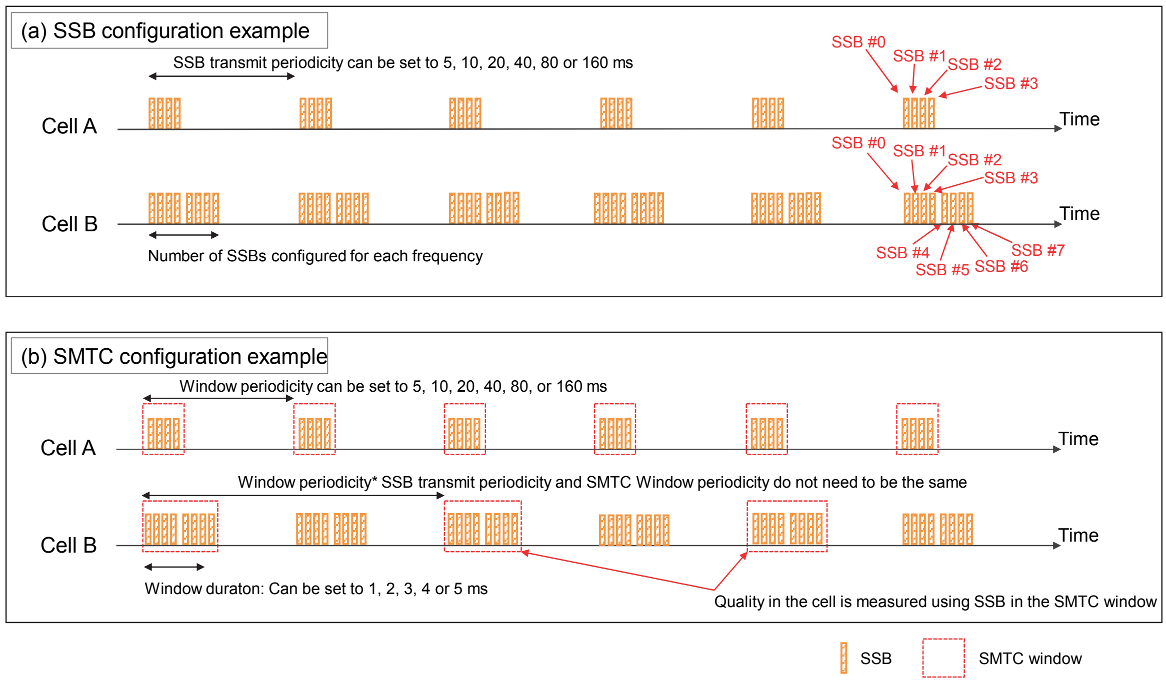

Figure 7 SSB/SMTC relationship in NR

same range as the SSB, of 5, 10, 20, 40, 80, or 160 ms, and the duration of the window can be set to 1, 2, 3, 4, or 5 ms, according to the number of SSBs transmitted on the cell being measured. When a terminal has been notified of the SMTC window by the base station, it detects and measures the SSBs within that window and reports the measurement results back to the base station.

5.2 Measurement Gap

Using the same RF module for measuring cell quality of neighbor cells or other CCs, and also for transmitting and receiving data in the serving cell can make it possible to reduce terminal manufacturing costs. However, this will mean that data cannot be transmitted or received in the serving cell during measurements of cells or CCs of different frequencies. With LTE, data transmission in the serving cell is suspended during a Measurement gap on the terminal, giving UE an opportunity to measure cells and CCs with a different frequency. A Measurement gap procedure similar to that in LTE is also introduced in NR. However, with NR, measurements are done using the SSB as described earlier, and the method for configuring the Measurement gap has been optimized. An overview of this method is given below.

1) Measurement Gap Configuration

(a) LTE

With LTE, the Measurement Gap Length

*43 SS: Synchronization signal for detecting carrier frequency of the cell, reception timing, and cell ID in order to connect the cell.

