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Technical Report

3rd Generation Partnership Project;

Technical Specification Group Radio Access Network;

Study on channel model for frequencies from 0.5 to 100 GHz (Release 16)

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# Foreword

This Technical Report has been produced by the 3rd Generation Partnership Project (3GPP).

The contents of the present document are subject to continuing work within the TSG and may change following formal TSG approval. Should the TSG modify the contents of the present document, it will be re-released by the TSG with an identifying change of release date and an increase in version number as follows:

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where:

x the first digit:

1 presented to TSG for information;

2 presented to TSG for approval;

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y the second digit is incremented for all changes of substance, i.e. technical enhancements, corrections, updates, etc.

z the third digit is incremented when editorial only changes have been incorporated in the document.

# 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]" and the study item "Study on Channel Modeling for Indoor Industrial Scenarios [23]". 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.

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[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".

# 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:

 antenna radiation power pattern

 maximum attenuation

*d*2D 2D distance between Tx and Rx

*d*3D3D distance between Tx and Rx

 antenna element spacing in horizontal direction

 antenna element spacing in vertical direction

*f* frequency

*fc* center frequency /carrier frequency

*F*rx,u,θ Receive antenna element *u* field pattern in the direction of the spherical basis vector 

*F*rx,u,ϕ Receive antenna element *u* field pattern in the direction of the spherical basis vector 

*F*tx,s,θ Transmit antenna element *s* field pattern in the direction of the spherical basis vector 

*F*rx,s,ϕ Transmit antenna element *s* field pattern in the direction of the spherical basis vector 

*h*BS antenna height for BS

*h*UT antenna height for UT

 spherical unit vector of cluster *n*, ray *m*, for receiver

 spherical unit vector of cluster *n*, ray *m*, for transmitter

*α* bearing angle

*β* downtilt angle

*γ* slant angle

 wavelength

** cross-polarization power ratio in linear scale

**lgASA mean value of 10-base logarithm of azimuth angle spread of arrival

**lgASD mean value of 10-base logarithm of azimuth angle spread of departure

**lgDSmean value of 10-base logarithm of delay spread

**lgZSAmean value of 10-base logarithm of zenith angle spread of arrival

**lgZSDmean value of 10-base logarithm of zenith angle spread of departure

 LOS probability

 side-lobe attenuation in vertical direction

**lgASA standard deviation of 10-base logarithm of azimuth angle spread of arrival

**lgASD standard deviation of 10-base logarithm of azimuth angle spread of departure

**lgDSstandard deviation value of 10-base logarithm of delay spread

**lgZSA standard deviation of 10-base logarithm of zenith angle spread of arrival

**lgZSD standard deviation of 10-base logarithm of zenith angle spread of departure

 standard deviation of SF

 azimuth angle

 zenith angle

 spherical basis vector (unit vector) for GCS

 spherical basis vector (unit vector) for LCS

 horizontal 3 dB beamwidth of an antenna

 spherical basis vector (unit vector), orthogonal to , for GCS

 spherical basis vector (unit vector), orthogonal to , for LCS

 electrical steering angle in vertical direction

 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

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

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.

Subsequently, at the 3GPP 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.

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, and indoor factory.

- 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.

# 5 General

# 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

- 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](http://www.hhi.fraunhofer.de/wn) 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).

(7) Indoor industrial scenarios

Note: The scenarios of interest are based on the plenary email discussion and different from the supported scenarios in clause 7. The indoor industrial scenarios were identified at a later stage in the 3GPP TSG RAN #81 meeting.

## 6.3 Channel measurement capabilities

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

Table 6.3-1: Channel measurement capabilities

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | 6 - 20 GHz | 20 - 30 GHz | 30 - 60 GHz | >60 GHz |
| Urban macro | CMCC  Nokia/Aalborg | Nokia/Aalborg | NYU |  |
| Urban micro | Aalto University  CMCC  Ericsson  Intel/Fraunhofer HHI  Nokia/Aalborg  NTT DOCOMO  Orange | AT&T  Aalto University  CMCC  Huawei  Intel/Fraunhofer HHI  Nokia/Aalborg  NTT DOCOMO  NYU  Qualcomm  Samsung  CATT  KT  ETRI  ITRI/CCU  ZTE | AT&T  Huawei  Intel/Fraunhofer HHI  NTT DOCOMO  Qualcomm  CATT  ETRI  ITRI/CCU  ZTE | AT&T  Aalto University  Huawei  Intel/Fraunhofer HHI  NYU |
| Indoor | Aalto University  CMCC  Ericsson  Huawei  Intel/Fraunhofer HHI  Nokia/Aalborg  NTT DOCOMO  Orange | AT&T  Alcatel-Lucent  Aalto University  BUPT  CMCC  Huawei  Intel/Fraunhofer HHI  Nokia/Aalborg  NTT DOCOMO  NYU  Qualcomm  Samsung  CATT  KT  ETRI  ITRI/CCU  ZTE | AT&T  Ericsson  Huawei  Intel/Fraunhofer HHI  NTT DOCOMO  NYU  Qualcomm  CATT  ETRI  ITRI/CCU  ZTE | AT&T  Aalto University  Huawei  Intel/Fraunhofer HHI  NYU |
| O2I | Ericsson  Huawei  Intel/Fraunhofer HHI  Nokia/Aalborg  NTT DOCOMO  Orange | AT&T  Alcatel-Lucent  Ericsson  Huawei  Intel/Fraunhofer HHI  NTT DOCOMO  NYU  Samsung  KT | AT&T  Ericsson  Huawei  Intel/Fraunhofer HHI  NTT DOCOMO | AT&T  Huawei  Intel/Fraunhofer HHI |

## 6.4 Modelling objectives

The requirements for channel modelling are as follows.

- Channel model SI should take into account the outcome of RAN-level discussion in the '5G' requirement study item

- Complexity in terms of Description, Generating channel coefficients, development complexity and Simulation time should be considered.

- Support frequency range up to 100 GHz.

- The critical path of the SI is 6 – 100 GHz

- Take care of mmW propagation aspects such as blocking and atmosphere attenuation.

- The model should be consistent in space, time and frequency

- Support large channel bandwidths (up to 10% of carrier frequency)

- Aim for the channel model to cover a range of coupling loss considering current typical cell sizes, e.g. up to km-range macro cells. Note: This is to enable investigation of the relevance of the 5G system using higher frequency bands to existing deployments.

- Accommodate UT mobility

- Mobile speed up to 500 km/h.

- Develop a methodology considering that model extensions to D2D and V2V may be developed in future SI.

- Support large antenna arrays

# 7 Channel model(s) for 0.5-100 GHz

## 7.1 Coordinate system

### 7.1.1 Definition

A coordinate system is defined by the x, y, z axes, the spherical angles and the spherical unit vectors as shown in Figure 7.1.1. Figure 7.1.1 defines the zenith angle  and the azimuth angle in a Cartesian coordinate system. Note that points to the zenith and points to the horizon. The field component in the direction of  is given by and the field component in the direction of  is given by .



Figure 7.1.1: Definition of spherical angles and spherical unit vectors in a Cartesian coordinate system, whereis the given direction,  and are the spherical basis vectors

### 7.1.2 Local and global coordinate systems

A Global Coordinate System (GCS) is defined for a system comprising multiple BSs and UTs. An array antenna for a BS or a UT can be defined in a Local Coordinate System (LCS). An LCS is used as a reference to define the vector far-field that is pattern and polarization, of each antenna element in an array. It is assumed that the far-field is known in the LCS by formulae. The placement of an array within the GCS is defined by the translation between the GCS and a LCS. The orientation of the array with respect to the GCS is defined in general by a sequence of rotations (described in clause 7.1.3). Since this orientation is in general different from the GCS orientation, it is necessary to map the vector fields of the array elements from the LCS to the GCS. This mapping depends only on the orientation of the array and is given by the equations in clause 7.1.3. Note that any arbitrary mechanical orientation of the array can be achieved by rotating the LCS with respect to the GCS.

### 7.1.3 Transformation from a LCS to a GCS

A GCS with coordinates (*x*, *y*, *z*, , ) and unit vectors (, ) and an LCS with "primed" coordinates (*x'*, *y'*, *z'*, , ) and "primed" unit vectors (, ) are defined with a common origins in Figures 7.1.3-1 and 7.1.3-2. Figure 7.1.3-1 illustrates the sequence of rotations that relate the GCS (gray) and the LCS (blue). Figure 7.1.3-2 shows the coordinate direction and unit vectors of the GCS (gray) and the LCS (blue). Note that the vector fields of the array antenna elements are defined in the LCS. In Figure 7.1.3-1 we consider an arbitrary 3D-rotation of the LCS with respect to the GCS given by the angles *α*, *β*, *γ*. The set of angles *α*, *β*, *γ* can also be termed as the orientation of the array antenna with respect to the GCS.

Note that the transformation from a LCS to a GCS depends only on the angles *α*, *β*, *γ*. The angle *α* is called the bearing angle, *β* is called the downtilt angle and *γ* is called the slant angle.

|  |  |
| --- | --- |
|  |  |
| Figure 7.1.3-1: Orienting the LCS (blue) with respect to the GCS (gray) by a sequence of 3 rotations: *α*, *β*, *γ*. | Figure 7.1.3-2: Definition of spherical coordinates and unit vectors in both the GCS and LCS. |

Let denote an antenna element pattern in the LCS and denote the same antenna element pattern in the GCS. Then the two are related simply by

 (7.1-1)

with  and  given by (7.1-7) and (7.1-8).

Let us denote the polarized field components in the LCS by , and in the GCS by , . Then they are related by equation (7.1-11).

Any arbitrary 3D rotation can be specified by at most 3 elemental rotations, and following the framework of Figure 7.1.3-1, a series of rotations about the z, and axes are assumed here, in that order. The dotted and double-dotted marks indicate that the rotations are intrinsic, which means that they are the result of one (⋅) or two (⋅⋅) intermediate rotations. In other words, the  axis is the original y axis after the first rotation about z, and the  axis is the original x axis after the first rotation about z and the second rotation about. A first rotation of *α* about *z* sets the antenna bearing angle (i.e. the sector pointing direction for a BS antenna element). The second rotation of *β* about  sets the antenna downtilt angle. Finally, the third rotation of *γ* about  sets the antenna slant angle. The orientation of the *x*, *y* and *z* axes after all three rotations can be denoted as ,  and . These triple-dotted axes represents the final orientation of the LCS, and for notational purposes denoted as the *x'*, *y'* and *z'* axes (local or "primed" coordinate system).

In order to establish the equations for transformation of the coordinate system and the polarized antenna field patterns between the GCS and the LCS, it is necessary to determine the composite rotation matrix that describes the transformation of point (*x*, *y*, *z*) in the GCS into point (*x'*, *y'*, *z'*) in the LCS. This rotation matrix is computed as the product of three elemental rotation matrices. The matrix to describe rotations about the *z*,and  axes by the angles *α*, *β* and *γ* respectively and in that order is defined as

 (7.1-2)

The reverse transformation is given by the inverse of *R*, which is also equal to the transpose of *R* since it is orthogonal.

 (7.1-3)

The simplified forward and reverse composite rotation matrices are given by

 (7.1-4)

and

 (7.1-5)

These transformations can be used to derive the angular and polarization relationships between the two coordinate systems.

In order to establish the angular relationships, consider a point (*x*, *y*, *z*) on the unit sphere defined by the spherical coordinates (*ρ*=1, *θ*, *φ*), where *ρ* is the unit radius, *θ* is the zenith angle measured from the +*z*-axis, and *φ* is the azimuth angle measured from the +*x*-axis in the *x*-*y* plane. The Cartesian representation of that point is given by

 (7.1-6)

The zenith angle is computed as  and the azimuth angle as , where ,  and  are the Cartesian unit vectors. If this point represents a location in the GCS defined by *θ* and *φ*, the corresponding position in the LCS is given by , from which local angles *θ'* and *φ'* can be computed. The results are given in equations (7.1-7) and (7.1-8).

 (7.1-7)

 (7.1-8)

These formulae relate the spherical angles (*θ*, *φ*) of the GCS to the spherical angles (*θ'*, *φ'*) of the LCS given the rotation operation defined by the angles (*α*, *β*, *γ*).

Let us denote the polarized field components,  in the GCS and,  in the LCS. These are related by

 (7.1-9)

In this equation,  and  represent the spherical unit vectors of the GCS, and  and are the representations in the LCS. The forward rotation matrix R transforms the LCS unit vectors into the GCS frame of reference. These pairs of unit vectors are orthogonal and can be represented as shown in Figure 7.1.3-3.

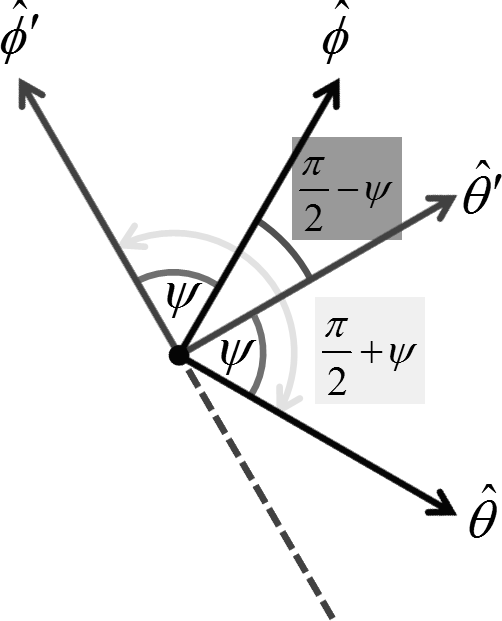


Figure 7.1.3-3: Rotation of the spherical basis vectors by an angle *ψ* due to the orientation of the LCS with respect to the GCS

Assuming an angular displacement of *ψ* between the two pairs of unit vectors, the rotation matrix of equation (7.1-9) can be further simplified as:

 (7.1-10)

and equation (7.1-9) can be written as:

 (7.1-11)

The angle *ψ* can be computed in numerous ways from equation (7.1-10), with one such way approach being

 (7.1-12)

The dot products are readily computed using the Cartesian representation of the spherical unit vectors. The general expressions for these unit vectors are given by

 (7.1-13)

and

 (7.1-14)

The angle *ψ* can be expressed as a function of mechanical orientation (*α*, *β*, *γ*) and spherical position (*θ*, *φ*), and is given by

 (7.1-15)

It can be shown thatandcan be expressed as:

 (7.1-16)

 (7.1-17)

### 7.1.4 Transformation from an LCS to a GCS for downtilt angle only

In this clause equations are provided for the transformation from LCS to GCS assuming that the orientation of the LCS (with respect to the GCS) is such that the bearing angle *α*=0, the downtilt angle *β* is non-zero and the slant angle *γ*=0. In other words the *y'*-axis of the LCS is parallel to the *y*-axis of the GCS. Considering a BS antenna element the *x*-axis of the GCS is aligned with the pointing direction of the sector. Mechanical downtilt is modelled as a rotation of the LCS around the *y*-axis. For zero mechanical downtilt the LCS coincides with the GCS.

This transformation relates the spherical angles (,) in the global coordinate system to spherical angles (,) in the local (antenna-fixed) coordinate system and is defined as follows:

 (7.1-18)

 (7.1-19)

where  is the mechanical tilt angle around the *y*-axis as defined in Figure 7.1.4. Note that the equations (7.1-7), (7.1-8) reduce to equations (7.1-18), (7.1-19) if both *α* and *γ* are zero.

The antenna element pattern in the GCS is related to the antenna element pattern in the LCS by the relation

 (7.1-20)

with  and given by (7.1-18) and (7.1-19).

Figure 7.1.4: Definition of angles and unit vectors when the LCS has been rotated an angle  around the *y*-axis of the GCS

For a mechanical tilt angle , the global coordinate system field components  and , are calculated from the field components  and  of the radiation pattern in the local (antenna-fixed) coordinate system as:

 (7.1-21)

 (7.1-22)

where  and  are defined as in (7.1-18) and (7.1-19), and  is defined as:

. (7.1-23)

Note that the equation (7.1-15) is reduced to equation (7.1-23) if both α and γ are zero.

As an example, in the horizontal cut, i.e., for , equations (7.1-18), (7.1-19) and (7.1-23) become

 (7.1-24)

 (7.1-25)

 (7.1-26)

## 7.2 Scenarios

The detailed scenario description in this clause can be used for channel model calibration.

