Technology Reports

5G | Requirements | Evaluation Conditions

Special Articles on 5G Standardization Trends Toward 2020

3GPP Defined 5G Requirements and Evaluation Conditions

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Standardization of the new radio interface for fifth-generation mobile communications systems (5G) is advancing at the 3GPP. Before starting discussions on the specifications of the 5G radio interface, the 3GPP defined the requirements and evaluation conditions for 5G. This article provides an overview of the 5G requirements and scenarios defined by the 3GPP together with an explanation of the evaluation conditions, including channel models, used for evaluating 5G requirements.

1. Introduction

There is great anticipation of fifth-generation mobile communications systems (5G), which are the next generation following LTE and LTE-Advanced, the fourth-generation (4G), and which will handle the explosive increase in mobile communications traffic and the diversification of services in the year 2020 and beyond. In addition to realizing high system performance, 5G will also require extensibility for a wide range of services. To meet these demands in a timely fashion, NTT DOCOMO began activities in 2010 targeting 5G commercialization by 2020, taking a lead in the discussion of 5G technical concepts and requirements [1]. These discussions were held by 5G promotional organizations and research projects that were formed later in several regions around the world in 2012 and 2013, and the discussion results are being consolidated by organizations including the Mobile and wireless communications Enablers for the Twenty-twenty Information Society (METIS)*1 project in Europe, the Next Generation Mobile Networks (NGMN)*2 alliance, the Association of Radio Industries and Businesses 2020 and Beyond Ad Hoc (ARIB 20B AH)*3 group in Japan, the 5G Forum*4 in Korea, and the International Mobile Telecommunications (IMT)-2020 Promotion Group*5 in China [2] - [4]. The International Telecommunication Union - Radiocommunication sector (ITU-R)*6 has also studied its vision for mobile communication systems in 2020 and beyond. The results of this study are summarized in the recommendation, ITU-R M.2083, published in September, 2015 [5]. One main result of this report is the identification of three typical usage scenarios for 5G. These are (1) enhanced Mobile BroadBand (eMBB), (2) massive Machine Type Communications (mMTC), supporting massive numbers of simultaneous connections, and (3) Ultra-Reliable and Low Latency Communications (URLLC).

Amid this activity, the 3rd Generation Partnership Project (3GPP), a standardization organization for mobile communications systems, held the 3GPP RAN Workshop on 5G in September 2015, to begin the study of 5G. Also, prior to initiating discussions on 5G radio interface specifications, Study Items (SI)*7 were initiated related to 5G scenarios, requirements and channel models*8. These extended channel models used earlier for 6 GHz and below, to be used with high frequencies above 6 GHz, so that technologies designed for high-frequency bands can be evaluated. The SI for 5G scenarios and requirements was held from December 2015 (70th TSG-RAN meeting) through December 2016 (73rd TSG-RAN meeting), and the results are documented in Technical Report (TR) 38.913 [6]. The channel model SI was discussed from September 2015 (69th TSG-RAN) through June 2016 (72nd TSG-RAN) and the results are documented in TR 38.900 [7]. This article describes the current status of discussions on 5G requirements and evaluation conditions, including channel models, as defined by the 3GPP.

2. 5G Requirements and Target Performance Values

In the SI related to scenarios and requirements, Key Performance Indicators (KPI)*9 and target performance values for 5G were discussed, and many 5G requirements and target values from various organizations, enterprises and research projects in the mobile communications industry, as well as proposals from other industries were considered, as shown in **Figure 1**. In particular, KPI target values were set for mMTC and URLLC, which relate to the Internet of Things (IoT), giving full consideration of future services in industries other than mobile communications, such as automotive, robotics, and sensors. The results consist of 19 KPIs for 5G as well as a wide range of network and service requirements. The KPIs and related target values

*1 METIS: EU research project laying the foundation of 5G wireless technology. Ran from November 2012 to April 2015. Participants included communication vendors, mobile carriers, and universities. A successor project, METIS-II ran from July 2015 to June 2017.

*2 NGMN: An organization composed of NTT DOCOMO and other vendors and operators, which is creating a vision and roadmap for next-generation mobile communications networks.