*44 PBCH: Common channel for reporting system information. Terminals receive this channel to get information such as operator code, common channel configuration, neighbor cell information, etc.

*45 SMTC window: Measurement window configured on the terminal for informing the measurement timing, duration and periodicity for each cell being measured when the terminal performs cell quality measurements using the SSB.

(MGL) is fixed, such that at least one SS is included within one gap. LTE SSs are transmitted at 5 ms periodicity, so the MGL of LTE is 6 ms, allowing 0.5 ms for RF retuning at the beginning and end of the MGL. Terminals detect the SS within the MGL, identify the cell ID*46 and reception timing, and thereafter terminals perform measurements with CRS.

(b) MGL extensions on NR

With NR, the SMTC window and window duration can be set to match SSB transmissions as described earlier. However, having a fixed MGL could cause unnecessarily degradation of throughput in the serving cell. For example, if the SMTC window duration is 2 ms and the Measurement gap has MGL of 6 ms, a 4 ms segment would not be available for transmission and reception of data in the serving cell.

To reduce such unnecessary degradation of throughput, the MGL for NR was extended to be configurable to 5.5 ms, 4 ms, 3.5 ms, 3 ms, or 1.5 ms in addition to the original 6 ms. This is shown concretely in **Figure 8** (1) and (2). The case in Fig. 8 (1) uses an SMTC

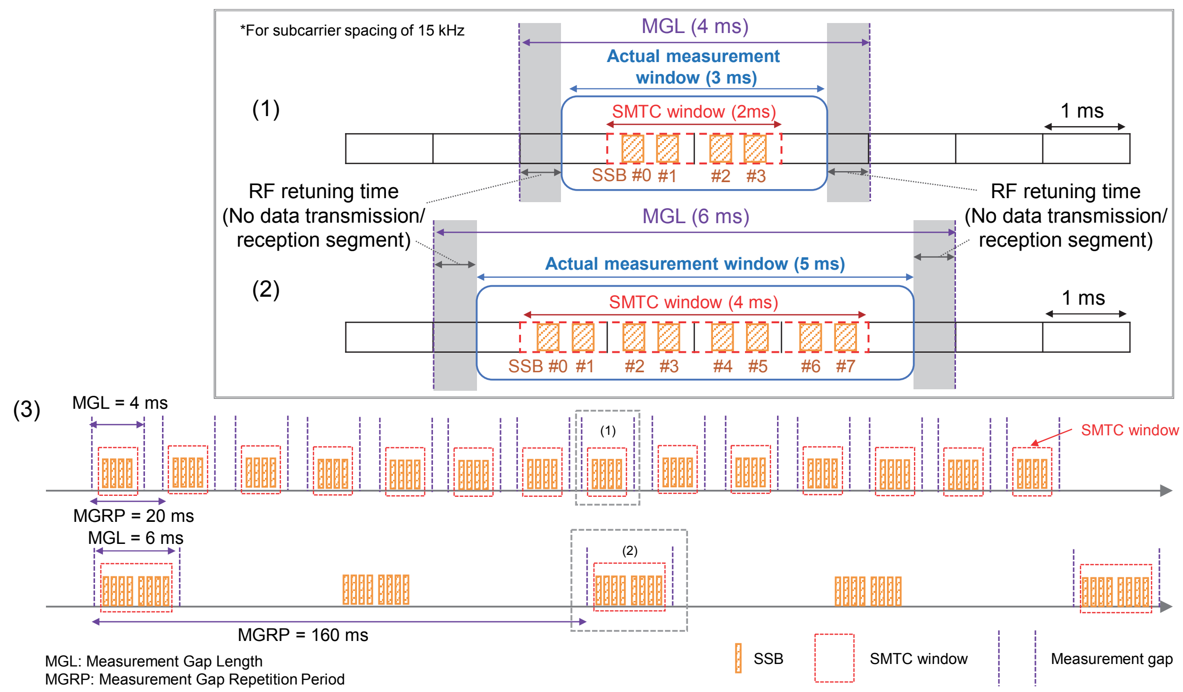

Figure 8　Measurement gap configuration in NR

*46　Cell ID: Identifying information assigned to each cell.

window of 2 ms and gap with MGL of 4 ms, while Fig. 8 (2) uses a 4 ms SMTC window and longer 6 ms MGL. The Measurement Gap Repetition Period (MGRP) can also be set more flexibly than LTE, as shown in Fig. 8 (3) (LTE values: 40, 80 ms; NR values: 20, 40, 80, 160 ms).

