



TECHNICAL REPORT

5G;
Study on channel model for frequencies from 0.5 to 100 GHz
(3GPP TR 38.901 version 19.3.0 Release 19)

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Reference

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Foreword

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 - 2 presented to TSG for approval;
 - 3 or greater indicates TSG approved document under change control.
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In the present document, modal verbs have the following meanings:

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shall not indicates an interdiction (prohibition) to do something

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should indicates a recommendation to do something

should not indicates a recommendation not to do something

may indicates permission to do something

need not indicates permission not to do something

The construction "may not" is ambiguous and is not used in normative elements. The unambiguous constructions "might not" or "shall not" are used instead, depending upon the meaning intended.

can indicates that something is possible

cannot indicates that something is impossible

The constructions "can" and "cannot" are not substitutes for "may" and "need not".

will indicates that something is certain or expected to happen as a result of action taken by an agency the behaviour of which is outside the scope of the present document

will not indicates that something is certain or expected not to happen as a result of action taken by an agency the behaviour of which is outside the scope of the present document

might indicates a likelihood that something will happen as a result of action taken by some agency the behaviour of which is outside the scope of the present document

might not indicates a likelihood that something will not happen as a result of action taken by some agency the behaviour of which is outside the scope of the present document

In addition:

is (or any other verb in the indicative mood) indicates a statement of fact

is not (or any other negative verb in the indicative mood) indicates a statement of fact

The constructions "is" and "is not" do not indicate requirements.

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1 Scope

The present document captures the findings of the study item, "Study on channel model for frequency spectrum above 6 GHz" [2] and from further findings of:

- the study item, "Study on New Radio Access Technology [22]",
- the study item "Study on Channel Modeling for Indoor Industrial Scenarios [23]",
- the study item "New SID: Study on channel modelling enhancements for 7-24GHz for NR [24]",
- and the study item "Study on channel modelling for Integrated Sensing And Communication (ISAC) for NR [26]".

The channel models in the present document address the frequency range 0.5-100 GHz. The purpose of this TR is to help TSG RAN WG1 to properly model and evaluate the performance of physical layer techniques using the appropriate channel model(s). Therefore, the TR will be kept up-to-date via CRs in the future.

This document relates to the 3GPP evaluation methodology and covers the modelling of the physical layer of both Mobile Equipment and Access Network of 3GPP systems.

This document is intended to capture the channel model(s) for frequencies from 0.5GHz up to 100GHz.

2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

- [1] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".
- [2] 3GPP TD RP-151606: "Study on channel model for frequency spectrum above 6 GHz".
- [3] 3GPP TR 36.873 (V12.2.0): "Study on 3D channel model for LTE".
- [4] 3GPP RP-151847: "Report of RAN email discussion about >6GHz channel modelling", Samsung.
- [5] 3GPP TD R1-163408: "Additional Considerations on Building Penetration Loss Modelling for 5G System Performance Evaluation", Straight Path Communications.
- [6] ICT-317669-METIS/D1.4: "METIS channel model, METIS 2020, Feb, 2015".
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- [15] 3GPP TR36.101: "User Equipment (UE) radio transmission and reception".
- [16] 3GPP TR36.104: "Base Station (BS) radio transmission and reception".
- [17] Asplund, H., Medbo, J., Göransson, B., Karlsson, J., Sköld, J.: "A simplified approach to applying the 3GPP spatial channel model", in Proc. of PIMRC 2006.
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- [19] ITU-R Rec. P.2040-1: "Effects of building materials and structures on radiowave propagation above about 100 MHz", International Telecommunication Union Radiocommunication Sector ITU-R, 07/2015.
- [20] ITU-R Rec. P.527-3: "Electrical characteristics of the surface of the earth", International Telecommunication Union Radiocommunication Sector ITU-R, 03/1992.
- [21] Jordan, E.C., Balmain, K.G.: "Electromagnetic Waves and Radiating Systems", Prentice-Hall Inc., 1968.
- [22] 3GPP TD RP-162469: "Study on New Radio (NR) Access Technology".
- [23] 3GPP TD RP-182138: "SID on Channel Modeling for Indoor Industrial Scenarios".
- [24] 3GPP TD RP-234018: "New SID: Study on channel modelling enhancements for 7-24GHz for NR".
- [25] 3GPP TD R1-2504960: "Data source descriptions for 7 – 24 GHz SI".
- [26] 3GPP TD RP-242348: "Study on channel modelling for Integrated Sensing And Communication (ISAC) for NR".
- [27] 3GPP TD R1-2504948: "Information on validations for ISAC"

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the terms and definitions given in TR 21.905 [1] apply.