*3 ARIB 20B AH: ARIB is an organization, subordinate to the Ministry of Internal Affairs and Communications (MIC), that sets standards for systems using the radio spectrum in the fields of communications and broadcasting in Japan. ARIB 20B AH is an ad hoc group established under ARIB to create a vision for next-generation mobile communications systems after 2020.

*4 5G Forum: The main organization promoting activities toward implementation of 5G in Korea.

*5 IMT-2020 Promotion Group: The main organization promoting activities toward implementation of IMT-2020 (5G) in China.

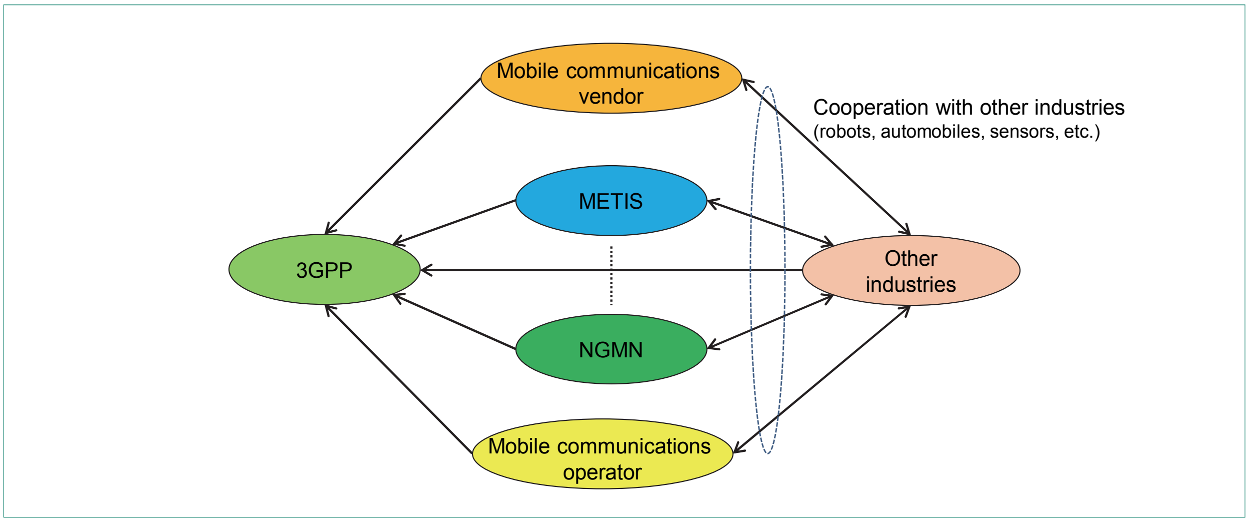

Figure 1 Overview of 3GPP role of consolidating 5G requirements and evaluation conditions from various other organizations and industries

are shown in **Table 1** [6]. Please refer to TR 38.913 for detailed definitions of each KPI [6].

1) KPIs for eMBB Usage Scenarios

For eMBB usage scenarios, the main KPIs are improvements on the average (TRxP) spectral efficiency*10 and the 5% user spectral efficiency*11, which stipulate system performance in the same way as LTE-Advanced, and support for high-speed mobility. For eMBB, target values were set for approximately three times improvement in spectral efficiency, based on the requirement values set previously for IMT-Advanced*12. The use of wide-band and high frequencies and carrier aggregation spanning multiple bands is anticipated, so requirements for peak user data rates were added and target values set at 20 Gbps on the downlink and 10 Gbps on the uplink. In addition to the above, KPIs for low power consumption were also set to prevent increases in power consumption in networks and terminals as system capacity and user throughput increase. These were added as design principle requirements for the 5G radio interface.

2) KPIs for mMTC Usage Scenarios

The main KPIs for mMTC usage scenarios are to increase the connection density, expand coverage, and increase battery life. Considering the wide spread of IoT terminals, a target value for connection density of one million devices/km^2, or one device/m^2, was set for urban environments. This is approximately 16 times the design value (approx. 60k devices/km^2) set for Narrow Band (NB) - IoT*13 in the LTE-Advanced standards. Regarding battery life, terminals are required to operate for 10 to 15 years without changing or charging of batteries.