2) Measurement Gap Timing Advance

As mentioned earlier, RF retuning time is anticipated at the beginning and end of the configured Measurement gap, and during this time the terminal can neither perform measurements nor transmit or receive data. If, as shown in **Figure 9** (1), the SMTC window and Measurement gap start at the same time, the start of the SMTC window overlaps with RF retuning time and the UE cannot perform measurements in such duration. As such, the new Measurement gap timing advance function was introduced, which enables all of the measurement signal in the SMTC window to be used by advancing the start of the gap by the amount of the RF retuning time, as shown in Fig. 9 (2).

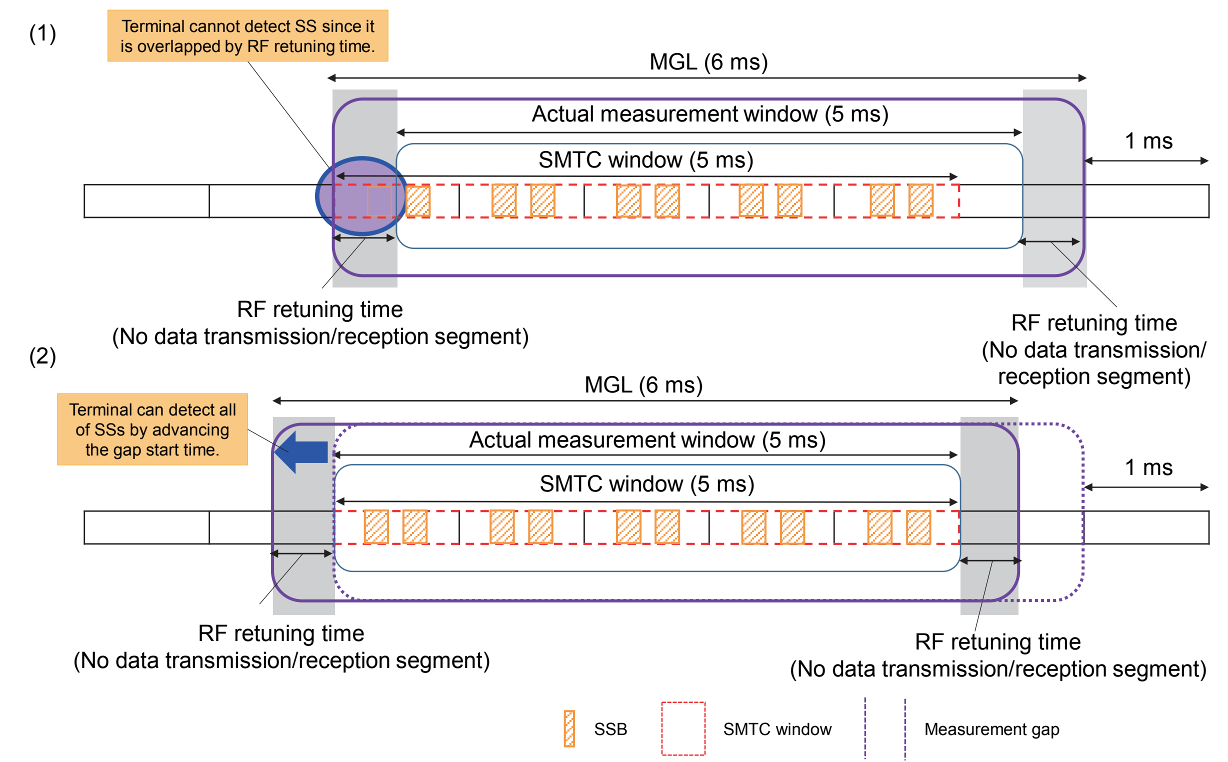

Figure 9　Measurement gap timing advance

5.3 Asynchronous Network Reception Quality Measurement

1) SFN[*47] and Frame boundary Timing Difference (SFTD) Measurement

The SMTC window and Measurement gap are set based on the timing of SSB transmission for the cell being measured. However, when measuring other cells and some other cases, the base station in the serving cell may not have such information. In such case, it is not possible to set SMTC window and Measurement gap appropriately for the terminal. For this reason, a new SFTD measurement function was introduced, in which the terminal measures the timing difference of SFN and frame boundary between the serving cell and NR neighbor cells being measured and reports it to the base station.

2) SFTD Configuration

The base station configures SFTD measurements for a terminal's NR neighbor cells. For a terminal to perform SFTD measurements for NR neighbor cells to which it is not connected, basically the Measurement gap is needed. However if the base station does not know the SSB transmission timing as described above, it cannot be configured appropriately (**Figure 10**). In such a case, the base station would need to configure the Measurement gap repeatedly changing the Measurement gap settings until the terminal detects the SSB of the NR neighbor cell. This would increase the signaling[*48] and delay until the terminal is able to connect to the NR cell. Accordingly, a new procedure for performing SFTD measurement of NR neighbor cells, without