3.2 Symbols

For the purposes of the present document, the following symbols apply:

A	antenna radiation power pattern
A_{\max}	maximum attenuation
d_{2D}	2D distance between Tx and Rx
d_{3D}	3D distance between Tx and Rx

d_H	antenna element spacing in horizontal direction
d_V	antenna element spacing in vertical direction
f	frequency
f_c	center frequency / carrier frequency
$F_{rx,u,\theta}$	Receive antenna element u field pattern in the direction of the spherical basis vector $\hat{\theta}$
$F_{rx,u,\phi}$	Receive antenna element u field pattern in the direction of the spherical basis vector $\hat{\phi}$
$F_{tx,s,\theta}$	Transmit antenna element s field pattern in the direction of the spherical basis vector $\hat{\theta}$
$F_{tx,s,\phi}$	Transmit antenna element s field pattern in the direction of the spherical basis vector $\hat{\phi}$
h_{BS}	antenna height for BS
h_{UT}	antenna height for UT
$\hat{r}_{rx,n,m}$	spherical unit vector of cluster n , ray m , for receiver
$\hat{r}_{tx,n,m}$	spherical unit vector of cluster n , ray m , for transmitter
α	bearing angle
β	downtilt angle
γ	slant angle
λ	wavelength
κ	cross-polarization power ratio in linear scale
μ_{gASA}	mean value of 10-base logarithm of azimuth angle spread of arrival
μ_{gASD}	mean value of 10-base logarithm of azimuth angle spread of departure
μ_{gDS}	mean value of 10-base logarithm of delay spread
μ_{gZSA}	mean value of 10-base logarithm of zenith angle spread of arrival
μ_{gZSD}	mean value of 10-base logarithm of zenith angle spread of departure
Pr_{LOS}	LOS probability
SLA_V	side-lobe attenuation in vertical direction
σ_{gASA}	standard deviation of 10-base logarithm of azimuth angle spread of arrival
σ_{gASD}	standard deviation of 10-base logarithm of azimuth angle spread of departure
σ_{gDS}	standard deviation value of 10-base logarithm of delay spread
σ_{gZSA}	standard deviation of 10-base logarithm of zenith angle spread of arrival
σ_{gZSD}	standard deviation of 10-base logarithm of zenith angle spread of departure
σ_{SF}	standard deviation of SF
ϕ	azimuth angle
θ	zenith angle
$\hat{\phi}$	spherical basis vector (unit vector) for GCS
$\hat{\phi}'$	spherical basis vector (unit vector) for LCS
ϕ_{3dB}	horizontal 3 dB beamwidth of an antenna
$\hat{\theta}$	spherical basis vector (unit vector), orthogonal to $\hat{\phi}$, for GCS
$\hat{\theta}'$	spherical basis vector (unit vector), orthogonal to $\hat{\phi}'$, for LCS
θ_{etilt}	electrical steering angle in vertical direction
θ_{3dB}	vertical 3 dB beamwidth of an antenna
ψ	Angular displacement between two pairs of unit vectors

3.3 Abbreviations

For the purposes of the present document, the abbreviations given in TR 21.905 [1] and the following apply. An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in TR 21.905 [1].