**UMi-street canyon and UMa**

Details on UMi-street canyon and UMa scenarios are listed in Table 7.2-1.

Table 7.2-1: Evaluation parameters for UMi-street canyon and UMa scenarios

|  |  |  |  |
| --- | --- | --- | --- |
| Parameters | | UMi - street canyon | UMa |
| Cell layout | | Hexagonal grid, 19 micro sites, 3 sectors per site (ISD = 200m) | Hexagonal grid, 19 macro sites, 3 sectors per site (ISD = 500m) |
| BS antenna height | | 10m | 25m |
| UT location | Outdoor/indoor | Outdoor and indoor | Outdoor and indoor |
| LOS/NLOS | LOS and NLOS | LOS and NLOS |
| Height | Same as 3D-UMi in TR36.873 | Same as 3D-UMa in TR36.873 |
| Indoor UT ratio | | 80% | 80% |
| UT mobility (horizontal plane only) | | 3km/h | 3km/h |
| Min. BS - UT distance (2D) | | 10m | 35m |
| UT distribution (horizontal) | | Uniform | Uniform |

**Indoor-office**

Details on indoor-office scenarios are listed in Table 7.2-2 and presented in Figure 7.2-1. More details, if necessary, can be added to Figure 7.2-1.

Table 7.2-2: Evaluation parameters for indoor-office scenarios

|  |  |  |  |
| --- | --- | --- | --- |
| Parameters | | Indoor - office  open office | Indoor - office  mixed office |
| Layout | Room size (WxLxH) | 120mx50mx3m | |
| ISD | 20m | |
| BS antenna height | | 3 m (ceiling) | |
| UT location | LOS/NLOS | LOS and NLOS | |
| Height | 1 m | |
| UT mobility (horizontal plane only) | | 3 km/h | |
| Min. BS - UT distance (2D) | | 0 | |
| UT distribution (horizontal) | | Uniform | |

Note: The only difference between the open office and mixed office models in this TR is the line of sight probability.

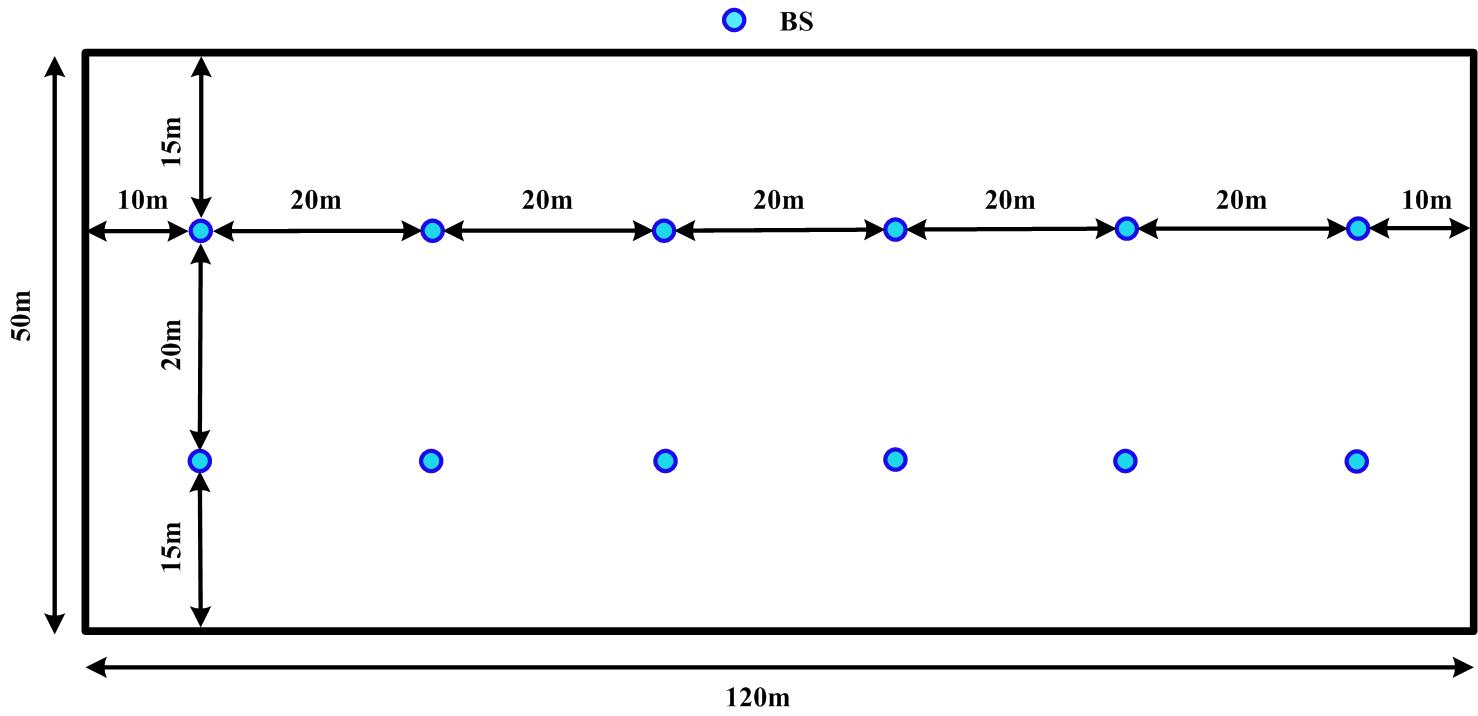


Figure 7.2-1: Layout of indoor office scenarios.

**RMa**

The rural deployment scenario focuses on larger and continuous coverage. The key characteristics of this scenario are continuous wide area coverage supporting high speed vehicles. This scenario will be noise-limited and/or interference-limited, using macro TRPs. Details of RMa scenario is described in Table 7.2-3.

Table 7.2-3: Evaluation parameters for RMa

|  |  |
| --- | --- |
| Parameters | RMa |
| Carrier Frequency | Up to 7Ghz |
| BS height | 35m |
| Layout | Hexagonal grid, 19 Macro sites, 3sectors per site, ISD = 1732m or 5000m |
| UT height | 1.5m |
| UT distribution | Uniform |
| Indoor/Outdoor | 50% indoor and 50% in car |
| LOS/NLOS | LOS and NLOS |
| Min BS - UT distance(2D) | 35m |

**Indoor Factory (InF)**

The indoor factory (InF) scenario focuses on factory halls of varying sizes and with varying levels of density of "clutter", e.g. machinery, assembly lines, storage shelves, etc. Details of the InF scenario are listed in Table 7.2-4.

Table 7.2-4: Evaluation parameters for InF

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | | InF | | | | |
| Parameters | | InF-SL  (sparse clutter, low BS) | InF-DL  (dense clutter, low BS) | InF-SH  (sparse clutter, high BS) | InF-DH  (dense clutter, high BS) | InF-HH  (high Tx, high Rx) |
| Layout | Room size | Rectangular: 20-160000 m2 | | | | |
| Ceiling height | 5-25 m | 5-15 m | 5-25 m | 5-15 m | 5-25 m |
|  | Effective clutter height | < Ceiling height, 0-10 m | | | | |
|  | External wall and ceiling type | Concrete or metal walls and ceiling with metal-coated windows | | | | |
| Clutter type | | Big machineries composed of regular metallic surfaces.  For example: several mixed production areas with open spaces and storage/commissioning areas | Small to medium metallic machinery and objects with irregular structure.  For example: assembly and production lines surrounded by mixed small-sized machineries. | Big machineries composed of regular metallic surfaces.  For example: several mixed production areas with open spaces and storage/commissioning areas | Small to medium metallic machinery and objects with irregular structure.  For example: assembly and production lines surrounded by mixed small-sized machineries. | Any |
| Typical clutter size, | | 10 m | 2 m | 10 m | 2 m | Any |
| Clutter density (percentage of surface area occupied by clutter) | | Low clutter density  (<40%) | High clutter density  (≥40%) | Low clutter density  (<40%) | High clutter density  (≥40%) | Any |
| BS antenna height cid:image001.png@01D4B35D.C4D8CCE0 | | Clutter-embedded, i.e. the BS antenna height is below the average clutter height | | Above clutter | | Above clutter |
| UT location | LOS/NLOS | LOS and NLOS | | | | 100% LOS |
| Height cid:image003.png@01D4B35D.C4D8CCE0 | Clutter-embedded | | | | Above clutter |

## 7.3 Antenna modelling

*This clause captures the antenna array structures considered in this SI for calibration.*

The BS antenna is modelled by a uniform rectangular panel array, comprising *MgNg*panels, as illustrated in Figure 7.3-1 with *Mg* being the number of panels in a column and *Ng* being the number of panels in a row. Furthermore the following properties apply:

- Antenna panels are uniformly spaced in the horizontal direction with a spacing of *dg,H* and in the vertical direction with a spacing of *dg,V*.

- On each antenna panel, antenna elements are placed in the vertical and horizontal direction, where *N* is the number of columns, *M* is the number of antenna elements with the same polarization in each column.

- Antenna numbering on the panel illustrated in Figure 7.3-1 assumes observation of the antenna array from the front (with x-axis pointing towards broad-side and increasing y-coordinate for increasing column number).

- The antenna elements are uniformly spaced in the horizontal direction with a spacing of *dH* and in the vertical direction with a spacing of *dV*.

- The antenna panel is either single polarized (*P* =1) or dual polarized (*P* =2).

The rectangular panel array antenna can be described by the following tuple .



Figure 7.3-1: Cross-polarized panel array antenna model

The antenna radiation power pattern of each antenna element is generated according to Table 7.3-1.

Table 7.3-1: Radiation power pattern of a single antenna element

|  |  |
| --- | --- |
| **Parameter** | **Values** |
| Vertical cut of the radiation power pattern (dB) |  |
| Horizontal cut of the radiation power pattern (dB) |  |
| 3D radiation power pattern (dB) |  |
| Maximum directional gain of an antenna element *GE,max* | 8 dBi |

### 7.3.1 Antenna port mapping

Legacy BS array antennas, i.e. uniform linear arrays with fix phase shifts between its *M* elements to obtain a beamtilt in vertical direction are modelled using complex weights

 (7.3-1)

where *m*=*1, …, M*,  is the electrical vertical steering angle defined between 0° and 180° (90° represents perpendicular to the array).  denotes the wavelength and  the vertical element spacing.

### 7.3.2 Polarized antenna modelling

In general the relationship between radiation field and power pattern is given by:

. (7.3-2)

The following two models represent two options on how to determine the radiation field patterns based on a defined radiation power pattern.

**Model-1**:

In case of polarized antenna elements assume  is the polarization slant angle where  degrees corresponds to a purely vertically polarized antenna element and degrees correspond to a pair of cross-polarized antenna elements. Then the antenna element field components in  and  direction are given by

 (7.3-3)

where , .

Note that the zenith and the azimuth field components , ,  and  are defined in terms of the spherical basis vectors of an LCS as defined in Clause 7.1. The difference between the single-primed and the double-primed components is that the single-primed field components account for the polarization slant and the double-primed field components do not. For a single polarized antenna (purely vertically polarized antenna) we can write  and  where is the 3D antenna radiation power pattern as a function of azimuth angle  and zenith angle  in the LCS as defined in Table 7.3-1 converted into linear scale.

**Model-2**:

In case of polarized antennas, the polarization is modelled as angle-independent in both azimuth and elevation, in an LCS. For a linearly polarized antenna, the antenna element field pattern, in the vertical polarization and in the horizontal polarization, are given by

 (7.3-4)

and

, (7.3-5)

respectively, where  is the polarization slant angle and is the 3D antenna element power pattern as a function of azimuth angle,  and elevation angle, in the LCS. Note that  degrees correspond to a purely vertically polarized antenna element. The vertical and horizontal field directions are defined in terms of the spherical basis vectors,  and  respectively in the LCS as defined in Clause 7.1.2. Also =, = and =  as defined in Table 7.1-1.

## 7.4 Pathloss, LOS probability and penetration modelling

### 7.4.1 Pathloss

The pathloss models are summarized in Table 7.4.1-1 and the distance definitions are indicated in Figure 7.4.1-1 and Figure 7.4.1-2. Note that the distribution of the shadow fading is log-normal, and its standard deviation for each scenario is given in Table 7.4.1-1.

|  |  |
| --- | --- |
|  |  |
| Figure7.4.1-1: Definition of *d2D* and *d3D*  for outdoor UTs | Figure 7.4.1-2: Definition of *d2D-out*, *d2D-in*  and *d3D-out*, *d3D-in* for indoor UTs. |

Note that

 (7.4-1)

Table 7.4.1-1: Pathloss models

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Scenario | LOS/NLOS | Pathloss [dB], *fc* is in GHz and *d* is in meters, see note 6 | Shadow  fading  std [dB] | Applicability range,  antenna height  default values |
| RMa | LOS | , see note 5 |  | h = avg. building height  W = avg. street width  The applicability ranges: |
| NLOS | for |  |
| UMa | LOS | , see note 1 |  |  |
| NLOS | for |  | Explanations: see note 3 |
| Optional |  |  |
| UMi - Street Canyon | LOS | , see note 1 |  |  |
| NLOS | for |  | Explanations: see note 4 |
| Optional |  |  |
| InH - Office | LOS |  |  |  |
| NLOS |  |  |  |
| Optional |  |  |
| InF | LOS |  |  |  |
| NLOS | InF-SL: |  |
| InF-DL: |  |
| InF-SH: |  |
| InF-DH: |  |
| Note 1: Breakpoint distance *d*'BP = 4 *h*'BS *h*'UT *f*c/*c*, where *f*c is the centre frequency in Hz, *c* = 3.0×108 m/s is the propagation velocity in free space, and *h*'BS and *h*'UT are the effective antenna heights at the BS and the UT, respectively. The effective antenna heights *h*'BS and *h*'UT are computed as follows: *h*'BS = *h*BS – *h*E, *h*'UT = *h*UT – *h*E, where *h*BS and *h*UT are the actual antenna heights, and hE is the effective environment height. For UMi *h*E = 1.0m. For UMa *h*E=1m with a probability equal to 1/(1+C(*d*2D, *h*UT)) and chosen from a discrete uniform distribution uniform(12,15,…,(*h*UT-1.5)) otherwise. With C(*d*2D, *h*UT) given by  ,  where  .  Note that *h*E depends on *d*2D and *h*UT and thus needs to be independently determined for every link between BS sites and UTs. A BS site may be a single BS or multiple co-located BSs.  Note 2: The applicable frequency range of the PL formula in this table is 0.5 < *fc* < *f*H GHz, where *f*H = 30 GHz for RMa and *f*H = 100 GHz for all the other scenarios. It is noted that RMa pathloss model for >7 GHz is validated based on a single measurement campaign conducted at 24 GHz.  Note 3: UMa NLOS pathloss is from TR36.873 with simplified format and PLUMa-LOS = Pathloss of UMa LOS outdoor scenario.  Note 4: PLUMi-LOS = Pathloss of UMi-Street Canyon LOS outdoor scenario.  Note 5: Break point distance *dBP* = 2π *hBS* *hUT* *fc*/*c*, where *fc* is the centre frequency in Hz, *c* = 3.0 × 108 m/s is the propagation velocity in free space, and *hBS* and *hUT* are the antenna heights at the BS and the UT, respectively.  Note 6: *fc* denotes the center frequency normalized by 1GHz, all distance related values are normalized by 1m, unless it is stated otherwise. | | | | |

### 7.4.2 LOS probability

The Line-Of-Sight (LOS) probabilities are given in Table 7.4.2-1.

Table 7.4.2-1 LOS probability

|  |  |
| --- | --- |
| Scenario | LOS probability (distance is in meters) |
| RMa |  |
| UMi - Street canyon |  |
| UMa | where |
| Indoor - Mixed office |  |
| Indoor - Open office |  |
| InF-SL  InF-SH  InF-DL  InF-DH | where  The parameters , , and are defined in Table 7.2-4 |
| InF-HH |  |
| Note: The LOS probability is derived with assuming antenna heights of 3m for indoor, 10m for UMi, and 25m for UMa | |

### 7.4.3 O2I penetration loss

#### 7.4.3.1 O2I building penetration loss

The pathloss incorporating O2I building penetration loss is modelled as in the following:

 (7.4-2)

where  is the basic outdoor path loss given in Clause 7.4.1, where  is replaced by  .  is the building penetration loss through the external wall,  is the inside loss dependent on the depth into the building, and σ*P* is the standard deviation for the penetration loss.

 is characterized as:

 (7.4-3)

 is an additional loss is added to the external wall loss to account for non-perpendicular incidence; , is the penetration loss of material *i*, example values of which can be found in Table 7.4.3-1;  is proportion of *i*-th materials, where ; and *N* is the number of materials.