3) KPIs for URLLC Usage Scenarios

URLLC usage scenarios require both high reliability and low latency simultaneously. Latency is specified as latency in the U-Plane [6], requiring

*6 ITU-R: The Radiocommunication Sector of the ITU, which is an international organization in the telecommunications field. It conducts studies required to revise international regulations for radio communications and conducts research on radio communications technology and operation.

*7 SI: Work on a particular feature requiring study of feasibility and specifications.

*8 Channel model: A model simulating the behavior of radio waves, used for evaluating the performance of wireless communications systems.

*9 KPI: The main indices for measuring user or system performance.

*10 Average (TRxP) spectral efficiency: The average number of data bits that can be sent per unit time, unit frequency bandwidth, cell, and Transmission Reception Point (TRxP). The units are bps/Hz.

*11 5% user spectral efficiency: The number of data bits that a user can send per unit time and unit frequency bandwidth at the 5% point on a user throughput Cumulative Distribution Function (CDF). The units are bps/Hz.

Table 1 5G KPIs and target values at the 3GPP

Usage scenario	KPI	Target values	
		DL	UL
eMBB	Peak data rate	20 Gbps	10 Gbps
	Peak spectral efficiency	30 bps/Hz	15 bps/Hz
	Control plane latency	10 ms	
	User plane latency	4 ms	
	Average (TRxP) spectral efficiency (bps/Hz)	3 times higher than IMT-Advanced*	
	Area traffic capacity (bps/m²)	Related to average (TRxP) spectral efficiency	
	User experienced data rate (bps)	Related to 5% user spectral efficiency	
	5% user spectral efficiency (bps/Hz/user)	3 times higher than IMT-Advanced*	
	Target maximum mobility speed	500 km/h	
	Mobility interruption time (Also related to URLLC and mMTC)	0 ms	
	Network energy efficiency (Also related to URLLC and mMTC)	Required as design principle (No quantitative requirement)	
	UE energy efficiency (Also related to URLLC and mMTC)	Required as design principle (No quantitative requirement)	
	Bandwidth (Also related to URLLC and mMTC)	No requirement from 3GPP	
mMTC	Coverage	Max coupling loss 164 dB	
	UE battery life	Beyond 10 years	
	Connection density	1,000,000 device/km²	
	Latency of infrequent small packets	10 s	
URLLC	User plane latency	0.5 ms	
	Reliability	$1\text{-}10^{-5}$ success probability for 32 bytes within 1 ms user plane delay	

TRxP: Transmission Reception Point
*ITU-R Report M.2134

0.5 ms or less on both the uplink and the downlink. The target value for reliability is to send 32-byte data packets within 1 ms with $1 - 10^{-5}$ (99.999%) probability of success.

3. 5G Evaluation Conditions

The SI for scenarios and requirements also studied evaluation scenarios (environments) and evaluation

*12 IMT-Advanced: A standard positioned as the successor to IMT-2000 at ITU-R. It calls for data rates of about 100 Mbit/s for high mobility and 1 Gbit/s for low mobility.

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

conditions for evaluating each of the requirements. This resulted in specifications for multiple deployment scenarios for each usage scenario, requiring support for a wide range of environments and frequency bands. For example, several usage scenarios were envisioned for eMBB, so a wide range of Base Station (BS) Inter-Site Distance (ISD) ranges (from 20 to 5000 m) and a wide range of frequency bands (center carrier frequencies*14 of 700 MHz to 70 GHz) need to be evaluated. In particular, the number of frequency bands in a given usage environment is not limited to one, and in most usage scenarios, both a low frequency band (e.g. 4 GHz) and a high frequency band (e.g. 30 GHz) must be evaluated.

3.1 eMBB

The eMBB deployment scenarios and main evaluation conditions are shown in **Table 2**. It was agreed that average spectral efficiency and 5% user spectral efficiency are to be evaluated in the Indoor Hotspot*15, Dense Urban, Rural, and Urban Macro user environments. The main differences among these user environments are in applicable frequency bands, cell layout (determined by ISD), user distribution and mobility speed.