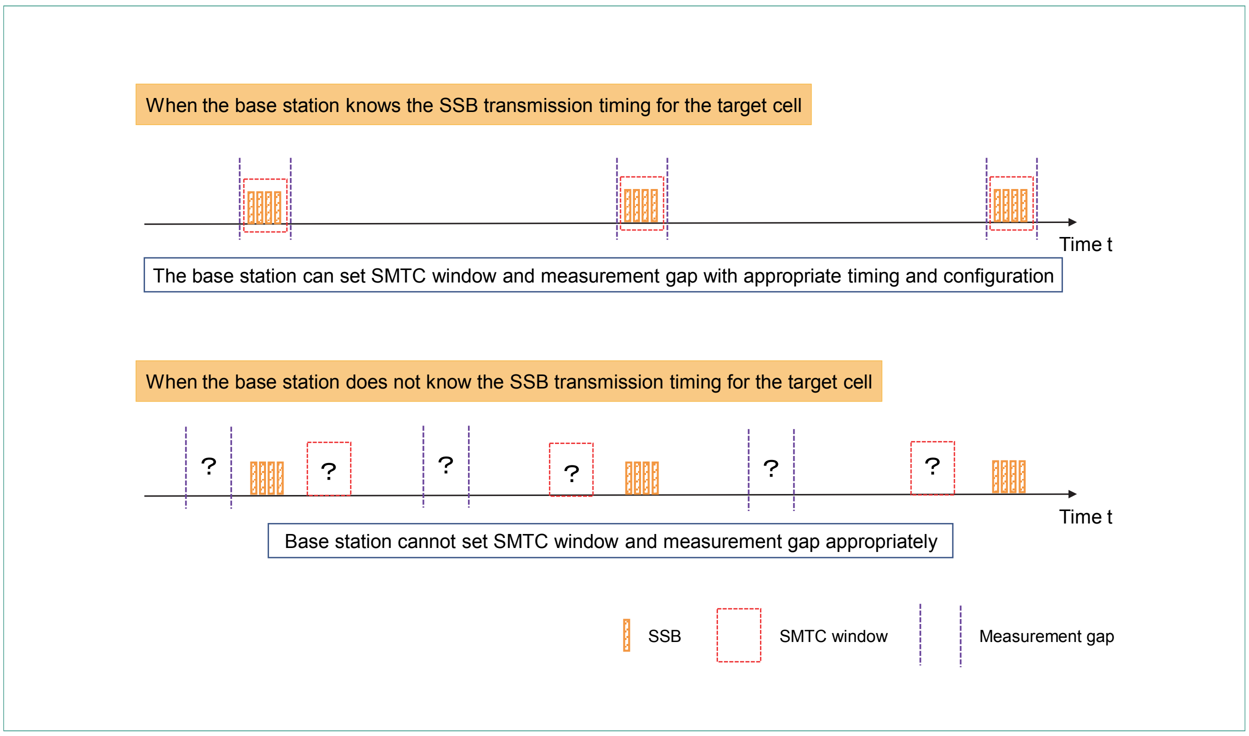

Figure 10 When SSB transmission timing is unknown for the cell being measured

*47 SFN: A number assigned to each radio frame. The value ranges from 0 to 1,023.

*48 Signaling: The sharing of information necessary for connection between base station and terminals (e.g. frequency band, coding and modulation formats, etc.).

using the Measurement gap and while maintaining transmission and reception data in the serving cell was introduced.

A concrete example of the SFTD measurement method is shown in **Figure 11**. Rather than stopping transmission and reception data by the RF device to perform measurements, this method uses a separate RF device on the terminal, which is used in case of CA. When the RF device used for measurement is turned ON or OFF, the RF device being used for transmission and reception data in the serving cell is affected, so the terminal cannot transmit and receive data in one sub-frame before and after the measurement window, but in the rest of the duration, the terminal can transmit and receive data in the serving cell while SFTD measurements for the NR neighbor cells are being performed.