Table 7.4.3-1: Material penetration losses

|  |  |
| --- | --- |
| Material | Penetration loss [dB] |
| Standard multi-pane glass |  |
| IRR glass |  |
| Concrete |  |
| Wood |  |
| Note: f is in GHz | |

Table 7.4.3-2 gives ,  and σ*P* for two O2I penetration loss models. The O2I penetration is UT-specifically generated, and is added to the SF realization in the log domain.

Table 7.4.3-2: O2I building penetration loss model

|  |  |  |  |
| --- | --- | --- | --- |
|  | Path loss through external wall:  in [dB] | Indoor loss:  in [dB] | Standard deviation:  σ*P* in [dB] |
| **Low-loss model** |  | 0.5 | 4.4 |
| **High-loss model** |  | 0.5 | 6.5 |

 is minimum of two independently generated uniformly distributed variables between 0 and 25 m for UMa and UMi-Street Canyon, and between 0 and 10 m for RMa.  shall be UT-specifically generated.

Both low-loss and high-loss models are applicable to UMa and UMi-Street Canyon.

Only the low-loss model is applicable to RMa.

Only the high-loss model is applicable to InF.

The composition of low and high loss is a simulation parameter that should be determined by the user of the channel models, and is dependent on the use of metal-coated glass in buildings and the deployment scenarios. Such use is expected to differ in different markets and regions of the world and also may increase over years to new regulations and energy saving initiatives. Furthermore, the use of such high-loss glass currently appears to be more predominant in commercial buildings than in residential buildings in some regions of the world (see note).

Note: One example survey for the US market can be found in [5]. The survey does not necessarily be representative for all the scenarios. Other ratios outside of the survey should not be precluded.

For backwards compatibility with TR 36.873 [3], the following building penetration model should be used for UMa and UMi single-frequency simulations at frequencies below 6 GHz.

Table 7.4.3-3. O2I building penetration loss model for single-frequency simulations <6 GHz

|  |  |
| --- | --- |
| Parameter | Value |
|  | 20 dB |
|  | 0.5  with  being *a single, link-specific,* uniformly distributed variable between 0 and 25 m |
|  | 0 dB |
|  | 7 dB (note: replacing the respective value in Table 7.4.1-1) |

#### 7.4.3.2 O2I car penetration loss

The pathloss incorporating O2I car penetration loss is modelled as in the following:

 (7.4-4)

where  is the basic outdoor path loss given in Clause 7.4.1. *μ* = 9, and σ*P* = 5. The car penetration loss shall be UT-specifically generated. Optionally, for metallized car windows, *μ* = 20 can be used. The O2I car penetration loss models are applicable for at least 0.6-60 GHz.

### 7.4.4 Autocorrelation of shadow fading

The long-term (log-normal) fading in the logarithmic scale around the mean path loss *PL* (dB) is characterized by a Gaussian distribution with zero mean and standard deviation. Due to the slow fading process versus distance *x*   
(*x* is in the horizontal plane), adjacent fading values are correlated. Its normalized autocorrelation function *R*(*x*) can be described with sufficient accuracy by the exponential function ITU-R Rec. P.1816 [18]

 (7.4-5)

with the correlation length *dcor* being dependent on the environment, see the correlation parameters for shadowing and other large scale parameters in Table 7.5-6 (Channel model parameters). In a spatial consistency procedure in Clause 7.6.3, the cluster specific random variables are also correlated following the exponential function with respect to correlation distances in the two dimensional horizontal plane.

## 7.5 Fast fading model

The radio channel realizations are created using the parameters listed in Table 7.5-1. The channel realizations are obtained by a step-wise procedure illustrated in Figure 7.5-1 and described below. It has to be noted that the geometric description covers arrival angles from the last bounce scatterers and respectively departure angles to the first scatterers interacted from the transmitting side. The propagation between the first and the last interaction is not defined. Thus, this approach can model also multiple interactions with the scattering media. This indicates also that e.g., the delay of a multipath component cannot be determined by the geometry. In the following steps, downlink is assumed. For uplink, arrival and departure parameters have to be swapped.

Note: the channel generation in this clause is enough for at least the following cases.

- Case 1: For low complexity evaluations

- Case 2: To compare with earlier simulation results,

- Case 3: When none of the additional modelling components are turned on.

For other advanced simulations, e.g., spatially consistency, large bandwidth and arrays, oxygen absorption, blockage, absolute time of arrival, dual mobility, embedded devices, etc., some of the additional modelling components of Clause 7.6 should be considered.



Figure 7.5-1 Channel coefficient generation procedure

Figure 7.5-2: Definition of a global coordinate system showing the zenith angle *θ* and the azimuth angle *ϕ*. *θ=*0° points to zenith and *θ=*+90° points to the horizon.   
The spherical basis vectors  and  shown above are defined based on the direction of propagation.

Table 7.5-1: Notations in the global coordinate system (GCS)

|  |  |
| --- | --- |
| Parameter | Notation |
| LOS AOD | ϕLOS,AOD |
| LOS AOA | ϕLOS,AOA |
| LOS ZOD | θLOS,ZOD |
| LOS ZOA | θLOS,ZOA |
| AOA for cluster *n* | ϕn,AOA |
| AOD for cluster *n* | ϕn,AOD |
| AOA for ray *m* in cluster *n* | ϕn,m,AOA |
| AOD for ray *m* in cluster *n* | ϕn,m,AOD |
| ZOA for cluster *n* | θn,ZOA |
| ZOD for cluster *n* | θn,ZOD |
| ZOA for ray *m* in cluster *n* | θn,m,ZOA |
| ZOD for ray *m* in cluster *n* | θn,m,ZOD |
| Receive antenna element *u* field pattern in the direction of the spherical basis vector | Frx,u,θ |
| Receive antenna element *u* field pattern in the direction of the spherical basis vector | Frx,u,ϕ |
| Transmit antenna element *s* field pattern in the direction of the spherical basis vector | Ftx,s,θ |
| Transmit antenna element *s* field pattern in the direction of the spherical basis vector | Frx,s,ϕ |

Step 1: Set environment, network layout, and antenna array parameters

a) Choose one of the scenarios (e.g. UMa, UMi-Street Canyon, RMa, InH-Office or InF). Choose a global coordinate system and define zenith angle *θ*, azimuth angle *ϕ*, and spherical basis vectors ,  as shown in Figure 7.3-2. Note: Scenario RMa is for up to 7GHz while others are for up to 100GHz

b) Give number of BS and UT

c) Give 3D locations of BS and UT, and determine LOS AOD (*ϕLOS,AOD*), LOS ZOD (*θLOS,ZOD*), LOS AOA (*ϕLOS,AOA*), and LOS ZOA (*θLOS,ZOA*) of each BS and UT in the global coordinate system

d) Give BS and UT antenna field patterns *Frx* and *Ftx* in the global coordinate system and array geometries

e) Give BS and UT array orientations with respect to the global coordinate system. BS array orientation is defined by three angles Ω*BS,α* (BS bearing angle), Ω*BS,β* (BS downtilt angle) and Ω*BS,γ* (BS slant angle). UT array orientation is defined by three angles Ω*UT,α* (UT bearing angle), Ω*UT,β* (UT downtilt angle) and Ω*UT,γ* (UT slant angle).

f) Give speed and direction of motion of UT in the global coordinate system

g) Specify system centre frequency  and bandwidth 

Note: In case wrapping is used, each wrapping copy of a BS or site should be treated as a separate BS/site considering channel generation.

**Large scale parameters:**

Step 2: Assign propagation condition (LOS/NLOS) according to Table 7.4.2-1. The propagation conditions for different BS-UT links are uncorrelated.

Also, assign an indoor/outdoor state for each UT. It is noted that all the links from a UT have the same indoor/outdoor state.

Step 3: Calculate pathloss with formulas in Table 7.4.1-1 for each BS-UT link to be modelled.

Step 4: Generate large scale parameters, e.g. delay spread (DS), angular spreads (ASA, ASD, ZSA, ZSD), Ricean K factor (K) and shadow fading (SF) taking into account cross correlation according to Table 7.5-6 and using the procedure described in clause 3.3.1 of [14] with the square root matrixbeing generated using the Cholesky decomposition and the following order of the large scale parameter vector: **s***M* = [*sSF, sK, sDS, sASD, sASA, sZSD, sZSA*]*T*.

These LSPs for different BS-UT links are uncorrelated, but the LSPs for links from co-sited sectors to a UT are the same. In addition, these LSPs for the links of UTs on different floors are uncorrelated.

Limit random RMS azimuth arrival and azimuth departure spread values to 104 degrees, i.e., ASA= min(ASA, 104°), ASD= min(ASD, 104°). Limit random RMS zenith arrival and zenith departure spread values to 52 degrees, i.e., ZSA= min(ZSA, 52°), ZSD= min(ZSD, 52°).

**Small scale parameters:**

Step 5: Generate cluster delays **

Delays are drawn randomly from the delay distribution defined in Table 7.5-6. With exponential delay distribution calculate

, (7.5-1)

Where *r* is the delay distribution proportionality factor, *Xn* ~ uniform(0,1), and cluster index *n* = 1,…,*N*. With uniform delay distribution the delay values are drawn from the corresponding range. Normalise the delays by subtracting the minimum delay and sort the normalised delays to ascending order:

. (7.5-2)

*In the case of LOS condition,* additional scaling of delays is required to compensate for the effect of LOS peak addition to the delay spread. The heuristically determined Ricean K-factor dependent scaling constant is

, (7.5-3)

where *K* [dB] is the Ricean K-factor as generated in Step 4. The scaled delays

, (7.5-4)

are **not** to be used in cluster power generation.

Step 6: Generate cluster powers .

Cluster powers are calculated assuming a single slope exponential power delay profile. Power assignment depends on the delay distribution defined in Table 7.5-6. With exponential delay distribution the cluster powers are determined by

 (7.5-5)

where  is the per cluster shadowing term in [dB]. Normalize the cluster powers so that the sum of all cluster powers is equal to one, i.e.,

 (7.5-6)

*In the case of LOS condition* an additional specular component is added to the first cluster. Power of the single LOS ray is:

 (7.5-7)

and the cluster powers are not normalized as in equation (7.5-6) , but:

 (7.5-8)

where δ(.) is Dirac's delta function and *KR* is the Ricean *K*-factor as generated in Step 4 converted to linear scale. These power values are used *only* in equations (7.5-9) and (7.5-14), but *not* in equation (7.5-22).

Assign the power of each ray within a cluster as *Pn/ M*, where *M* is the number of rays per cluster.

Remove clusters with less than -25 dB power compared to the maximum cluster power. The scaling factors need not be changed after cluster elimination.

Step 7: Generate arrival angles and departure angles for both azimuth and elevation.

The composite PAS in azimuth of all clusters is modelled as wrapped Gaussian. The AOAs are determined by applying the inverse Gaussian function (7.5-9) with input parameters *Pn* and RMS angle spread ASA

, (7.5-9)

with  defined as

, (7.5-10)

where  is defined as a scaling factor related to the total number of clusters and is given in Table 7.5-2:

Table 7.5-2: Scaling factors for AOA, AOD generation

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| # clusters | 4 | 5 | 8 | 10 | 11 | 12 | 14 | 15 | 16 | 19 | 20 | 25 |
|  | 0.779 | 0.860 | 1.018 | 1.090 | 1.123 | 1.146 | 1.190 | 1.211 | 1.226 | 1.273 | 1.289 | 1.358 |

*In the LOS case,* constant  also depends on the Ricean K-factor *K* in [dB], as generated in Step 4. Additional scaling of the angles is required to compensate for the effect of LOS peak addition to the angle spread.

Assign positive or negative sign to the angles by multiplying with a random variable *Xn* with uniform distribution to the discrete set of {1,–1}, and add component  to introduce random variation

, (7.5-11)

where *ϕLOS,AOA* is the LOS direction defined in the network layout description, see Step1c.

*In the LOS case,* substitute (7.5-11) by (7.5-12) to enforce the first cluster to the LOS direction *ϕLOS, AOA*

 (7.5-12)

Finally add offset angles *m* from Table 7.5-3 to the cluster angles

, (7.5-13)

where *cASA* is the cluster-wise rms azimuth spread of arrival angles (cluster ASA) in Table 7.5-6.

Table 7.5-3: Ray offset angles within a cluster, given for rms angle spread normalized to 1

|  |  |
| --- | --- |
| Ray number *m* | Basis vector of offset angles *m* |
| 1,2 | ± 0.0447 |
| 3,4 | ± 0.1413 |
| 5,6 | ± 0.2492 |
| 7,8 | ± 0.3715 |
| 9,10 | ± 0.5129 |
| 11,12 | ± 0.6797 |
| 13,14 | ± 0.8844 |
| 15,16 | ± 1.1481 |
| 17,18 | ± 1.5195 |
| 19,20 | ± 2.1551 |

The generation of AOD () follows a procedure similar to AOA as described above.

The generation of ZOA assumes that the composite PAS in the zenith dimension of all clusters is Laplacian (see Table 7.5-6). The ZOAs are determined by applying the inverse Laplacian function (7.5-14) with input parameters *Pn* and RMS angle spread ZSA

, (7.5-14)

with  defined as

, (7.5-15)

Where  is a scaling factor related to the total number of clusters and is given in Table 7.5-4:

Table 7.5-4: Scaling factors for ZOA, ZOD generation

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| # clusters | 8 | 10 | 11 | 12 | 15 | 19 | 20 | 25 |
|  | 0.889 | 0.957 | 1.031 | 1.104 | 1.1088 | 1.184 | 1.178 | 1.282 |

*In the LOS case,* constant  also depends on the Ricean K-factor *K* in [dB], as generated in Step 4. Additional scaling of the angles is required to compensate for the effect of LOS peak addition to the angle spread.

Assign positive or negative sign to the angles by multiplying with a random variable *Xn* with uniform distribution to the discrete set of {1,–1}, and add component  to introduce random variation

, (7.5-16)

where  if the BS-UT link is O2I and otherwise. The LOS direction is defined in the network layout description, see Step1c.

*In the LOS case,* substitute (7.5-16) by (7.5-17) to enforce the first cluster to the LOS direction *θLOS,ZOA*

. (7.5-17)

Finally add offset angles *m* from Table 7.5-3 to the cluster angles

, (7.5-18)

where *cZSA* is the cluster-wise rms spread of ZOA (cluster ZSA) in Table 7.5-6. Assuming that is wrapped within [0, 360°], if , thenis set to .

The generation of ZOD follows the same procedure as ZOA described above except equation (7.5-16) is replaced by

, (7.5-19)

where variable *Xn* is with uniform distribution to the discrete set of {1,–1}, , is given in Tables 7.5-6/7/8 and equation (7.5-18) is replaced by

 (7.5-20)

where is the mean of the ZSD log-normal distribution.

*In the LOS case,* the generation of ZOD follows the same procedure as ZOA described above using equation (7.5-17).

Step 8: Coupling of rays within a cluster for both azimuth and elevation

Couple randomly AOD angles *φn,m,AOD* to AOA angles *φn,m,AOA* within a cluster *n*, or within a sub-cluster in the case of two strongest clusters (see Step 11 and Table 7.5-3). Couple randomly ZOD angles  with ZOA angles using the same procedure. Couple randomly AOD angles *φn,m,AOD* with ZOD angles within a cluster *n* or within a sub-cluster in the case of two strongest clusters.

Step 9: Generate the cross polarization power ratios

Generate the cross polarization power ratios (XPR) **for each ray *m* of each cluster *n*. XPR is log-Normal distributed. Draw XPR values as

, (7.5-21)

where  is Gaussian distributed with and  from Table 7.5-6.

Note:  is independently drawn for each ray and each cluster.

The outcome of Steps 1-9 shall be identical for all the links from co-sited sectors to a UT.