For mobility, speeds of 500 km/h are to be supported, faster than the 350 km/h maximum value set for IMT-Advanced, considering maximum speeds for high-speed trains. For evaluation of mobility, linear cell layouts with base stations in a straight line are specified, anticipating cell layouts used for high-speed trains. Scenarios are specified for base stations connecting directly to terminals within a train car, and also relay-based communication

Table 2 Deployment scenarios and main evaluation conditions related to eMBB

Deployment scenarios	Main features		
	Carrier frequency	Cell layout	User distribution
Indoor hotspot	30 GHz or 70 GHz or 4 GHz	ISD = 20 m, open office, one floor	100% indoor (3 km/h)
Dense urban	4 GHz + 30 GHz (macro + micro layers)	ISD = 200 m, hexagonal grid layout for macro layer, random drop for micro layer	80% indoor (3 km/h), 20% outdoor (30 km/h)
Rural	700 MHz or 4 GHz (ISD = 1,732 m case) 700 MHz + 2 GHz (ISD = 5 km case)	ISD = 1,732 m or 5 km, hexagonal grid layout	50% outdoor vehicles (120 km/h) and 50% indoor (3 km/h)
Urban macro	2 GHz or 4 GHz or 30 GHz	ISD = 500 m, hexagonal grid layout	20% outdoor in cars (30 km/h) 80% indoor in houses (3 km/h)
High speed (High-speed train)	4 GHz or 30 GHz	ISD = 1,732 m, linear cell layout	User speed up to 500 km/h
Extreme long distance coverage in low density areas	Below 1 GHz, e.g., 700 MHz	At least 100 km range (Up to 150 km - 300 km range) isolated macro cell	User speed up to 160 km/h

*14 Center carrier frequency: The center carrier frequency in a frequency band used for communication. A carrier frequency is a radio wave that is modulated in order to transmit information.

*15 Hotspot: An indoor office, plaza in front of a train station or other location where concentrated traffic can be generated.

scenarios in which communication is done through antennas installed on a train car.

Both 4 GHz and 30 GHz frequency bands are to be evaluated. Also, the target value for maximum coverage of an isolated cell, for deployment of large cells in developing countries and areas with low population density, is at least 100 km.

A key technology for realizing these eMBB requirements in the eMBB usage environments is Massive Multiple Input Multiple Output (Massive MIMO)*16, which uses large numbers of antenna elements [7]. The maximum number of transceiver antenna elements for Massive MIMO expected at base stations and terminals for each frequency band are shown in **Table 3**.

3.2 mMTC

For mMTC, evaluation scenarios were specified with base stations installed for macrocell*17 arrangements in urban environments, using low carrier frequencies of 6 GHz and lower, and supporting terminals distributed indoors and outdoors. A list of evaluation conditions is given in **Table 4**.

Terminals such as smart meters*18, sensors, and industrial robots are expected, so generally, traffic is of low density. As such, 3GPP specifies evaluation for capacity and connection density of 20 to 200 bytes of uplink data occurring intermittently

Table 3 Numbers of Massive MIMO transceiver antenna elements for eMBB related deployment scenarios

Parameters	Values
Number of BS antenna elements	700 MHz: Up to 64 Tx/Rx 4 GHz (& 2 GHz) : Up to 256 Tx/Rx 30 GHz: Up to 256 Tx/Rx 70 GHz: Up to 1024 Tx/Rx
Number of UE antenna elements	700 MHz: Up to 4 Tx/Rx 4 GHz (& 2 GHz) : Up to 8 Tx/Rx 30 GHz: Up to 32 Tx/Rx 70 GHz: Up to 64 Tx/Rx

Tx: Transmitter
Rx: Receiver

Table 4 List of evaluation conditions related to mMTC

Parameters	Values
Carrier frequency	700 MHz (2,100 MHz as optional)
Deployment scenario	Urban Macro: ISD = 500 m or 1,732 m 20% of outdoor users (3 km/h) + 80% of indoor users (3 km/h)
Physical layer packet size	Follow 3GPP TR45.820 or use 40 bytes fixed packet size
Traffic model	Non-full buffer with small packets (with Poisson arrival)
BS antenna elements	2 or 4 Rx ports (8 Rx ports as optional)
UE antenna elements	1 Tx

*16 Massive MIMO: MIMO transmission formats use multi-element antennas at both transmitter and receiver to spatially multiplex the radio signal. Massive MIMO is a technique that is able to realize narrow radio wave beam forming, to compensate for carrier losses when using high frequency bands or to transmit more streams at the same time, by utilizing large-scale antennas with even more elements. This can achieve high speed data communications while securing the desired service area.