2D	two-dimensional
----	-----------------

3D	three-dimensional
AGV	Automated Guided Vehicles
AOA	Azimuth angle Of Arrival
AOD	Azimuth angle Of Departure
AS	Angular Spread
ASA	Azimuth angle Spread of Arrival
ASD	Azimuth angle Spread of Departure
BF	Beamforming
BS	Base Station
BP	Breakpoint
BW	Beamwidth
CDF	Cumulative Distribution Function
CDL	Clustered Delay Line
CRS	Common Reference Signal
D2D	Device-to-Device
DFT	Discrete Fourier Transform
DS	Delay Spread
EO	Environment Object
GCS	Global Coordinate System
IID	Independent and identically distributed
InF	Indoor Factory
InF-SL	Indoor Factory with Sparse clutter and Low base station height (both Tx and Rx are below the average height of the clutter)
InF-DL	Indoor Factory with Dense clutter and Low base station height (both Tx and Rx are below the average height of the clutter)
InF-SH	Indoor Factory with Sparse clutter and High base station height (Tx or Rx elevated above the clutter)
InF-DH	Indoor Factory with Dense clutter and High base station height (Tx or Rx elevated above the clutter)
InF-HH	Indoor Factory with High Tx and High Rx (both elevated above the clutter)
InH	Indoor Hotspot
IRR	Infrared Reflecting
ISAC	Integrated Sensing and Communication
ISD	Intersite Distance
K	Ricean K factor
LCS	Local Coordinate System
LOS	Line Of Sight
MIMO	Multiple-Input-Multiple-Output
MPC	Multipath Component
NLOS	Non-LOS
O2I	Outdoor-to-Indoor
O2O	Outdoor-to-Outdoor
OFDM	Orthogonal Frequency-Division Multiplexing
PAS	Power angular spectrum
PL	Path Loss
PRB	Physical Resource Block
RCS	Radar cross-section
RMa	Rural Macro
RMS	Root Mean Square
RP	Reference Point
RSRP	Reference Signal Received Power
Rx	Receiver
SCM	Spatial Channel Model
SINR	Signal-to-Interference-plus-Noise Ratio
SIR	Signal-to-Interference Ratio
SSCM	Statistical Spatial Channel Model
SF	Shadow Fading
SLA	Sidelobe Attenuation
SPST	Scattering Point of a ST
SRX	Sensing Receiver
ST	Sensing Target
STX	Sensing Transmitter

TDL	Tapped Delay Line
TOA	Time Of Arrival
TRP	Transmission Reception Point
Tx	Transmitter
UAV	Unmanned Aerial Vehicle
UMa	Urban Macro
UMi	Urban Micro
UT	User Terminal
UTD	Uniform Theory of Diffraction
V2V	Vehicle-to-Vehicle
XPR	Cross-Polarization Ratio
ZOA	Zenith angle Of Arrival
ZOD	Zenith angle Of Departure
ZSA	Zenith angle Spread of Arrival
ZSD	Zenith angle Spread of Departure

4 Introduction

At TSG RAN #69 meeting the Study Item Description on "Study on channel model for frequency spectrum above 6 GHz" was approved [2]. This study item covers the identification of the status/expectation of existing information on high frequencies (e.g. spectrum allocation, scenarios of interest, measurements, etc), and the channel model(s) for frequencies up to 100 GHz. This technical report documents the channel model(s). The new channel model has to a large degree been aligned with earlier channel models for <6 GHz such as the 3D SCM model (TR 36.873) or IMT-Advanced (ITU-R M.2135). The new model supports comparisons across frequency bands over the range 0.5-100 GHz. The modelling methods defined in this technical report are generally applicable over the range 0.5-100 GHz, unless explicitly mentioned otherwise in this technical report for specific modelling method, involved parameters and/or scenario.

Subsequently, at the TSG RAN #81 meeting the Study Item Description "Study on Channel Modeling for Indoor Industrial Scenarios" was approved [23]. The findings from this study item is also captured in the present technical report. The Industrial channel model was developed by considering new measurements and information in the literature. An overview list of all such contributions and sources is available in tdoc R1-1909706.

Subsequently, at the TSG RAN #102 meeting the Study Item Description "Study on channel modelling enhancements for 7-24GHz for NR" was approved [24]. The findings from this study are also captured in the present technical report. Channel modeling was further updated by considering new measurements and information in the literature. An overview of the information sources is available in tdoc R1-2504960 [25].

At TSG RAN #102 meeting the Study Item Description "Study on channel modelling for Integrated Sensing And Communication (ISAC) for NR" was approved. The findings from this study item are captured in Clause 7.9. The ISAC channel model was developed considering new measurements and information in the literature. The RCS validation results are obtained based on certain object sizes. An overview list of the sources is available in [27].

The channel model is applicable for link and system level simulations in the following conditions:

- For system level simulations, supported scenarios are urban microcell street canyon, urban macrocell, indoor office, rural macrocell, indoor factory, and suburban macrocell.
- Bandwidth is supported up to 10% of the center frequency but no larger than 2GHz.
- Mobility of either one end of the link or both ends of the link is supported
- For the stochastic model, spatial consistency is supported by correlation of LSPs and SSPs as well as LOS/NLOS state.
- Large array support is based on far field assumption and stationary channel over the size of the array.
- Near field channel modeling (i.e., characteristics of spherical wavefront) and spatial non-stationarity (i.e., antenna element-wise power variation) are supported.