**Coefficient generation:**

Step 10: Draw initial random phases

Draw random initial phase  for each ray *m* of each cluster *n* and for four different polarisation combinations (*θθ*, *θϕ,* *ϕθ,* *ϕϕ*). The distribution for initial phases is uniform within (-**).

Step 11: Generate channel coefficients for each cluster *n* and each receiver and transmitter element pair *u, s*.

The method described below is used at least for *drop-based evaluations* irrespective of UT speeds. Relevant cases for drop-based evaluations are:

- Case 1: For low complexity evaluations

- Case 2: To compare with earlier simulation results,

- Case 3: When none of the additional modelling components are turned on.

- Case 4: When spatial consistency and/or blockage is modeled for MU-MIMO simulations

- Other cases are not precluded

*For the N – 2 weakest clusters*, say *n* = 3, 4,…, *N*, the channel coefficients are given by:

 (7.5-22)

where *Frx,u,θ* and *Frx,u,ϕ* are the field patterns of receive antenna element *u* according to (7.1-11) and in the direction of the spherical basis vectors,  and  respectively, *Ftx,s,θ* and *Ftx,s,ϕ* are the field patterns of transmit antenna element *s* in the direction of the spherical basis vectors,  and  respectively. Note that the patterns are given in the GCS and therefore include transformations with respect to antenna orientation as described in Clause 7.1.  is the spherical unit vector with azimuth arrival angle *ϕn,m,AOA* and elevation arrival angle *θn,m,ZOA*, given by

, (7.5-23)

where *n* denotes a cluster and *m* denotes a ray within cluster *n*.  is the spherical unit vector with azimuth departure angle *ϕn,m,AOD* and elevation departure angle *θn,m,ZOD*, given by

, (7.5-24)

where *n* denotes a cluster and *m* denotes a ray within cluster *n*. Also, is the location vector of receive antenna element *u* and is the location vector of transmit antenna element *s*, *n,m* is the cross polarisation power ratio in linear scale, and **0 is the wavelength of the carrier frequency. If polarisation is not considered, the 2x2 polarisation matrix can be replaced by the scalar  and only vertically polarised field patterns are applied.

The Doppler frequency component depends on the arrival angles (AOA, ZOA), and the UT velocity vector with speed *v*, travel azimuth angle *ϕv*, elevation angle *θv* and is given by

 (7.5-25)

*For the two strongest clusters*, say *n* = 1 and 2, rays are spread in delay to three sub-clusters (per cluster), with fixed delay offset. The delays of the sub-clusters are

 (7.5-26)

where  is cluster delay spread specified in Table 7.5-6. When intra-cluster delay spread is unspecified (i.e., N/A) the value 3.91 ns is used; it is noted that this value results in the legacy behaviour with 5 and 10 ns sub-cluster delays.

Twenty rays of a cluster are mapped to sub-clusters as presented in Table 7.5-5 below. The corresponding offset angles are taken from Table 7.5-3 with mapping of Table 7.5-5.

Table 7.5-5: Sub-cluster information for intra cluster delay spread clusters

|  |  |  |  |
| --- | --- | --- | --- |
| sub-cluster # | mapping to rays | Power | delay offset |
|  |  | 10/20 | 0 |
|  |  | 6/20 | 1.28 |
|  |  | 4/20 | 2.56 |

Then, the channel impulse response is given by:

 (7.5-27)

where  is given in (7.5-22) and  defined as:

 (7.5-28)

*In the LOS case,* determine the LOS channel coefficient by:

 (7.5-29)

where **(**.**) is the Dirac's delta function and *KR* is the Ricean K-factor as generated in Step 4 converted to linear scale.

Then, the channel impulse response is given by adding the LOS channel coefficient to the NLOS channel impulse response and scaling both terms according to the desired K-factor  as

. (7.5-30)

Step 12: Apply pathloss and shadowing for the channel coefficients.

Table 7.5-6 Part-1: Channel model parameters for UMi-Street Canyon and UMa

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Scenarios | | UMi - Street Canyon | | | UMa | | |
| LOS | NLOS | O2I | LOS | NLOS | O2I |
| Delay spread (DS)  lgDS=log10(DS/1s) | **lgDS | -0.24 log10(1+ *fc*) - 7.14 | -0.24 log10(1+ *fc*) - 6.83 | -6.62 | -6.955 - 0.0963 log10(*fc*) | -6.28 - 0.204 log10(*fc*) | -6.62 |
| **lgDS | 0.38 | 0.16 log10(1+ *fc*) + 0.28 | 0.32 | 0.66 | 0.39 | 0.32 |
| AOD spread (ASD)  lgASD=log10(ASD/1°) | **lgASD | -0.05 log10(1+ *fc*) + 1.21 | -0.23 log10(1+ *fc*) + 1.53 | 1.25 | 1.06 + 0.1114 log10(*fc*) | 1.5 - 0.1144 log10(*fc*) | 1.25 |
| **lgASD | 0.41 | 0.11 log10(1+ *fc*) + 0.33 | 0.42 | 0.28 | 0.28 | 0.42 |
| AOA spread (ASA)  lgASA=log10(ASA/1°) | **lgASA | -0.08 log10(1+ *fc*) + 1.73 | -0.08 log10(1+ *fc*) + 1.81 | 1.76 | 1.81 | 2.08 - 0.27 log10(*fc*) | 1.76 |
| **lgASA | 0.014 log10(1+ *fc*) + 0.28 | 0.05 log10(1+ *fc*) + 0.3 | 0.16 | 0.20 | 0.11 | 0.16 |
| ZOA spread (ZSA)  lgZSA=log10(ZSA/1°) | **lgZSA | -0.1 log10(1+ *fc*) + 0.73 | -0.04 log10(1+ *fc*) + 0.92 | 1.01 | 0.95 | -0.3236 log10(*fc*) + 1.512 | 1.01 |
| **lgZSA | -0.04 log10(1+ *fc*) + 0.34 | -0.07 log10(1+ *fc*) + 0.41 | 0.43 | 0.16 | 0.16 | 0.43 |
| Shadow fading (*SF*)[dB] | *SF* | See Table 7.4.1-1 | See Table 7.4.1-1 | 7 | See Table 7.4.1-1 | See Table 7.4.1-1 | 7 |
| K-factor (*K*) [dB] | *K* | 9 | N/A | N/A | 9 | N/A | N/A |
| *K* | 5 | N/A | N/A | 3.5 | N/A | N/A |
| Cross-Correlations | *ASD* vs *DS* | 0.5 | 0 | 0.4 | 0.4 | 0.4 | 0.4 |
| *ASA* vs *DS* | 0.8 | 0.4 | 0.4 | 0.8 | 0.6 | 0.4 |
| *ASA* vs *SF* | -0.4 | -0.4 | 0 | -0.5 | 0 | 0 |
| *ASD* vs *SF* | -0.5 | 0 | 0.2 | -0.5 | -0.6 | 0.2 |
| *DS* vs *SF* | -0.4 | -0.7 | -0.5 | -0.4 | -0.4 | -0.5 |
| *ASD*vs *ASA* | 0.4 | 0 | 0 | 0 | 0.4 | 0 |
| *ASD* vs ** | -0.2 | N/A | N/A | 0 | N/A | N/A |
| *ASA* vs ** | -0.3 | N/A | N/A | -0.2 | N/A | N/A |
| *DS* vs ** | -0.7 | N/A | N/A | -0.4 | N/A | N/A |
| *SF* vs ** | 0.5 | N/A | N/A | 0 | N/A | N/A |
| Cross-Correlations 1) | *ZSD* vs *SF* | 0 | 0 | 0 | 0 | 0 | 0 |
| *ZSA* vs *SF* | 0 | 0 | 0 | -0.8 | -0.4 | 0 |
| *ZSD* vs *K* | 0 | N/A | N/A | 0 | N/A | N/A |
| *ZSA* vs *K* | 0 | N/A | N/A | 0 | N/A | N/A |
| *ZSD* vs *DS* | 0 | -0.5 | -0.6 | -0.2 | -0.5 | -0.6 |
| *ZSA*vs *DS* | 0.2 | 0 | -0.2 | 0 | 0 | -0.2 |
| *ZSD* vs *ASD* | 0.5 | 0.5 | -0.2 | 0.5 | 0.5 | -0.2 |
| *ZSA* vs *ASD* | 0.3 | 0.5 | 0 | 0 | -0.1 | 0 |
| *ZSD* vs *ASA* | 0 | 0 | 0 | -0.3 | 0 | 0 |
| *ZSA* vs *ASA* | 0 | 0.2 | 0.5 | 0.4 | 0 | 0.5 |
| *ZSD* vs *ZSA* | 0 | 0 | 0.5 | 0 | 0 | 0.5 |
| Delay scaling parameter *rτ* | | 3 | 2.1 | 2.2 | 2.5 | 2.3 | 2.2 |
| XPR[dB] | **XPR | 9 | 8.0 | 9 | 8 | 7 | 9 |
| **XPR | 3 | 3 | 5 | 4 | 3 | 5 |
| Number of clusters | | 12 | 19 | 12 | 12 | 20 | 12 |
| Number of rays per cluster | | 20 | 20 | 20 | 20 | 20 | 20 |
| Cluster *DS* () in [ns] | | 5 | 11 | 11 | max(0.25, 6.5622  -3.4084 log10(*f*c)) | max(0.25, 6.5622  -3.4084 log10(*f*c)) | 11 |
| Cluster *ASD* () in [deg] | | 3 | 10 | 5 | 5 | 2 | 5 |
| Cluster *ASA* () in [deg] | | 17 | 22 | 8 | 11 | 15 | 8 |
| Cluster *ZSA* () in [deg] | | 7 | 7 | 3 | 7 | 7 | 3 |
| Per cluster shadowing std  [dB] | | 3 | 3 | 4 | 3 | 3 | 4 |
| Correlation distance in the horizontal plane [m] | *DS* | 7 | 10 | 10 | 30 | 40 | 10 |
| *ASD* | 8 | 10 | 11 | 18 | 50 | 11 |
| *ASA* | 8 | 9 | 17 | 15 | 50 | 17 |
| *SF* | 10 | 13 | 7 | 37 | 50 | 7 |
| ** | 15 | N/A | N/A | 12 | N/A | N/A |
| *ZSA* | 12 | 10 | 25 | 15 | 50 | 25 |
| *ZSD* | 12 | 10 | 25 | 15 | 50 | 25 |
| *fc* is carrier frequency in GHz; *d*2D is BS-UT distance in km.  NOTE 1: *DS* = rms delay spread, *ASD* = rms azimuth spread of departure angles, *ASA* = rms azimuth spread of arrival angles, *ZSD* = rms zenith spread of departure angles, *ZSA* = rms zenith spread of arrival angles, *SF* = shadow fading, and *K* = Ricean K-factor.  NOTE 2: The sign of the shadow fading is defined so that positive SF means more received power at UT than predicted by the path loss model.  NOTE 3: All large scale parameters are assumed to have no correlation between different floors.  NOTE 4: The following notation for mean (*μ*lgX=mean{log10(X) }) and standard deviation (*σ*lgX=std{log10(X) }) is used for logarithmized parameters X.  NOTE 5: For all considered scenarios the AOD/AOA distributions are modelled by a wrapped Gaussian distribution, the ZOD/ZOA distributions are modelled by a Laplacian distribution and the delay distribution is modelled by an exponential distribution.  NOTE 6: For UMa and frequencies below 6 GHz, use *fc* = 6 when determining the values of the frequency-dependent LSP values  NOTE 7: For UMi and frequencies below 2 GHz, use *fc* = 2 when determining the values of the frequency-dependent LSP values | | | | | | | |

Table 7.5-6 Part-2: Channel model parameters for RMa (up to 7GHz) and Indoor-Office

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Scenarios | | RMa | | | Indoor-Office | |
| LOS | NLOS | O2I | LOS | NLOS |
| Delay spread (DS)  lgDS=log10(DS/1s) | **lgDS | -7.49 | -7.43 | -7.47 | -0.01 log10(1+*fc*) - 7.692 | -0.28 log10(1+*fc*) - 7.173 |
| **lgDS | 0.55 | 0.48 | 0.24 | 0.18 | 0.10 log10(1+*fc*) + 0.055 |
| AOD spread (ASD)  lgASD=log10(ASD/1°) | **lgASD | 0.90 | 0.95 | 0.67 | 1.60 | 1.62 |
| **lgASD | 0.38 | 0.45 | 0.18 | 0.18 | 0.25 |
| AOA spread (ASA)  lgASA=log10(ASA/1°) | **lgASA | 1.52 | 1.52 | 1.66 | -0.19 log10(1+*fc*) + 1.781 | -0.11 log10(1+*fc*) + 1.863 |
| **lgASA | 0.24 | 0.13 | 0.21 | 0.12 log10(1+*fc*) + 0.119 | 0.12 log10(1+*fc*) + 0.059 |
| ZOA spread (ZSA)  lgZSA=log10(ZSA/1°) | **lgZSA | 0.47 | 0.58 | 0.93 | -0.26 log10(1+*fc*) + 1.44 | -0.15 log10(1+*fc*) + 1.387 |
| **lgZSA | 0.40 | 0.37 | 0.22 | -0.04 log10(1+*fc*) + 0.264 | -0.09 log10(1+*fc*) + 0.746 |
| Shadow fading (SF) [dB] | *SF* | See Table 7.4.1-1 | | 8 | See Table 7.4.1-1 | |
| K-factor (*K*) [dB] | *K* | 7 | N/A | N/A | 7 | N/A |
| *K* | 4 | N/A | N/A | 4 | N/A |
| Cross-Correlations | *ASD* vs *DS* | 0 | -0.4 | 0 | 0.6 | 0.4 |
| *ASA* vs *DS* | 0 | 0 | 0 | 0.8 | 0 |
| *ASA* vs *SF* | 0 | 0 | 0 | –0.5 | –0.4 |
| *ASD* vs *SF* | 0 | 0.6 | 0 | –0.4 | 0 |
| *DS* vs *SF* | -0.5 | -0.5 | 0 | –0.8 | –0.5 |
| *ASD*vs *ASA* | 0 | 0 | -0.7 | 0.4 | 0 |
| *ASD* vs ** | 0 | N/A | N/A | 0 | N/A |
| *ASA* vs ** | 0 | N/A | N/A | 0 | N/A |
| *DS* vs ** | 0 | N/A | N/A | -0.5 | N/A |
| *SF* vs ** | 0 | N/A | N/A | 0.5 | N/A |
| Cross-Correlations 1) | *ZSD* vs *SF* | 0.01 | -0.04 | 0 | 0.2 | 0 |
| *ZSA* vs *SF* | -0.17 | -0.25 | 0 | 0.3 | 0 |
| *ZSD* vs *K* | 0 | N/A | N/A | 0 | N/A |
| *ZSA* vs *K* | -0.02 | N/A | N/A | 0.1 | N/A |
| *ZSD* vs *DS* | -0.05 | -0.10 | 0 | 0.1 | -0.27 |
| *ZSA*vs *DS* | 0.27 | -0.40 | 0 | 0.2 | -0.06 |
| *ZSD* vs *ASD* | 0.73 | 0.42 | 0.66 | 0.5 | 0.35 |
| *ZSA* vs *ASD* | -0.14 | -0.27 | 0.47 | 0 | 0.23 |
| *ZSD* vs *ASA* | -0.20 | -0.18 | -0.55 | 0 | -0.08 |
| *ZSA* vs *ASA* | 0.24 | 0.26 | -0.22 | 0.5 | 0.43 |
| *ZSD* vs *ZSA* | -0.07 | -0.27 | 0 | 0 | 0.42 |
| Delay scaling parameter *rτ* | | 3.8 | 1.7 | 1.7 | 3.6 | 3 |
| XPR[dB] | **XPR | 12 | 7 | 7 | 11 | 10 |
| **XPR | 4 | 3 | 3 | 4 | 4 |
| Number of clusters | | 11 | 10 | 10 | 15 | 19 |
| Number of rays per cluster | | 20 | 20 | 20 | 20 | 20 |
| Cluster *DS* () in [ns] | | N/A | N/A | N/A | N/A | N/A |
| Cluster *ASD* () in [deg] | | 2 | 2 | 2 | 5 | 5 |
| Cluster *ASA* () in [deg] | | 3 | 3 | 3 | 8 | 11 |
| Cluster *ZSA* () in [deg] | | 3 | 3 | 3 | 9 | 9 |
| Per cluster shadowing std  [dB] | | 3 | 3 | 3 | 6 | 3 |
| Correlation distance in the horizontal plane [m] | *DS* | 50 | 36 | 36 | 8 | 5 |
| *ASD* | 25 | 30 | 30 | 7 | 3 |
| *ASA* | 35 | 40 | 40 | 5 | 3 |
| *SF* | 37 | 120 | 120 | 10 | 6 |
| ** | 40 | N/A | N/A | 4 | N/A |
| *ZSA* | 15 | 50 | 50 | 4 | 4 |
| *ZSD* | 15 | 50 | 50 | 4 | 4 |
| *fc* is carrier frequency in GHz; *d*2D is BS-UT distance in km.  NOTE 1: *DS* = rms delay spread, *ASD* = rms azimuth spread of departure angles, *ASA* = rms azimuth spread of arrival angles, *ZSD* = rms zenith spread of departure angles, *ZSA* = rms zenith spread of arrival angles, *SF* = shadow fading, and *K* = Ricean K-factor.  NOTE 2: The sign of the shadow fading is defined so that positive SF means more received power at UT than predicted by the path loss model.  NOTE 3: The following notation for mean (*μ*lgX=mean{log10(X) }) and standard deviation (*σ*lgX=std{log10(X) }) is used for logarithmized parameters X.  NOTE 4: Void.  NOTE 5: For all considered scenarios the AOD/AOA distributions are modelled by a wrapped Gaussian distribution, the ZOD/ZOA distributions are modelled by a Laplacian distribution and the delay distribution is modelled by an exponential distribution.  NOTE 6: For InH and frequencies below 6 GHz, use *fc* = 6 when determining the values of the frequency-dependent LSP values | | | | | | |