*17 Macrocell: In mobile communications systems, a cell is the area covered by a single base station antenna. A macrocell generally covers a relatively large area with radius of 500 m or more.

*18 Smart meter: A device that enables real-time measurement and visualization of electricity usage.

following a Poisson distribution*19, using a File Transfer Protocol (FTP)*20 or similar model. The target for packet loss rates*21 supported for each terminal is 1% or less. In addition, low terminal cost is extremely important to enable large-scale spread of mMTC terminals. To achieve this, very simple transmission circuits and a single transmission antenna for the uplink are anticipated. mMTC transmission packets are small and the ratio of control signal to data signal tends to be large, so for efficient data transmission, it is important to reduce the amount of control signal. As such, transmitting uplink data without allocating base station resources and using control signals was studied. If base station resources are not allocated and control is not used, uplink data signal collisions among users could occur, so use of non-orthogonal multiple access*22 technology on the uplink to increase its capacity*23 was studied to keep packet errors due to such collisions below a specified level [8]. Also, mMTC coverage is to be evaluated under conditions of 200 bytes transmitted per terminal per day, with coupling losses*24 of a maximum of 164 dB.

Requirements for mMTC are expected to be achieved through extension of LTE-Advanced NB-IoT and eMTC requirements [9]. For example, part of the evaluations showed that by using the NB-IoT bandwidth extension technology, it should be possible to meet connection density requirements [10].

3.3 URLLC

For URLLC, the data signal must be transmitted with very low latency and high reliability. A list of evaluation conditions is given in **Table 5**. In addition to the indoor hotspot environment evaluation scenario, which uses carrier frequencies of 6 GHz or lower and all terminals are indoors, an evaluation scenario with base stations arranged in macrocells in an urban environment, supporting terminals distributed both indoors and outdoors,

Table 5　List of evaluation conditions related to URLLC

Parameters	Values
Carrier frequency	700 MHz and 4 GHz (FDD and TDD)
Deployment scenario	Urban macro: ISD = 500 m, 20% Outdoor in cars (30 km/h) + 80% Indoor (3 km/h) or Indoor hotspot: ISD = 20 m, Up to 12 BS per 120 m × 50 m, 100% Indoor (3 km/h)
SNR range	-5 dB to 20 dB
Physical layer packet size	e.g., 32, 50, 200 bytes
Traffic model	Non-full buffer with small packets (with Poisson arrival) or periodic packet arrivals
BS antenna elements	Up to 256 Tx/Rx, 2/4/8 Tx/Rx ports as starting point
UE antenna elements	Up to 8 Tx/Rx, 2/4 Tx/Rx ports as starting point

FDD: Frequency Division Duplex
TDD: Time Division Duplex

*19 Poisson distribution: When counting discrete events occurring within a given time period, the discrete probability distribution of the characteristic probability variable X.

*20 FTP: A protocol that is generally used for transferring files over a TCP/IP network such as the Internet.

*21 Packet loss rate: The probability that transmission of a packet will not complete within a specified timer interval (e.g.: from 10 ms to 10 s).

*22 Non-orthogonal multiple access: A technology in which multiple terminals share communication resources that are not orthogonal to increase data capacity.

*23 Link capacity: The transmission speed attainable on a single link.

*24 Coupling losses: The total power losses occurring between the transmitter and receiver.

was studied. Latency was studied based on a theoretical calculation incorporating processing delay, transmission delay, and retransmission delay [11]. On the other hand, for reliability, a packet success probability was defined based on block error rate within a set period of time elapsed from the start of data transmission, and evaluation is done using link-level simulation*25. To compare characteristics in environments with varied transmission quality, a range of Signal-to-Noise Ratios (SNR)*26 from –5 dB to 20 dB is specified for the signals being evaluated. Data packet sizes are from 32 to 200 bytes, occurring according to an FTP model.