- The sensing target is assumed in the far field of the sensing transmitter/receiver for the channel model(s) for ISAC in Clause 7.9.

5 Void

6 Status/expectation of existing information on high frequencies

6.1 Channel modelling works outside of 3GPP

This clause summarizes the channel modelling work outside of 3GPP based on the input from companies.

Groups and projects with channel models:

- METIS (Mobile and wireless communications Enablers for the Twenty-twenty Information Society)
- MiWEBA (Millimetre-Wave Evolution for Backhaul and Access)
- ITU-R M
- COST2100
- IEEE 802.11
- NYU WIRELESS: interdisciplinary academic research center
- Fraunhofer HHI has developed the QuaDRiGa channel model, Matlab implementation is available at <http://quadriga-channel-model.de>

Groups and projects which intend to develop channel models:

- 5G mmWave Channel Model Alliance: NIST initiated, North America based
- mmMAGIC (Millimetre-Wave Based Mobile Radio Access Network for Fifth Generation Integrated Communications): Europe based
- IMT-2020 5G promotion association: China based

METIS Channel Models:

- Identified 5G requirements (e.g., wide frequency range, high bandwidth, massive MIMO, 3-D and accurate polarization modelling)
- Performed channel measurements at various bands between 2GHz and 60 GHz
- Provided different channel model methodologies (map-based model, stochastic model or hybrid model). For stochastic model, the proposed channel is focused on outdoor square, Indoor cafeteria and indoor shopping mall scenarios.

MiWEBA Channel Models:

- Addressed various challenges: Shadowing, spatial consistency, environment dynamics, spherical wave modelling, dual mobility Doppler model, ratio between diffuse and specular reflections, polarization
- Proposed Quasi-deterministic channel model
- Performed channel measurements at 60 GHz

- Focused on university campus, street canyon, hotel lobby, backhaul, and D2D scenarios.

ITU-R M Channel Models:

- Addressed the propagation loss and atmospheric loss on mmW
- Introduced enabling antenna array technology and semiconductor technology
- Proposed deployment scenarios, focused on dense urban environment for high data rate service: indoor shopping mall, indoor enterprise, in home, urban hotspot in a square/street, mobility in city.

COST2100 and COST IC1004 Channel Models:

- Geometry-based stochastic channel model that reproduce the stochastic properties of MIMO channels over time, frequency and space. It is a cluster-level model where the statistics of the large scale parameters are always guaranteed in each series of channel instances.

NYU WIRELESS Channel Models:

- Conducted many urban propagation measurements on 28/38/60/73 GHz bands for both outdoor and indoor channels, measurements are continuing.
- Proposed 3 areas for 5G mmWave channel modelling which are small modifications or extensions from 3GPP's current below 6GHz channel models
- 1) LOS/NLOS/blockage modelling (a squared exponential term); 2). Wideband power delay profiles (time clusters and spatial lobes for a simple extension to the existing 3GPP SSCM model); 3). Physics-based path loss model (using the existing 3GPP path loss equations, but simply replacing the "floating" optimization parameter with a deterministic 1 m "close-in" free space reference term in order to provide a standard and stable definition of "path loss exponent" across all different parties, scenarios, and frequencies).

802.11 ad/ay Channel Models:

- Conducted ray-tracing methodology on 60 GHz band indoor channels, including conference room, cubicle, living room scenarios
- Intra cluster parameters were proposed in terms of ray excess delay and ray power distribution
- Human blockage models were proposed in terms of blockage probability and blockage attenuation

5G mmWave Channel Model Alliance:

- Will provide a venue to promote fundamental research into measurement, analysis, identification of physical parameters, and statistical representations of mmWave propagation channels.
- Divided into six collaborative working groups that include a Steering Committee; Modelling Methodology Group; Measurement Methodology Group; and groups that focus on defining and parameterizing Indoor, Outdoor, and Emerging Usage Scenarios.
- Sponsored by Communications Technology Research Laboratory within the NIST.

mmMAGIC:

- Brings together major infrastructure vendors, major European operators, leading research institutes and universities, measurement equipment vendors and one SME.
- Will undertake extensive radio channel measurements in the 6-100 GHz range.
- Will develop and validate advanced channel models that will be used for rigorous validation and feasibility analysis of the proposed concepts and system, as well as for usage in regulatory and standards fora.

IMT-2020 5G promotion association

- Jointly established by three ministries of China based on the original IMT-Advanced promotion group
- Members including the main operators, vendors, universities and research institutes in China