Table 7.5-6 Part-3: Channel model parameters for InF

|  |  |  |  |
| --- | --- | --- | --- |
| Scenarios | | InF | |
| LOS | NLOS |
| Delay spread (DS)  lgDS=log10(DS/1s) 4) | **lgDS | log10(26(V/S)+14)-9.35 | log10(30(V/S)+32)-9.44 |
| **lgDS | 0.15 | 0.19 |
| AOD spread (ASD)  lgASD=log10(ASD/1°) | **lgASD | 1.56 | 1.57 |
| **lgASD | 0.25 | 0.2 |
| AOA spread (ASA)  lgASA=log10(ASA/1°) | **lgASA | **-**0.18\*log10(1+fc) + 1.78 | 1.72 |
| **lgASA | 0.12\*log10(1+fc) + 0.2 | 0.3 |
| ZOA spread (ZSA)  lgZSA=log10(ZSA/1°) | **lgZSA | -0.2\*log10(1+fc) + 1.5 | -0.13\*log10(1+fc) + 1.45 |
| **lgZSA | 0.35 | 0.45 |
| Shadow fading (SF) [dB] | *SF* | Specified as part of path loss models | |
| K-factor (*K*) [dB] | *K* | 7 | N/A |
| *K* | 8 | N/A |
| Cross-Correlations | *ASD* vs *DS* | 0 | 0 |
| *ASA* vs *DS* | 0 | 0 |
| *ASA* vs *SF* | 0 | 0 |
| *ASD* vs *SF* | 0 | 0 |
| *DS* vs *SF* | 0 | 0 |
| *ASD*vs *ASA* | 0 | 0 |
| *ASD* vs ** | -0.5 | N/A |
| *ASA* vs ** | 0 | N/A |
| *DS* vs ** | -0.7 | N/A |
| *SF* vs ** | 0 | N/A |
| Cross-Correlations 1) | *ZSD* vs *SF* | 0 | 0 |
| *ZSA* vs *SF* | 0 | 0 |
| *ZSD* vs *K* | 0 | N/A |
| *ZSA* vs *K* | 0 | N/A |
| *ZSD* vs *DS* | 0 | 0 |
| *ZSA*vs *DS* | 0 | 0 |
| *ZSD* vs *ASD* | 0 | 0 |
| *ZSA* vs *ASD* | 0 | 0 |
| *ZSD* vs *ASA* | 0 | 0 |
| *ZSA* vs *ASA* | 0 | 0 |
| *ZSD* vs *ZSA* | 0 | 0 |
| Delay scaling parameter *rτ* | | 2.7 | 3 |
| XPR[dB] | **XPR | 12 | 11 |
| **XPR | 6 | 6 |
| Number of clusters | | 25 | 25 |
| Number of rays per cluster | | 20 | 20 |
| Cluster *DS* () in [ns] | | N/A | N/A |
| Cluster *ASD* () in [deg] | | 5 | 5 |
| Cluster *ASA* () in [deg] | | 8 | 8 |
| Cluster *ZSA* () in [deg] | | 9 | 9 |
| Per cluster shadowing std  [dB] | | 4 | 3 |
| Correlation distance in the horizontal plane [m] 5) | *DS* | 10 | 10 |
| *ASD* | 10 | 10 |
| *ASA* | 10 | 10 |
| *SF* | 10 | 10 |
| ** | 10 | N/A |
| *ZSA* | 10 | 10 |
| *ZSD* | 10 | 10 |
| *fc* is carrier frequency in GHz; *d*2D is BS-UT distance in km.  NOTE 1: *DS* = rms delay spread, *ASD* = rms azimuth spread of departure angles, *ASA* = rms azimuth spread of arrival angles, *ZSD* = rms zenith spread of departure angles, *ZSA* = rms zenith spread of arrival angles, *SF* = shadow fading, and *K* = Ricean K-factor.  NOTE 2: The sign of the shadow fading is defined so that positive SF means more received power at UT than predicted by the path loss model.  NOTE 3: The following notation for mean (*μ*lgX=mean{log10(X) }) and standard deviation (*σ*lgX=std{log10(X) }) is used for logarithmized parameters X.  NOTE 4: V = hall volume in m3, S = total surface area of hall in m2 (walls+floor+ceiling)  NOTE 5: When the simulation scenario is small it is recommended to consider methods to improve the statistical confidence, such as using multiple random seeds in simulations. | | | |

Table 7.5-7: ZSD and ZOD offset parameters for UMa

|  |  |  |  |
| --- | --- | --- | --- |
| Scenarios | | LOS | NLOS |
| ZOD spread (ZSD)  lgZSD=log10(ZSD/1°) | **lgZSD | max[-0.5, -2.1(*d2D*/1000)  -0.01 (*hUT* - 1.5)+0.75] | max[-0.5, -2.1(*d2D*/1000)  -0.01(*hUT* - 1.5)+0.9] |
| **lgZSD | 0.40 | 0.49 |
| ZOD offset | *µoffset,ZOD* | 0 | *e*(*fc*)-10^{*a*(*fc*) log10(max(*b*(*fc*), *d2D*))  +*c*(*fc*) -0.07(*hUT*-1.5)} |
| Note: For NLOS ZOD offset:  *a*(*fc*) = 0.208log10(*fc*)- 0.782;  *b*(*fc*) = 25;  *c*(*fc*) = -0.13log10(*fc*)+2.03;  *e*(*fc*) = 7.66log10(*fc*)-5.96. | | | |

Table 7.5-8: ZSD and ZOD offset parameters for UMi – Street Canyon

|  |  |  |  |
| --- | --- | --- | --- |
| Scenarios | | LOS | NLOS |
| ZOD spread (ZSD)  lgZSD=log10(ZSD/1°) | **lgZSD | max[-0.21, -14.8(*d*2D/1000)  + 0.01|*h*UT-*h*BS| + 0.83] | max[-0.5, -3.1(*d*2D/1000)  + 0.01 max(*h*UT-*h*BS,0) +0.2] |
| **lgZSD | 0.35 | 0.35 |
| ZOD offset | *µ*offset,ZOD | 0 | -10^{-1.5log10(max(10, *d*2D))+3.3} |

Table 7.5-9: ZSD and ZOD offset parameters for RMa

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Scenarios** | | **LOS** | **NLOS** | **O2I** |
| ZOD spread (ZSD)  lgZSD=log10(ZSD/1°) | **lgZSD | max[-1, -0.17(*d*2D/1000)  -0.01(*h*UT - 1.5) + 0.22] | max[-1, -0.19(*d*2D/1000)  -0.01(*h*UT - 1.5) + 0.28] | max[-1, -0.19(*d*2D/1000)  -0.01(*h*UT - 1.5) + 0.28] |
| **lgZSD | 0.34 | 0.30 | 0.30 |
| ZOD offset | *µ*offset,ZOD | 0 | arctan((35 - 3.5)/*d*2D)  -arctan((35 - 1.5)/*d*2D) | arctan((35 - 3.5)/*d*2D)  -arctan((35 - 1.5)/*d*2D) |

Table 7.5-10: ZSD and ZOD offset parameters for Indoor-Office

|  |  |  |  |
| --- | --- | --- | --- |
| Scenarios | | LOS | NLOS |
| ZOD spread (ZSD)  lgZSD=log10(ZSD/1°) | **lgZSD | -1.43 log10(1+ *fc*)+2.228 | 1.08 |
| **lgZSD | 0.13 log10(1+*fc*)+0.30 | 0.36 |
| ZOD offset | *µ*offset,ZOD | 0 | 0 |

Table 7.5-11: ZSD and ZOD offset parameters for InF

|  |  |  |  |
| --- | --- | --- | --- |
| Scenarios | | LOS | NLOS |
| ZOD spread (ZSD)  lgZSD=log10(ZSD/1°) | **lgZSD | 1.35 | 1.2 |
| **lgZSD | 0.35 | 0.55 |
| ZOD offset | *µ*offset,ZOD | 0 | 0 |

Notes for Tables 7.5-7, 7.5-8, 7.5-9, 7.5-10, 7.5-11:

NOTE 1: *fc* is center frequency in GHz; *d*2D is BS-UT distance in m.

NOTE 2: *h*BS and *h*UT are antenna heights in m for BS and UT **respectively.**

NOTE 3: The following notation for mean (*μ*lgX=mean{log10(X) }) and standard deviation (*σ*lgX=std{log10(X) }) is used for logarithmized parameters X**.**

NOTE 4: For frequencies below 6 GHz, use *fc* = 6 when determining the values of the frequency-dependent ZSD and ZOD offset parameters in Table 7.5-7 and 7.5-10

NOTE 5:The ZSD parameters for O2I links are the same parameters that are used for outdoor links, depending on the LOS condition of the outdoor link part in Tables 7.5-7 and 7.5-8.

## 7.6 Additional modelling components

The additional modelling components in this clause are to support advanced simulations, such as simulations with very large arrays and large bandwidth, simulations affected by oxygen absorption (frequencies between 53 and 67 GHz), simulations in which spatial consistency is important (e.g. high number of closely located user), simulations of mobility, simulations of blockage effects, simulations of absolute time of arrival, simulations of dual mobility, simulations that include sources of EM interference, and simulations of devices embedded in machinery or enclosures. These modelling components affect some of the steps between Step 1 and Step 12 in Clause 7.5.

These extensions are computationally more expensive and might not be required in all evaluation cases.

### 7.6.1 Oxygen absorption

Oxygen absorption loss is applied to the cluster responses generated in Step 11 in Clause 7.5. The additional loss, OL*n*(*fc*) for cluster *n* at centre frequency *fc* is modelled as:

 [dB] (7.6-1)

where:

*- α*(*fc*) is frequency dependent oxygen loss [dB/km] characterized in Table 7.6.1-1;

- *c* is the speed of light [m/s]; and *d*3D is the distance [m];

*- τn* is the *n*-th cluster delay [s] in Step 11 in Clause 7.5;

*- τ*Δ is 0 in the LOS case and min() otherwise, where min() is the minimum delay in Step 5.

For centre frequencies not specified in this table, the frequency dependent oxygen loss *α*(*fc*) is obtained from a linear interpolation between two loss values corresponding to the two adjacent centre frequencies of the centre frequency *fc*.

Table 7.6.1-1 Frequency dependent oxygen loss *α*(*f*) [dB/km]

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **f in [GHz]** | 0-52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68-100 |
| **α(f) in [dB/km]** | 0 | 1 | 2.2 | 4 | 6.6 | 9.7 | 12.6 | 14.6 | 15 | 14.6 | 14.3 | 10.5 | 6.8 | 3.9 | 1.9 | 1 | 0 |

For large channel bandwidth, first transform the time-domain channel response of each cluster (all rays within one cluster share common oxygen absorption loss for simplicity) into frequency-domain channel response, and apply the oxygen absorption loss to the cluster's frequency-domain channel response for frequency *fc* + Δ*f* within the considered bandwidth. The oxygen loss, OL*n*(*fc*+ Δ*f*) for cluster *n* at frequency *fc*+ Δ*f* is modelled as:

 [dB] (7.6-2)

where:

*- α*(*fc*+ Δ*f*) is the oxygen loss (dB/km) at frequency *fc*+ Δ*f* characterized in Table 7.6.1-1. Note that Δ*f* is in [-B/2, B/2], where B is the bandwidth. Linear interpolation is applied for frequencies not provided in Table 7.6.1-1.

The final frequency-domain channel response is obtained by the summation of frequency-domain channel responses of all clusters.

Time-domain channel response is obtained by the reverse transform from the obtained frequency-domain channel response.

### 7.6.2 Large bandwidth and large antenna array

#### 7.6.2.1 Modelling of the propagation delay

The modelling in this clause applies only when the bandwidth *B* is greater than *c/D* Hz, where

*- D* is the maximum antenna aperture in either azimuth or elevation (m)

*- c* is the speed of light (m/s)

Each ray within a cluster for a given *u* (Rx) and *s* (Tx) has unique time of arrival (TOA). The channel coefficient generation step (Step 11 in Clause 7.5) is updated to model individual rays. In this case, the channel response of ray *m* in cluster *n* for a link between Rx antenna *u* and Tx antenna *s* at delay  at time *t* is given by:

 (7.6-3)

with  is the wavelength on frequency , which can be implemented by user's own method. The delay (TOA) for ray *m* in cluster *n* for a link between Rx antenna *u* and Tx antenna *s* is given by:

 (7.6-4)

Note that Equation (7.6-3) only considers the delays  intentionally. If unequal ray powers are considered,  are generated according to Clause 7.6.2.2. Otherwise, ray powers are equal within a cluster, i.e.,  for all m. Note: this model is developed assuming plane wave propagation.

#### 7.6.2.2 Modelling of intra-cluster angular and delay spreads

With large antenna arrays or large bandwidths, the angle and/or delay resolution can be larger than what the fast fading model in Clause 7.5 is designed to support. To model this effect, the following modifications to Step 7 in Clause 7.5 can be optionally used.

1. The offset angles *m* in (7.5-13), (7.5-18) and (7.5-20) are generated independently per cluster and ray using:

 (7.6-5)

where  denotes the continuous uniform distribution in the interval . These random variables may further be modelled as spatially consistent with correlation distance equal to the cluster-specific random variable correlation distance of Table 7.6.3.1-2.

2. The relative delay of *m*-th ray is given by , where *n* is the cluster index, , the cluster DS  is given in Table 7.5-6. These random variables may further be modelled as spatially consistent with correlation distance equal to the cluster-specific random variable correlation distance of Table 7.6.3.1-2. In this case, the sub-cluster mapping according to (7.5-26) and Table 7.5-5 shall not be applied. The delays to be used in Equation (7.6-3) are given by .

3. Ray powers are determined unequally by the following process:

The power of *m*-th ray in *n*-th cluster is given by  for *m* = 1,…,*M*, where

 (7.6-6)

and , , , and  are respectively the intra-cluster delay spread and the corresponding intra-cluster angular spread that are given in Table 7.5-6. The cluster zenith spread of departure is given by

, (7.6-7)

with  being defined in Tables 7.5-7, 7.5-8, 7.5-9, 7.5-10 and 7.5-11.

4. The number of rays per cluster shall be calculated as follows:

 (7.6-8)

where:

- 

- 

- 

-  is the upper limit of , and it should be selected by the user of channel model based on the trade-off between simulation complexity and accuracy.

- and  are the array size in m in horizontal and vertical dimension, *B* is bandwidth in Hz,  and  are the cluster spreads in degrees, and  is the wavelength.

-  is a "sparseness" parameter with value 0.5.

It is noted that each MPC may have different AOD, ZOD, and delay.