In addition to the above scenarios, latency and reliability were also verified in high-speed environments of up to 500 km/h on high-speed trains, and in urban transit environments for communication with connected automobiles.

Together with the above evaluation, system level evaluation of the number of URLLC terminals that can be accommodated is also required. Specifically, indices of the number of URLLC terminals able to realize a given level of reliability in indoor hotspot and urban macrocell environments are specified.

It is expected that requirements for URLLC can be achieved using new radio frame*27 structure (Orthogonal Frequency Division Multiplexing (OFDM)*28 subcarrier*29 spacing optimization) and a high-speed ACKnowledgement/Negative ACK (ACK/NACK)*30 feedback design [9].

3.4 Other

Several usage scenarios besides those described above have been proposed. Specific examples include Vehicle to Everything (V2X) communications*31, ultra-high-speed mobility (e.g. 1,000 km/h), and long distance communication such as air to ground*32 and satellite extension to terrestrial*33. These were proposed from various industries (verticals) other than mobile communications, indicating the extent of expectations for 5G.

4. Channel Models

The SI regarding channel models supporting frequency bands at 6 GHz and higher was held between September 2015 and June 2016, and the results are documented in TR 38.900 V1.0.1 [12]. With that, the SI was concluded, but results were integrated with channel models for 6 GHz and below in March 2017, in TR38.901 V14.0.0 [13].

1) 3D and 5G Channel Models for LTE Evaluation

A comparison of the 3D channel model created in TR36.873 for evaluation of LTE and 5G channel models is shown in **Table 6** [14]. The basic channel model design is the same for both, composed of a path-loss model, a line-of-sight probability model*34, and a fast fading model*35, statistically reflecting the levels of received radio waves, the propagation delay, and the arrival angle. Also, TR36.873 only applies to frequencies up to 6 GHz, but TR38.901 applies over the range from 0.5 to 100 GHz, supporting high frequency bands such as millimeter waves (although rural scenarios are an exception). In TR36.873, the delay spread*36 and angle spread*37 used in the fast fading model and the building absorption losses used to calculate path loss between

*25 **Link-level simulation:** Modeling of the transmitter, receiver, and the physical behavior of the radio propagation path between them, applied in experiments on functionality and performance from transmitter to receiver.

*26 **SNR:** The ratio of the desired signal power to the noise power.

*27 **Frame:** The period in which an encoder/decoder operates or a data signal of length corresponding to that period.

*28 **OFDM:** A digital modulation method where the information is transmitted over multiple orthogonal carriers and sent in parallel. It allows transmission at high data rates.

*29 **Subcarrier:** In OFDM and other multi-carrier transmission, the individual transport waves are called subcarriers.

*30 **ACK/NACK:** A control signal notifying of whether the data signal was correctly decoded or not.

*31 **V2X communications:** V2X is a generic name for wireless communications systems for communication between vehicles and other vehicles (V2V), vehicles and infrastructure such as traffic signals and road signs (V2I) and between vehicles and pedestrians carrying smartphones (V2P).

outdoor base stations and indoor mobile stations were uniform, regardless of frequency, but in TR38.901, both were made dependent on frequency in order to handle the wider range of frequencies. The building penetration loss model computation results from TR38.901 are shown in **Figure 2**. The figure shows how this model takes into consideration the increasing building penetration losses as frequency increases. There are also high-loss and low-loss models, which consider the building material, such as concrete or glass, so that more-detailed characteristics can be given. TR38.901 also includes additional modeling components to handle other technologies expected to be introduced with 5G.

2) Additional Modeling Components

An overview of additional modeling components is shown in **Table 7**. These models are mainly for more accurate evaluation of technologies such as large-scale array antennas*38 (Massive MIMO), beam tracking*39 (beam forming*40) and Multi-

Table 6 Comparison of channel models for LTE and 5G

	3D channel model for LTE	5G channel model
Document	3GPP TR36.873	3GPP TR38.901
Model type	GSCM	GSCM
Applicable frequency range	Up to 6 GHz	0.5 to 100 GHz
Features	・LSP (delay spread, angle spread, etc.) and building penetration loss are constant, not dependent on frequency.	・LSP and building penetration loss are dependent on frequency. ・Additional modeling components are provided (for handling 5G technologies).