6. Conclusion

This article has described the new radio format (NR) specified in Release 15, mainly regarding RAN 4 specifications for frequency bands, RF performance for base stations and terminals, and specifications related to radio resource management. In the future, baseband*49 performance and other specifications for base stations and terminals, regulating reception throughput, will be decided (planned completion by December, 2019). At the same time, study of Release 16 and later standard specifications will continue, to provide service areas that have even better quality and more advanced functionality.

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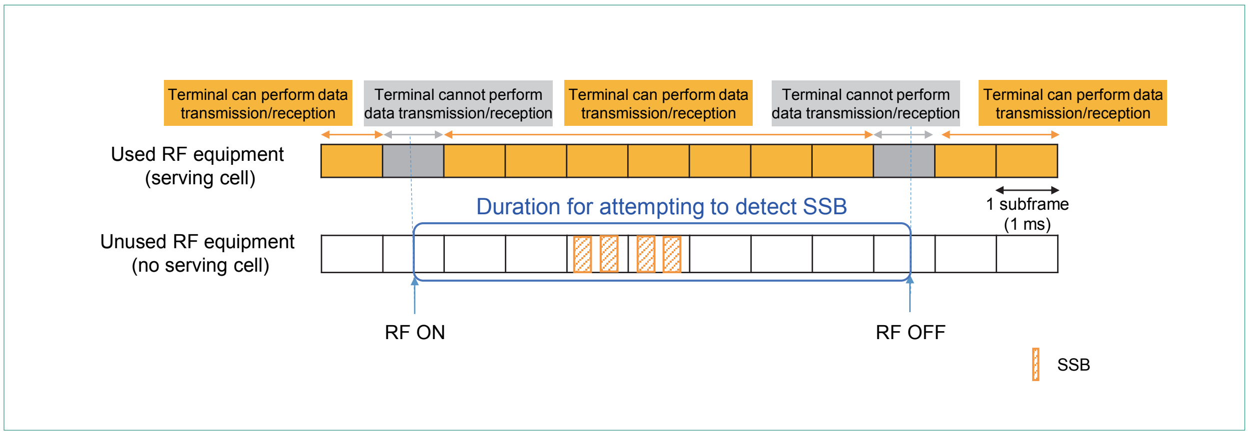

Figure 11 Implementing SFTD measurement without using measurement gap

*49 **Baseband**: The circuits or functional blocks that perform digital signal processing.

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