### 7.6.3 Spatial consistency

#### 7.6.3.1 Spatial consistency procedure

A new procedure, namely *a* *spatial consistency procedure*, can be used for both cluster-specific and ray-specific random variables to be generated in various channel generation steps in Clause 7.5, so that they are spatially consistent for drop-based simulations. Alternatively, this can be used together with Procedure B described in Clause 7.6.3.2 for spatially consistent mobility simulations.

The procedure can be considered as a 2D random process (in the horizontal plane) given the UT locations based on the parameter-specific correlation distance values for spatial consistency, specified in Table 7.6.3.1-2. The cluster specific random variables include:

- Cluster specific random delay in Step 5;

- Cluster specific shadowing in Step 6; and

- Cluster specific offset for AOD/AOA/ZOD/ZOA in Step 7.

- Cluster specific sign for AOD/AOA/ZOD/ZOA in Step 7.

- Optionally in case of large bandwidth as described in Clause 7.6.2.2 the procedure may apply as well for the parameters of rays within a cluster.

The procedure shall apply to each cluster before sorting the delay. Cluster specific sign for AOD/AOA/ZOD/ZOA in Step 7 shall be kept unchanged per simulation drop even if UT position changes during simulation. The ray specific random variables include:

- Random coupling of rays in Step 8;

- XPR in Step 9; and

- Random phase in Step 10.

The random coupling of rays in Step 8 and the intra-cluster delays in Step 11 shall be kept unchanged per simulation drop even if UT position changes during simulation.

Table 7.6.3.1-2 Correlation distance for spatial consistency

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Correlation distance in [m] | RMa | | | UMi | | | UMa | | | Indoor | InF |
| LOS | NLOS | O2I | LOS | NLOS | O2I | LOS | NLOS | O2I |
| Cluster and ray specific random variables | 50 | 60 | 15 | 12 | 15 | 15 | 40 | 50 | 15 | 10 | 10 |
| LOS/NLOS state | 60 | | | 50 | | | 50 | | | 10 |  |
| Indoor/outdoor state | 50 | | | 50 | | | 50 | | | N/A | N/A |

#### 7.6.3.2 Spatially-consistent UT/BS mobility modelling

For mobility simulation enhancement, two alternative spatial consistency procedures – Procedure A and Procedure B – are described as follows. The procedures presented below consider the downlink direction same as in Clause 7.5.

**Procedure A:**

For  when a UT/BS is dropped into the network, spatially consistent powers/delays/angles of clusters are generated according to Clause 7.6.3.1.

The updated distance of UT/BS should be limited within 1 meter, i.e. when , and the updated procedure in the following should take the closest realization instead of. In case the absolute time of arrival modeling of clause 7.6.9 is simultaneously used, the update distance should be the minimum of 1 meter and .

At , update channel cluster power/delay/angles based on UT/BS channel cluster power/delay/angles, moving speed moving direction and UT position at *.*

Cluster delay is updated as:

(7.6-9)

where

 is the speed of light in [m/s];



and are the BS and UTvelocity vectors respectively, with and ;

 is the 3D distance between Rx antenna and Tx antenna at  in [m];

 are the cluster delays in [s] as in Step 11 in Clause 7.5;

, where  are the delays from Equation (7.5-1). In case the absolute time of arrival modelling of clause 7.6.9 is simultaneously used,  where is determined according to clause 7.6.9.

Also,

 (7.6-10)



where  and  are cluster specific zenith and azimuth angles of arrival.

(7.6-10aa)

where and are the cluster specific zenith and azimuth angles of departure.

After updating the delays according to equation (7.6-9), the delays over the mobility range are normalized. Equation (7.5-2) of the fast fading model is replaced by

 (7.6-10a)

in which  covers the entire duration of the mobility model.

Cluster powers are updated as in Step 6 using the cluster delays from Equation (7.6-10a).



Cluster departure angles ( and ) and arrival angles ( and ) are updated using a cluster-wise transformation of the UT/BS velocity vector given by

(7.6-10b)

(7.6-10c)

with

,

and

,

where  and  being the rotation matrices around y-axis and z-axis as defined in Equation (7.1-2). Random variable  is sampled from a uniform distribution on a NLOS cluster basis and is not changed during the UT mobility within a drop. The cluster specific decorrelation distances are 60m, 15m, 50m and 10m for RMa, UMi, UMa and Indoor scenarios, respectively.

Now, the departure and arrival angles in radians are updated as:

(7.6-11)

(7.6-12)

and

(7.6-13)

, (7.6-14)

with  and  being the spherical unit vectors defined in Equations (7.1-13) and (7.1-14).

**Procedure B:**

In procedure B, spatial or time evolution of the channel is obtained by generating channel realizations separately for all links to different Rx positions using Steps 1-12 of Clause 7.5 together with the spatially consistent procedure of Clause 7.6.3.1. In the case of mobility these positions may be a function of time along one or more Rx trajectories. Furthermore, to ensure that the spatial or time evolution of delays and angles are within reasonable limits, Steps 5, 6, and 7 in Clause 7.5 should be replaced by the below procedure.

Note: For implementation purposes, LSPs and SSPs may be interpolated within the coherence length or time of the respective parameter.

Step 5: Generate cluster delays , with .

 delays are drawn randomly from a uniform distribution.

 (7.6-15)

Normalise the delays by subtracting the minimum delay: . The autocorrelation distance for  is .

In the case of LOS, set the delay of the first cluster  to 0.

Step 6: Generate  arrival angles and departure angles for both azimuth and elevation using (7.6-16) instead of (7.5-9) and (7.5-14).

 (7.6-16)

with . This step is repeated independently for AOD, AOA, ZOD, and ZOA with corresponding maximum angles for the uniform distribution. In case of LOS, set the angles of the first cluster (, etc) to 0.

The autocorrelation distances are for AOD, and ZOD, while they are fixed to 50m for AOA, and ZOA.

Offset angles etc are applied in the modified Step 7b below after cluster powers have been calculated.

Step 7: Generate cluster powers 

Cluster powers are calculated assuming a single slope exponential power profile and Laplacian angular power profiles. The cluster powers are determined by

 (7.6-17)

where  (autocorrelation distance same as for shadow fading) is the per cluster shadowing term in [dB]. Delay spread  and angular spreads , , , are generated in Step 4 of Clause 7.5. Normalize the cluster powers so that the sum of all cluster powers is equal to one, i.e.,

 (7.6-17a)

*In the case of LOS condition*, substitute  with  and {, , , } with {, , , } respectively to preserve the delay and angular spreads.  is the Ricean K-factor as generated in Step 4 converted to linear scale. Furthermore, an additional specular component is added to the first cluster. Power of the single LOS ray is:

 (7.6-17b)

and the cluster powers are not normalized as in equation (7.6-17a), but:

 (7.6-17c)

where δ(.) is Dirac's delta function.

Assign the power of each ray within a cluster as *Pn/ M*, where *M* is the number of rays per cluster.

Step 7b: Apply offset angles

The ray AOA angles are determined by

 (7.6-17d)

where  is the LOS direction defined in the network layout description, see Step1c.

The generation of AOD () follows a procedure similar to AOA as described above.

The ZOA angles are determined by

 (7.6-17e)

where  if the BS-UT link is O2I and otherwise. The LOS direction is defined in the network layout description, see Step1c.

The ZOA angles are determined by

 (7.6-17f)

where is the mean of the ZSD log-normal distribution.

Some of the delay and angle spreads and standard deviations used in equations (7.6-15) and (7.6-16) may be frequency-dependent. In the case of multi-frequency simulations according to Clause 7.6.5, the largest value among all the simulated frequencies should be used in (7.6-15) and (7.6-16) so that the cluster and ray delays and angles (but not the powers or the resulting delay or angular spreads) are the same for all frequencies.

#### 7.6.3.3 LOS/NLOS, indoor states and O2I parameters

The LOS state can be determined according to the spatial consistency procedure for random variables as mentioned in Clause 7.6.3.1, by comparing a realization of a random variable generated with distance-dependent LOS probability. If the realization is less than the LOS probability, the state is LOS; otherwise NLOS. Decision of LOS and NLOS status should be used in Step 2 in Clause 7.5 if this advanced simulation is performed.

The same procedure can be applied for determining the indoor state, with the indoor probability instead of the LOS probability.

The correlation distance for LOS state and indoor/outdoor is specified in Table 7.6.3.1-2.

The indoor distance can be modeled as the minimum of two spatially consistent uniform random variables within (0, 25) meters with correlation distance 25m.

Note in case the UT is in an indoor state, the pathloss model changes and a penetration loss is considered. For details on the model, see Clause 7.4.3. Here, the focus is on modelling aspects with respect to spatial consistency. As described in Clause 7.4.3, the penetration loss deviation σp represents variations within and between buildings of the same type. For spatial consistency this can be modeled as a spatially consistent random variable with correlation distance 10m, see Clause 7.6.3.1. The "building type" is determined using a spatially consistent uniform random variable with correlation distance 50 m. The building type is determined by comparing the random variable with P1, where P1 is the probability of the building type with low loss penetration. If the realization of the random variable is less than P1, the building type is low loss; otherwise the building type is high loss.

The cluster-specific and ray-specific random variables as defined in Clause 7.6.3.1 on the same floor are generated in the spatial consistency modelling; otherwise, these variables across different floors are uncorrelated.

In case there is a transition from LOS to NLOS due to UT mobility, there will be a hard transition in the channel response. This is because pathloss and LS parameters are different for these states, leading automatically to very different channel realizations. To circumvent such hard transitions the optional soft LOS state can be considered to determine the PL and the channel impulse responses containing characteristics of both LOS and NLOS. Soft LOS state  is generated by floating numbers between 0 (NLOS) and 1 (LOS) in the spatial consistency modelling. The value of is determined by

, (7.6-18)

where:

-  is a spatially consistent Gaussian random variable with correlation distance according to Table 7.6.3.1-2;

- ; and

-  is the distance dependent LOS probability function.

After is obtained, Steps 2-12 of the channel coefficient generation described in Clause 7.5 are performed twice, once with the propagation condition in Step 2 set as LOS and once with the propagation condition in Step 2 set as NLOS. The resulting channel coefficients are denoted as  and  respectively, where  is generated with the LOS path loss formula and channel model parameters while is  generated using the NLOS path loss formula and channel model parameters. The channel matrix  with soft LOS state is determined from a linear combination of  and  as:

 (7.6-19)

It is noted that soft indoor/outdoor states are not modelled in this TR. Thus the model does not support transitions between indoor/outdoor states in mobility simulations.

#### 7.6.3.4 Applicability of spatial consistency

According to the characteristics of different cluster specific parameters and ray specific parameters, the following types on spatial consistency are defined:

- Site-specific: parameters for different BS-UT links are uncorrelated, but the parameters for links from co-sited sectors to a UT are correlated.

- All-correlated: BS-UT links are correlated.

In Table 7.6.3.4-1, correlation type for each large scale parameter, cluster specific parameter and ray specific parameter is clarified.

Table 7.6.3.4-1: Correlation type among TRPs

|  |  |
| --- | --- |
| **Parameters** | **Correlation type** |
| Delays | Site-specific |
| Cluster powers | Site-specific |
| AOA/ZOA/AOD/ZOD offset | Site-specific |
| AOA/ZOA/AOD/ZOD sign | Site-specific |
| Random coupling | Site-specific |
| XPR | Site-specific |
| Initial random phase | Site-specific |
| LOS/NLOS states | Site-specific |
| Blockage (Model A) | All-correlated |
| O2I penetration loss | All-correlated |
| Indoor distance | All-correlated |
| Indoor states | All-correlated |

Spatial consistency is not modelled in the following situations:

- Different link types, e.g., outdoor LOS, outdoor NLOS or O2I

- UE locates on different floors

Table 7.6.3.4-2, lists conditions in which each large scale parameter, cluster specific parameter and ray specific parameter is assumed not spatially correlated.

Table 7.6.3.4-2: Conditions when parameters are not spatially correlated.

|  |  |
| --- | --- |
| **Parameters** | **Uncorrelated states** |
| Delays | Outdoor LOS/outdoor NLOS/O2I (different floors) |
| Cluster powers | Outdoor LOS/outdoor NLOS/O2I (different floors) |
| AOA/ZOA/AOD/ZOD offset | Outdoor LOS/outdoor NLOS/O2I (different floors) |
| AOA/ZOA/AOD/ZOD sign | Outdoor LOS/outdoor NLOS/O2I (different floors) |
| Random coupling | Outdoor LOS/outdoor NLOS/O2I (different floors) |
| XPR | Outdoor LOS/outdoor NLOS/O2I (different floors) |
| Initial random phase | Outdoor LOS/outdoor NLOS/O2I (different floors) |
| Blockage | Outdoor/O2I (different floors) |
| Standard deviation for O2I penetration loss | Different building types, i.e., high/low loss |

### 7.6.4 Blockage

Blockage modelling is an add-on feature to the channel model. The method described in the following applies only when this feature is turned on. In addition, the temporal variability of the blockage modelling parameters is on-demand basis. It is also noted that the modelling of the blockage does not change LOS/NLOS state of each link.

When blockage model is applied, the channel generation in Clause 7.5 should have several additional steps between Step 9 and 10 as illustrated in Figure 7.6.4-1.

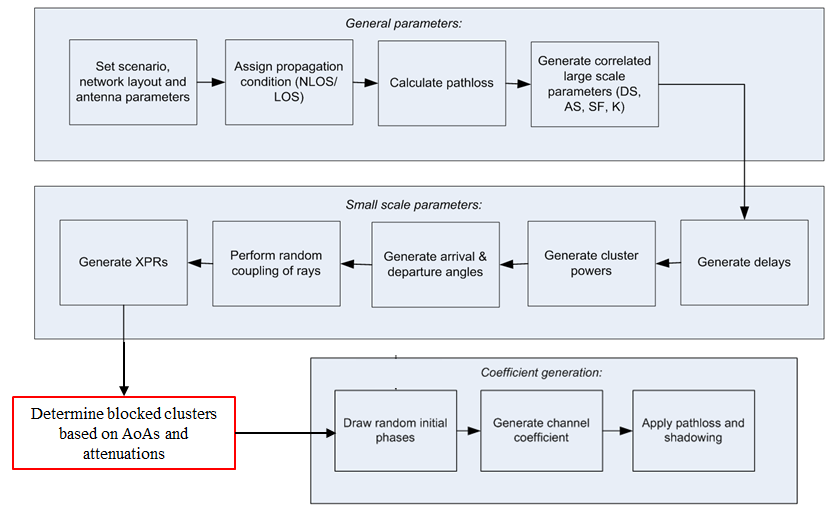


Figure.7.6.4-1 Channel generation procedure with blockage model

Two alternative models (Model A and Model B) are provided for the blockage modelling. Both approaches have their own use cases. Model A is applicable when a generic and computationally efficient blockage modelling is desired. Model B is applicable when a specific and more realistic blocking modelling is desired.

#### 7.6.4.1 Blockage model A

Model A adopts a stochastic method for capturing human and vehicular blocking.

Step a: Determine the number of blockers.

Multiple 2-dimensional (2D) angular blocking regions, in terms of centre angle, azimuth and elevation angular span are generated around the UT. There is one self-blocking region, and = 4 non-self-blocking regions, where  may be changed for certain scenarios (e.g., higher blocker density). Note that the self-blocking component of the model is important in capturing the effects of human body blocking.

Step b: Generate the size and location of each blocker.

For self-blocking, the blocking region in UT LCS is defined in terms of elevation and azimuth angles, (,) and azimuth and elevation angular span (, ).

 (7.6-20)

where the parameters are described in Table 7.6.4.1-1.

Table 7.6.4.1-1: Self-blocking region parameters.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  |  |  |  |
| Portrait mode | 260o | 120o | 100o | 80o |
| Landscape mode | 40o | 160o | 110o | 75o |

For non-self-blocking *k* = 1, …, 4, the blocking region in GCS is defined by

 (7.6-21)

where the parameters are described in Table 7.6.4.1-2, as well as the distance *r* between the UT and the blocker.

Table 7.6.4.1-2: Blocking region parameters.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Blocker index (*k* = 1, …, 4) |  |  |  |  | *r* |
| InH scenario | Uniform in  [0o, 360o] | Uniform in  [15o, 45o] | 90o | Uniform in  [5o, 15o] | 2 m |
| UMi, UMa, RMa scenarios | Uniform in  [0o, 360o] | Uniform in  [5o, 15o] | 90o | 5o | 10 m |

Step c: Determine the attenuation of each cluster due to blockers.