GSCM: Geometry-based Stochastic Channel Model
LSP: Large Scale Parameter

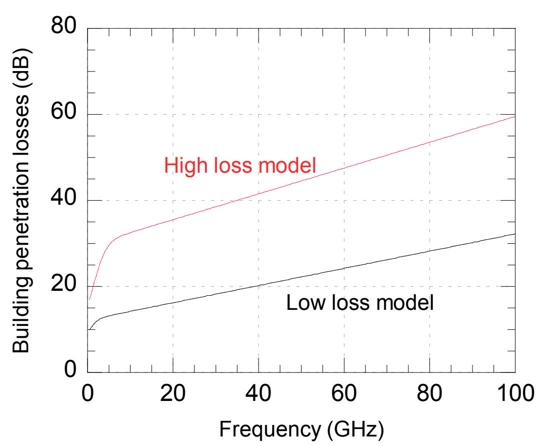

Figure 2 Building penetration losses

*32 Air to ground transmission: Technology for direct communication between aircraft and the ground, without using satellites.

*33 Satellite extension to terrestrial transmission: Satellite communication intended to complement terrestrial communication. This includes Low Earth Orbit (LEO) satellites, Medium Earth Orbit (MEO) satellites, and Geostationary Earth Orbit (GEO) satellites.

*34 Line-of-sight probability model: A model which assigns a probability to whether base station and mobile station have a line-of-sight situation, the main parameter for distance between them.

*35 Fast fading model: A model in which fading occurs with reception level changing over a short period.

*36 Delay spread: For radio propagation in mobile communications, the spread in delay time of signals along all paths due to reflection and diffraction from buildings and other objects. Defined by a standard deviation of delay times of signals arriving on all paths, weighted by received signal power.

*37 Angle spread: For radio propagation, the spread in arrival angle of signals along all paths due to reflection and diffraction from buildings and other objects. Defined by a standard deviation of arrival angles of signals arriving on all paths, weighted by received signal power.

Table 7 Overview of additional modeling components

Model name	Overview
Oxygen attenuation	A model accounting for power attenuation due to oxygen in the 52 to 68 GHz range
Wide band and large-scale array antenna	A model with delay and emission and arrival angles when there is high resolution in the time and space domains through use of wide band and large-scale array antennas
Spatial consistency	A model that continuously changes channels for evaluation of techniques including beam tracking and MU-MIMO
Blockage	A model for cases where the base station or mobile station is obstructed by a static or moving object
A correlation model for simulating multiple frequencies.	A model explaining procedures for simulating multiple frequencies simultaneously
Time-changing Doppler frequency	A model which gives a Doppler frequency, for cases when the mobile station is moving in a straight line, or the arrival angle is changing with time
User terminal rotation	A model which performs computation accounting for rotation of the mobile terminal
Ground reflection	A model that considers ground reflections for LOS environments

LOS: Line Of Sight

User MIMO*41, and to provide simulation as an add-on to the basic model.

5. Conclusion

This article described 5G requirements, scenarios and evaluation conditions defined by the 3GPP, as specification of the 5G radio interface progresses, including progress in technical development as interest in 5G continues to increase around the world. 5G requirements and evaluation conditions are being considered in corresponding working groups for the on-going design and evaluation of the new radio interface for 5G [8] [9]. NTT DOCOMO will continue to fulfill its role consolidating the related discussions, and actively contributing to 5G standardization.

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*38 Array antenna: An antenna consisting of an array of multiple antenna elements.

*39 Beam tracking: A technique for tracking the movement of a mobile station and increasing the antenna gain in that direction; forming a directivity pattern by controlling the signal amplitude and phase among multiple antennas.

*40 Beam forming: A technique for increasing or decreasing the gain of antennas in a specific direction by controlling the amplitude and phase of multiple antennas to form a directional pattern with the antennas.

*41 Multi-user MIMO: A technology that improves spectral efficiency by applying MIMO transmission to simultaneously transmit (multiplex) signals of multiple users.

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