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650 Route des Lucioles
F-06921 Sophia Antipolis Cedex - FRANCE

Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16

Siret N° 348 623 562 00017 - NAF 742 C
Association à but non lucratif enregistrée à la
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Foreword

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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 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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[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".

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 $\hat{\theta}$
$F_{rx,s,\phi}$	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_{lgASA}	mean value of 10-base logarithm of azimuth angle spread of arrival

$\mu_{\lg ASD}$	mean value of 10-base logarithm of azimuth angle spread of departure
$\mu_{\lg DS}$	mean value of 10-base logarithm of delay spread
$\mu_{\lg ZSA}$	mean value of 10-base logarithm of zenith angle spread of arrival
$\mu_{\lg ZSD}$	mean value of 10-base logarithm of zenith angle spread of departure
$\Pr_{LOS}$	LOS probability
SLA_V	side-lobe attenuation in vertical direction
$\sigma_{\lg ASA}$	standard deviation of 10-base logarithm of azimuth angle spread of arrival
$\sigma_{\lg ASD}$	standard deviation of 10-base logarithm of azimuth angle spread of departure
$\sigma_{\lg DS}$	standard deviation value of 10-base logarithm of delay spread
$\sigma_{\lg ZSA}$	standard deviation of 10-base logarithm of zenith angle spread of arrival
$\sigma_{\lg ZSD}$	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
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
GCS	Global Coordinate System
IID	Independent and identically distributed
InH	Indoor Hotspot
IRR	Infrared Reflecting
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
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
TDL	Tapped Delay Line
TOA	Time Of Arrival
TRP	Transmission Reception Point
Tx	Transmitter
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 3GPP 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 (3GPP 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.

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, and rural macrocell.

- Bandwidth is supported up to 10% of the center frequency but no larger than 2GHz.

- Mobility of one end 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.

5 General

6 Status/expectation of existing information on high frequencies

6.1 Channel modelling works outside of 3GPP

This subclause 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
- The major platform to promote 5G technology research in China and to facilitate international communication and cooperation

QuaDRiGa (Fraunhofer HHI)

- QuaDRiGa (QUAsi Deterministic RadIo channel GenerAtor) was developed at the Fraunhofer Heinrich Hertz Institute within the Wireless Communications and Networks Department to enable the modelling of MIMO radio channels for specific network configurations, such as indoor, satellite or heterogeneous configurations.
- Besides being a fully-fledged 3D geometry-based stochastic channel model (well aligned with TR36.873), QuaDRiGa contains a collection of features created in SCM(e) and WINNER channel models along with novel modelling approaches which provide features to enable quasi-deterministic multi-link tracking of users (receiver) movements in changing environments. QuaDRiGa supports Massive MIMO modelling enabled through a new multi-bounce scattering approach and spherical wave propagation. It will be continuously extended with features required by 5G and frequencies beyond 6 GHz. The QuaDRiGa model is supported by data from extensive channel measurement campaigns at 10 / 28 / 43 / 60 / 82 GHz performed by the same group.

6.2 Scenarios of interest

Brief description of the key scenarios of interest identified (see note):

(1) UMi (Street canyon, open area) with O2O and O2I: This is similar to 3D-UMi scenario, where the BSs are mounted below rooftop levels of surrounding buildings. UMi open area is intended to capture real-life scenarios such as a city or station square. The width of the typical open area is in the order of 50 to 100 m.

Example: [Tx height:10m, Rx height: 1.5-2.5 m, ISD: 200m]

(2) UMa with O2O and O2I: This is similar to 3D-UMa scenario, where the BSs are mounted above rooftop levels of surrounding buildings.

Example: [Tx height:25m, Rx height: 1.5-2.5 m, ISD: 500m]

(3) Indoor: This scenario is intended to capture various typical indoor deployment scenarios, including office environments, and shopping malls. The typical office environment is comprised of open cubicle areas, walled offices, open areas, corridors etc. The BSs are mounted at a height of 2-3 m either on the ceilings or walls. The shopping malls are often 1-5 stories high and may include an open area (or "atrium") shared by several floors. The BSs are mounted at a height of approximately 3 m on the walls or ceilings of the corridors and shops.

Example: [Tx height: 2-3m, Rx height: 1.5m, area: 500 square meters]

(4) Backhaul, including outdoor above roof top backhaul in urban area and street canyon scenario where small cell BSs are placed at lamp posts.

(5) D2D/V2V. Device-to-device access in open area, street canyon, and indoor scenarios. V2V is a special case where the devices are mobile.

(6) Other scenarios such as Stadium (open-roof) and Gym (close-roof).

Note: The scenarios of interest are based on the plenary email discussion and different from the supported scenarios in clause 7.

6.3 Channel measurement capabilities

The measurement capability as reported by each company is summarized in the following table.