The attenuation of each cluster due to self-blocking corresponding to the centre angle pair (,), is 30 dB provided that  and . Otherwise, the attenuation is 0 dB.

The attenuation of each cluster due to the non-self-blocking regions (*k*=1, …, 4) is given by

 (7.6-22)

provided that  and . Otherwise, the attenuation is 0 dB. The terms in the above equation are given as

 (7.6-23)

where

, (7.6-24)

, (7.6-25)

, (7.6-26)

 (7.6-27)

In the above formula for ,  is the wavelength. The appropriate signs ()within the  term are described in Table 7.6.4.1-3.

Table 7.6.4.1-3: Description of signs

|  |  |  |  |
| --- | --- | --- | --- |
|  |  |  |  |
|  | (-, +) for  (+, -) for | (-, +) for  (+, +) for | (-, +) for  (-, +) for |
|  | (+, +) for  (+, -) for | (+, +) for  (+, +) for | (+, +) for  (-, +) for |
|  | (+, -) for  (+, -) for | (+, -) for  (+, +) for | (+, -) for  (-, +) for |

Step d: Spatial and temporal consistency of each blocker.

The centre of the blocker is generated based on a uniformly distributed random variable, which is temporally and spatially consistent. The two-dimensional autocorrelation function  can be described with sufficient accuracy by the exponential function

 (7.6-28)

The spatial correlation distance  for the random variable determining the centre of the blocker is given in Table 7.6.4.1-4 for different scenarios.

Table 7.6.4.1-4: Spatial correlation distance for different scenarios.

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Spatial correlation distance  in [m] for the random variable determining the centre of the blocker | UMi | | | UMa | | | RMa | | | InH | |
| LOS | NLOS | O2I | LOS | NLOS | O2I | LOS | NLOS | O2I | LOS | NLOS |
| 10 | 10 | 5 | 10 | 10 | 5 | 10 | 10 | 5 | 5 | 5 |

The correlation time is defined by , where  is the speed of the moving blocker.

Note: The rectangular blocker description is chosen for self-blocking region with the specific choices of (, ) assumed here. Generalization of this description to other choices should be done with care as the rectangular description may not be accurate.

#### 7.6.4.2 Blockage model B

Model B adopts a geometric method for capturing e.g., human and vehicular blocking.

Step a: Determine blockers

A number, *,* ofblockers are modelled as rectangular screens that are physically placed on the map. Each screen has the dimension by height () and width (), with the screen centre at coordinate .

Note:

- The number of blockers (), their vertical and horizontal extensions ( and ), locations , density, and movement pattern (if non-stationary) are all simulation assumptions, to allow different blocking scenarios to be constructed depending on the need of the particular simulation study.

Recommended parameters for typical blockers are provided in Table 7.6.4.2-5.

- The blocking effect diminishes with increasing distance to the blocker. For implementation purposes it may be sufficient to consider only the  nearest blockers or the blockers closer than some distance from a specific UT.

Table 7.6.4.2-5: Recommended blocker parameters

|  |  |  |  |
| --- | --- | --- | --- |
|  | Typical set of blockers | Blocker dimensions | Mobility pattern |
| Indoor; Outdoor; InF | Human | Cartesian: w=0.3m; h=1.7m | Stationary or up to 3 km/h |
| Outdoor | Vehicle | Cartesian: w=4.8m; h=1.4m | Stationary or up to 100 km/h |
| InF | AGV | Cartesian: w=3m; h=1.5m | Up to 30 km/h |
| InF | Industrial robot | Cartesian: w=2m; h=0.2m | Up to 3 m/s |

Step b: Determine the blockage attenuation per sub-path

Attenuation caused by each blocker to each sub-path is modelled using a simple knife edge diffraction model and is given by

 (7.6-29)

where ,  and ,  account for knife edge diffraction at the four edges, and are given by

 (7.6-30)

where  is the wave length. As shown in Figure 7.6.4.2-2,  are the projected (onto the side and top view planes) distances between the receiver and four edges of the corresponding blocker, and are the projected (onto the side and top view planes) distances between the transmitter and four edges of the corresponding blocker. The side view plane is perpendicular to the horizontal ground plane. The top view is perpendicular to the side view. For each cluster, the blocker screen is rotated around its centre such that the arrival direction of the corresponding path is always perpendicular to the screen. It should be noted that different rotations are required for each individual sub-path. Meanwhile, the base and top edges of the screens are always parallel to the horizontal plane. As the screen is perpendicular to each sub-path,  is the distance between the transmitter and receiver for the direct path in LOS, and  is the distance between the blocker screen and receiver, projected onto the incoming sub-path direction, for all the other (NLOS) paths. In the equation of , the plus and minus signs are determined in such a way that, as shown in Figure 7.6.4.2-2,

- if the sub-path (terminated at the receiver or transmitter) does not intersect the screen in side view, minus sign is applied for the shortest path among and  in the NLOS case (and in the LOS case) and plus sign is applied for the other edge.

- if the sub-path (terminated at the receiver or transmitter) does not intersect the screen in top view, minus sign is applied for the shortest path among and  in the NLOS case (and for the LOS case) and plus sign is applied for the other edge.

- if the sub-path intersects the screen plus signs are applied for both edges.

For the case of multiple screens the total loss is given by summing the losses of each contributing screen in dB units.

The model according to option B is consistent in time, frequency and space, and is more appropriate to be used for simulations with arbitrarily designated blocker density.



Figure 7.6.4.2-2(a): Illustration of the geometric relation among blocker, receiver and transmitter for the LOS path



Figure 7.6.4.2-2(b): Illustration of the geometric relation between blocker and receiver for NLOS paths

### 7.6.5 Correlation modelling for multi-frequency simulations

This clause describes how to generate parameters to reflect correlation across different frequencies for a BS-UT link, for simulations involved with multiple frequencies.

For those simulations, the steps in Clause 7.5 should be revised according to the following:

- The parameters generated in Step 1 are the same for all the frequencies, except for antenna patterns, array geometries, system center frequency and bandwidth.

- Propagation conditions generated in Step 2 are the same for all the frequencies. It is noted that soft LOS states may be different due to frequency dependent function.

- The parameters generated in Step 4 are the same for all the frequencies, except for possibly frequency-dependent scaling of e.g. delay spread and angular spreads according to the LSP tables. I.e. let x be a random variable drawn from a Gaussian distribution: x ~ N(0,1). Then the delay spread at frequency f is DS(f)= 10^(**lgDS(f) + **lgDS(f)⋅x), where the same value of x is used for all frequencies. A corresponding procedure applies to each of the angular spreads.

- The cluster delays and angles resulting from Steps 5-7 are the same for all frequency bands

- Per-cluster shadowing *n* in Step 6 are independently generated for the frequency bands.

- Cluster powers in Step 6 may be frequency-dependent.

- Steps 8-11 are independently applied for the frequency bands.

In addition, when blockage is modeled according to Clause 7.6.4, the positions of blockers are the same across all the frequencies.

Note: The requirements above may not be fully aligned with the behavior of the model according to Clause 7.5, since cluster delays and angles will be frequency-dependent in scenarios where the DS or AS is frequency-dependent. The procedure below may alternatively be used to ensure that cluster delays and angles are frequency-independently generated.

#### 7.6.5.1 Alternative channel generation method

The alternative method replaces Steps 5-7 in Clause 7.5 with the below Steps 5'-7'. The inputs to the alternative method are the delay and angular spreads determined according to Step 4 at an anchor frequency, e.g. 2 GHz: DS0, ASD0, ASA0, ZSD0, ZSA0, the delay and angular spreads determined according to Step 4 at a frequency of interest: DS, ASD, ASA, ZSD, ZSA, and the number of clusters *N* from Table 7.5-6.

Step 5': Generate nominal delays  and angles , , , .

Generate *N* delays from a single-sided exponential distribution with zero mean and standard deviation of , according to  with .

Generate *N* AODs from a wrapped Gaussian distribution with zero mean and standard deviation of , according to  with .

Generate *N* AOAs from a wrapped Gaussian distribution with zero mean and standard deviation of , according to  with .

Generate *N* ZODs from a wrapped Laplacian distribution with zero mean and standard deviation of , according to  with .

Generate *N* ZOAs from a wrapped Laplacian distribution with zero mean and standard deviation of , according to  with .

*r* is a proportionality factor, r=1.5. The principal value of the arg function should be used, e.g. (-180,180).

*In case of LOS*, set , , , , and .

Step 6': Generate cluster powers .

Generate cluster powers as

 (7.6.30a)

where  is the per cluster shadowing term in [dB] and

 (7.6.30b)

 (7.6.30c)

 (7.6.30d)

 (7.6.30e)

 (7.6.30f)

Normalize the cluster powers so that the sum of all cluster powers is equal to one, i.e.,

 (7.6.30g)

or, in the case of LOS, so that

 (7.6.30h)

where  is the K-factor converted to linear scale.

Step 7': Generate delays  and angles , , , .

 (7.6.30i)

 (7.6.30j)

 (7.6.30k)

 (7.6.30l)

 (7.6.30m)

Repeat Steps 6'-7' for each frequency of interest, reusing the delays and angles from Step 5' for all frequencies.

Note: The resulting delay and angular spreads of channels generated with this alternative method will be similar but not identical to when using Steps 5-7 in Clause 7.5.

### 7.6.6 Time-varying Doppler shift

The Doppler shift generally depends on the time evolution of the channel as it is defined as the derivative of the channels phase over time. It can be the result from Tx, Rx, or scatterer movement. The more general form of the exponential Doppler term as used in Equation (7.5-22) is given by

. (7.6-31)

Here,  is the normalized vector that points into the direction of the incoming wave as seen from the Rx at time .  denotes the velocity vector of the Rx at time , while  denotes a reference point in time that defines the initial phase, e.g. .

Note that Equation (7.5-22) only holds for time-invariant Doppler shift, i.e. .

### 7.6.7 UT rotation

UT rotation modelling is an add-on feature. When modelled, Step 1 in Clause 7.5 shall consider UT rotational motion.

Step 1:

Add: h) Give rotational motion of UT in terms of its bearing angle, downtilt angle and slant angle.

### 7.6.8 Explicit ground reflection model

In case the ground reflection shall be modelled explicitly, Equation (7.5-30) has to be replaced by

 (7.6-32)

with the delays for the ground reflected and the LOS paths being defined by their lengths, according to the Tx-Rx separation  and the Tx and Rx heights  and  respectively, as

, (7.6-33)

and

. (7.6-34)

The channel coefficient for the ground reflected path is given by

 (7.6-35)

with the normalized vectors pointing towards the ground reflection point from the Tx

 (7.6-36)

and from the Rx side

. (7.6-37)

The angles for the ground reflected path are given by the geometry assuming a flat surface with its normal pointing into z-direction. The angles at the Tx side can be determined by

 (7.6-37a)

 (7.6-37b)

and at the Rx side by

 (7.6-37c)

. (7.6-37d)

The reflection coefficients for parallel and perpendicular polarization on the ground, cf. [21], are given by

, (7.6-38)

and

, (7.6-39)

with the complex relative permittivity of the ground material given by

. (7.6-40)

The electric constant  is given by 8.854187817... × 10−12 F·m−1.

For applicable frequency ranges, the real relative permittivity can be modelled by

, (7.6-41)

while the conductivity in [S/m] may be modelled by

, (7.6-42)

with  being the center frequency in Hz.

A selection of material properties from [19] is given below. Since the simplified models for conductivity and relative permittivity are only applicable for frequencies between 1 and 10 GHz, Figure 7.6.8-1 presents curves up to 100 GHz at least for very, medium dry and wet ground, cf. [20].

Table 7.6.8-1 Material properties [19]

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Material class** | **Relative permittivity** | | **Conductivity** | | **Frequency range in [GHz]** |
|  |  |  |  |
| Concrete | 5.31 | 0 | 0.0326 | 0.8095 | 1-100 |
| Brick | 3.75 | 0 | 0.038 | 0 | 1-10 |
| Plasterboard | 2.94 | 0 | 0.0116 | 0.7076 | 1-100 |
| Wood | 1.99 | 0 | 0.0047 | 1.0718 | 0.001-100 |
| Floorboard | 3.66 | 0 | 0.0044 | 1.3515 | 50-100 |
| Metal | 1 | 0 | 107 | 0 | 1-100 |
| Very dry ground | 3 | 0 | 0.00015 | 2.52 | 1-10 |
| Medium dry ground | 15 | −0.1 | 0.035 | 1.63 | 1-10 |
| Wet ground | 30 | −0.4 | 0.15 | 1.30 | 1-10 |

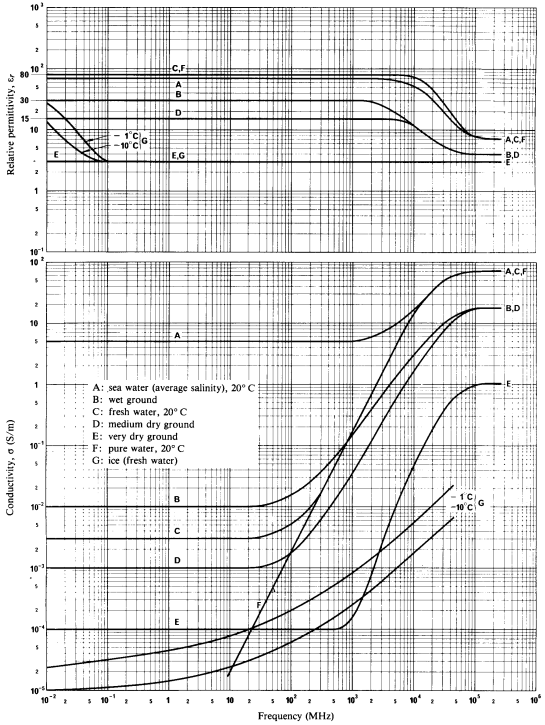


Figure 7.6.8-1: Relative permittivity and conductivity as a function of frequency [20]

### 7.6.9 Absolute time of arrival

To support simulations in which absolute time of arrival is important, the propagation time delay due to the total path length is considered in step 11 of the fast fading model as follows. The impulse response in NLOS is determined using equation (7.6-43) instead of (7.5-27) and the impulse response in LOS is determined using equation (7.6-44) instead of (7.5-30), where is the speed of light. is generated from a lognormal distribution with parameters according to Table 7.6.9-1. is generated independently for links between the same UT and different BS sites. The excess delay in NLOS, , should further be upper bounded by , where is the largest dimension of the factory hall, i.e. = max(length, width, height).

(7.6-43)

. (7.6-44)

Table 7.6.9-1: Parameters for the absolute time of arrival model

|  |  |  |  |
| --- | --- | --- | --- |
| Scenarios | | InF-SL, InF-DL | InF-SH, InF-DH |
|  |  | -7.5 | -7.5 |
|  |  | 0.4 | 0.4 |
| Correlation distance in the horizontal plane [m] | | 6 | 11 |

### 7.6.10 Dual mobility

To support simulations that involve dual Tx and Rx mobility or scatterer mobility, the Doppler frequency component in the channel coefficient generation in step 11 in clause 7.5 should be updated as follows.

For the LOS path, the Doppler frequency is given by

(7.6-45)

where and are defined in (7.5-23) and (7.5-24) respectively, and





For all other paths, the Doppler frequency component is given by:

(7.6-46)

where is a random variable from to , is a random variable of Bernoulli distribution with mean *p*, and is the maximum speed of the clutter. Parameter *p* determines the proportion of mobile scatterers and can thus be selected to appropriately model statistically larger number of mobile scatterers (higher *p*) or statistically smaller number of mobile scatterers (e.g. in case of a completely static environment: **p**=0 results in all scatteres having zero speed). A typical value of *p* is 0.2.

### 7.6.11 Sources of EM interference

When the simulation includes sources of EM interference in industrial scenarios, the channel(s) between the interferer(s) and the BS or UT should be modeled using the appropriate sub-scenario(s), e.g. clutter-embedded or elevated Tx or Rx and low or high clutter density. Characterization of EM interference sources is out of the scope of this TR.

### 7.6.12 Embedded devices

To simulate devices that are embedded inside machinery or enclosures, an additional loss parameter Lembedded is added to the path loss in step 12. The additional path loss parameter Lembedded to embedded devices is left as a simulation assumption, where it may be formulated e.g. as a value or range, or derived using a methodology similar to the building penetration loss in clause 7.4.3.1.

## 7.7 Channel models for link-level evaluations

### 7.7.1 Clustered Delay Line (CDL) models

The CDL models are defined for the full frequency range from 0.5 GHz to 100 GHz with a maximum bandwidth of 2 GHz. CDL models can be implemented by e.g., coefficient generation Step 10 and Step 11 in Clause 7.5 or generating TDL model using spatial filter from Clause 7.7.4. Three CDL models, namely CDL-A, CDL-B and CDL-C are constructed to represent three different channel profiles for NLOS while CDL-D and CDL-E are constructed for LOS, the parameters of which can be found respectively in Table 7.7.1-1, Table 7.7.1-2 , Table 7.7.1-3, Table 7.7.1-4 and Table 7.7.1-5.

Each CDL model can be scaled in delay so that the model achieves a desired RMS delay spread, according to the procedure described in Clause 7.7.3. Each CDL model can also be scaled in angles so that the model achieves desired angle spreads, according to the procedure described in Clause 7.7.5.1.

For LOS channel models, the K-factor of CDL-D and CDL-E can be set to a desired value following the procedure described in Clause 7.7.6.

For modelling effect of beamforming in a simplified way, a brick-wall window can be applied to a delay-scaled CDL model. The power shall be normalized after applying the window. A TDL model for simplified evaluations can be obtained from the CDL model, according to this method.

The following step by step procedure should be used to generate channel coefficients using the CDL models.

Step 1: Generate departure and arrival angles

Generate arrival angles of azimuth using the following equation

, (7.7-0a)

Where *n,*AOA is the cluster AOA and *c*ASA is the cluster-wise rms azimuth spread of arrival angles (cluster ASA) in Tables 7.7.1.1 – 7.7.1.5 below, and *m* denotes the ray offset angles within a cluster given by Table 7.5-3. If angular scaling according to Clause 7.7.5.1 is used, this is applied to the ray angles , The generation of AOD (), ZSA (), and ZSD () follows a procedure similar to AOA as described above.

Step 2: Coupling of rays within a cluster for both azimuth and elevation

Couple randomly AOD angles  to AOA angles  within a cluster *n*. Couple randomly ZOD angles  with ZOA angles using the same procedure. Couple randomly AOD angles  with ZOD angles within a cluster *n*.

Step 3: Generate the cross polarization power ratios

Generate the cross polarization power ratios (XPR) **for each ray *m* of each cluster *n* as

, (7.7-0b)

where *X* is the per-cluster XPR in dB from Tables 7.7.1.1 – 7.7.1.5.

Step 4: Coefficient generation

Follow the same procedure as in Steps 10 and 11 in Clause 7.5, with the exception that all clusters are treated as "weaker cluster", i.e. no further sub-clusters in delay should be generated. Additional clusters representing delay spread of the stronger clusters are already provided in Tables 7.7.1.1 – 7.7.1.5.

Table 7.7.1-1. CDL-A

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Cluster # | Normalized delay | | Power in [dB] | | AOD in [°] | | AOA in [°] | | ZOD in [°] | | ZOA in [°] |
| 1 | 0.0000 | | -13.4 | | -178.1 | | 51.3 | | 50.2 | | 125.4 |
| 2 | 0.3819 | | 0 | | -4.2 | | -152.7 | | 93.2 | | 91.3 |
| 3 | 0.4025 | | -2.2 | | -4.2 | | -152.7 | | 93.2 | | 91.3 |
| 4 | 0.5868 | | -4 | | -4.2 | | -152.7 | | 93.2 | | 91.3 |
| 5 | 0.4610 | | -6 | | 90.2 | | 76.6 | | 122 | | 94 |
| 6 | 0.5375 | | -8.2 | | 90.2 | | 76.6 | | 122 | | 94 |
| 7 | 0.6708 | | -9.9 | | 90.2 | | 76.6 | | 122 | | 94 |
| 8 | 0.5750 | | -10.5 | | 121.5 | | -1.8 | | 150.2 | | 47.1 |
| 9 | 0.7618 | | -7.5 | | -81.7 | | -41.9 | | 55.2 | | 56 |
| 10 | 1.5375 | | -15.9 | | 158.4 | | 94.2 | | 26.4 | | 30.1 |
| 11 | 1.8978 | | -6.6 | | -83 | | 51.9 | | 126.4 | | 58.8 |
| 12 | 2.2242 | | -16.7 | | 134.8 | | -115.9 | | 171.6 | | 26 |
| 13 | 2.1718 | | -12.4 | | -153 | | 26.6 | | 151.4 | | 49.2 |
| 14 | 2.4942 | | -15.2 | | -172 | | 76.6 | | 157.2 | | 143.1 |
| 15 | 2.5119 | | -10.8 | | -129.9 | | -7 | | 47.2 | | 117.4 |
| 16 | 3.0582 | | -11.3 | | -136 | | -23 | | 40.4 | | 122.7 |
| 17 | 4.0810 | | -12.7 | | 165.4 | | -47.2 | | 43.3 | | 123.2 |
| 18 | 4.4579 | | -16.2 | | 148.4 | | 110.4 | | 161.8 | | 32.6 |
| 19 | 4.5695 | | -18.3 | | 132.7 | | 144.5 | | 10.8 | | 27.2 |
| 20 | 4.7966 | | -18.9 | | -118.6 | | 155.3 | | 16.7 | | 15.2 |
| 21 | 5.0066 | | -16.6 | | -154.1 | | 102 | | 171.7 | | 146 |
| 22 | 5.3043 | | -19.9 | | 126.5 | | -151.8 | | 22.7 | | 150.7 |
| 23 | 9.6586 | | -29.7 | | -56.2 | | 55.2 | | 144.9 | | 156.1 |
| Per-Cluster Parameters | | | | | | | | | | | |
| Parameter | | *c*ASD in [°] | | *c*ASA in [°] | | *c*ZSD in [°] | | *c*ZSA in [°] | | XPR in [dB] | |
| Value | | 5 | | 11 | | 3 | | 3 | | 10 | |

Table 7.7.1-2. CDL-B

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Cluster #** | **Normalized delay** | | **Power in [dB]** | | **AOD in [°]** | | **AOA in [°]** | | **ZOD in [°]** | | **ZOA in [°]** |
| 1 | 0.0000 | | 0 | | 9.3 | | -173.3 | | 105.8 | | 78.9 |
| 2 | 0.1072 | | -2.2 | | 9.3 | | -173.3 | | 105.8 | | 78.9 |
| 3 | 0.2155 | | -4 | | 9.3 | | -173.3 | | 105.8 | | 78.9 |
| 4 | 0.2095 | | -3.2 | | -34.1 | | 125.5 | | 115.3 | | 63.3 |
| 5 | 0.2870 | | -9.8 | | -65.4 | | -88.0 | | 119.3 | | 59.9 |
| 6 | 0.2986 | | -1.2 | | -11.4 | | 155.1 | | 103.2 | | 67.5 |
| 7 | 0.3752 | | -3.4 | | -11.4 | | 155.1 | | 103.2 | | 67.5 |
| 8 | 0.5055 | | -5.2 | | -11.4 | | 155.1 | | 103.2 | | 67.5 |
| 9 | 0.3681 | | -7.6 | | -67.2 | | -89.8 | | 118.2 | | 82.6 |
| 10 | 0.3697 | | -3 | | 52.5 | | 132.1 | | 102.0 | | 66.3 |
| 11 | 0.5700 | | -8.9 | | -72 | | -83.6 | | 100.4 | | 61.6 |
| 12 | 0.5283 | | -9 | | 74.3 | | 95.3 | | 98.3 | | 58.0 |
| 13 | 1.1021 | | -4.8 | | -52.2 | | 103.7 | | 103.4 | | 78.2 |
| 14 | 1.2756 | | -5.7 | | -50.5 | | -87.8 | | 102.5 | | 82.0 |
| 15 | 1.5474 | | -7.5 | | 61.4 | | -92.5 | | 101.4 | | 62.4 |
| 16 | 1.7842 | | -1.9 | | 30.6 | | -139.1 | | 103.0 | | 78.0 |
| 17 | 2.0169 | | -7.6 | | -72.5 | | -90.6 | | 100.0 | | 60.9 |
| 18 | 2.8294 | | -12.2 | | -90.6 | | 58.6 | | 115.2 | | 82.9 |
| 19 | 3.0219 | | -9.8 | | -77.6 | | -79.0 | | 100.5 | | 60.8 |
| 20 | 3.6187 | | -11.4 | | -82.6 | | 65.8 | | 119.6 | | 57.3 |
| 21 | 4.1067 | | -14.9 | | -103.6 | | 52.7 | | 118.7 | | 59.9 |
| 22 | 4.2790 | | -9.2 | | 75.6 | | 88.7 | | 117.8 | | 60.1 |
| 23 | 4.7834 | | -11.3 | | -77.6 | | -60.4 | | 115.7 | | 62.3 |
| Per-Cluster Parameters | | | | | | | | | | | |
| Parameter | | *c*ASD in [°] | | *c*ASA in [°] | | *c*ZSD in [°] | | *c*ZSA in [°] | | XPR in [dB] | |
| Value | | 10 | | 22 | | 3 | | 7 | | 8 | |

Table 7.7.1-3. CDL-C

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Cluster #** | **Normalized delay** | | **Power in [dB]** | | **AOD in [°]** | | **AOA in [°]** | | **ZOD in [°]** | | **ZOA in [°]** |
| 1 | 0 | | -4.4 | | -46.6 | | -101 | | 97.2 | | 87.6 |
| 2 | 0.2099 | | -1.2 | | -22.8 | | 120 | | 98.6 | | 72.1 |
| 3 | 0.2219 | | -3.5 | | -22.8 | | 120 | | 98.6 | | 72.1 |
| 4 | 0.2329 | | -5.2 | | -22.8 | | 120 | | 98.6 | | 72.1 |
| 5 | 0.2176 | | -2.5 | | -40.7 | | -127.5 | | 100.6 | | 70.1 |
| 6 | 0.6366 | | 0 | | 0.3 | | 170.4 | | 99.2 | | 75.3 |
| 7 | 0.6448 | | -2.2 | | 0.3 | | 170.4 | | 99.2 | | 75.3 |
| 8 | 0.6560 | | -3.9 | | 0.3 | | 170.4 | | 99.2 | | 75.3 |
| 9 | 0.6584 | | -7.4 | | 73.1 | | 55.4 | | 105.2 | | 67.4 |
| 10 | 0.7935 | | -7.1 | | -64.5 | | 66.5 | | 95.3 | | 63.8 |
| 11 | 0.8213 | | -10.7 | | 80.2 | | -48.1 | | 106.1 | | 71.4 |
| 12 | 0.9336 | | -11.1 | | -97.1 | | 46.9 | | 93.5 | | 60.5 |
| 13 | 1.2285 | | -5.1 | | -55.3 | | 68.1 | | 103.7 | | 90.6 |
| 14 | 1.3083 | | -6.8 | | -64.3 | | -68.7 | | 104.2 | | 60.1 |
| 15 | 2.1704 | | -8.7 | | -78.5 | | 81.5 | | 93.0 | | 61.0 |
| 16 | 2.7105 | | -13.2 | | 102.7 | | 30.7 | | 104.2 | | 100.7 |
| 17 | 4.2589 | | -13.9 | | 99.2 | | -16.4 | | 94.9 | | 62.3 |
| 18 | 4.6003 | | -13.9 | | 88.8 | | 3.8 | | 93.1 | | 66.7 |
| 19 | 5.4902 | | -15.8 | | -101.9 | | -13.7 | | 92.2 | | 52.9 |
| 20 | 5.6077 | | -17.1 | | 92.2 | | 9.7 | | 106.7 | | 61.8 |
| 21 | 6.3065 | | -16 | | 93.3 | | 5.6 | | 93.0 | | 51.9 |
| 22 | 6.6374 | | -15.7 | | 106.6 | | 0.7 | | 92.9 | | 61.7 |
| 23 | 7.0427 | | -21.6 | | 119.5 | | -21.9 | | 105.2 | | 58 |
| 24 | 8.6523 | | -22.8 | | -123.8 | | 33.6 | | 107.8 | | 57 |
| Per-Cluster Parameters | | | | | | | | | | | |
| Parameter | | *c*ASD in [°] | | *c*ASA in [°] | | *c*ZSD in [°] | | *c*ZSA in [°] | | XPR in [dB] | |
| Value | | 2 | | 15 | | 3 | | 7 | | 7 | |

Table 7.7.1-4. CDL-D.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Cluster #** | **Cluster PAS** | **Normalized Delay** | **Power in [dB]** | **AOD in [°]** | **AOA in [°]** | **ZOD in [°]** | | **ZOA in [°]** |
| 1 | Specular(LOS path) | 0 | -0.2 | 0 | -180 | 98.5 | | 81.5 |
| Laplacian | 0 | -13.5 | 0 | -180 | 98.5 | | 81.5 |
| 2 | Laplacian | 0.035 | -18.8 | 89.2 | 89.2 | 85.5 | | 86.9 |
| 3 | Laplacian | 0.612 | -21 | 89.2 | 89.2 | 85.5 | | 86.9 |
| 4 | Laplacian | 1.363 | -22.8 | 89.2 | 89.2 | 85.5 | | 86.9 |
| 5 | Laplacian | 1.405 | -17.9 | 13 | 163 | 97.5 | | 79.4 |
| 6 | Laplacian | 1.804 | -20.1 | 13 | 163 | 97.5 | | 79.4 |
| 7 | Laplacian | 2.596 | -21.9 | 13 | 163 | 97.5 | | 79.4 |
| 8 | Laplacian | 1.775 | -22.9 | 34.6 | -137 | 98.5 | | 78.2 |
| 9 | Laplacian | 4.042 | -27.8 | -64.5 | 74.5 | 88.4 | | 73.6 |
| 10 | Laplacian | 7.937 | -23.6 | -32.9 | 127.7 | 91.3 | | 78.3 |
| 11 | Laplacian | 9.424 | -24.8 | 52.6 | -119.6 | 103.8 | | 87 |
| 12 | Laplacian | 9.708 | -30.0 | -132.1 | -9.1 | 80.3 | | 70.6 |
| 13 | Laplacian | 12.525 | -27.7 | 77.2 | -83.8 | 86.5 | | 72.9 |
| Per-Cluster Parameters | | | | | | | | |
| Parameter | | *c*ASD in [°] | *c*ASA in [°] | *c*ZSD in [°] | *c*ZSA in [°] | | XPR in [dB] | |
| Value | | 5 | 8 | 3 | 3 | | 11 | |

Table 7.7.1-5. CDL-E.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Cluster #** | **Cluster PAS** | | **Normalized Delay** | **Power in [dB]** | **AOD in [°]** | **AOA in [°]** | **ZOD in [°]** | | **ZOA in [°]** |
| 1 | Specular (LOS path) | | 0.000 | -0.03 | 0 | -180 | 99.6 | | 80.4 |
| Laplacian | | 0.000 | -22.03 | 0 | -180 | 99.6 | | 80.4 |
| 2 | Laplacian | | 0.5133 | -15.8 | 57.5 | 18.2 | 104.2 | | 80.4 |
| 3 | Laplacian | | 0.5440 | -18.1 | 57.5 | 18.2 | 104.2 | | 80.4 |
| 4 | Laplacian | | 0.5630 | -19.8 | 57.5 | 18.2 | 104.2 | | 80.4 |
| 5 | Laplacian | | 0.5440 | -22.9 | -20.1 | 101.8 | 99.4 | | 80.8 |
| 6 | Laplacian | | 0.7112 | -22.4 | 16.2 | 112.9 | 100.8 | | 86.3 |
| 7 | Laplacian | | 1.9092 | -18.6 | 9.3 | -155.5 | 98.8 | | 82.7 |
| 8 | Laplacian | | 1.9293 | -20.8 | 9.3 | -155.5 | 98.8 | | 82.7 |
| 9 | Laplacian | | 1.9589 | -22.6 | 9.3 | -155.5 | 98.8 | | 82.7 |
| 10 | Laplacian | | 2.6426 | -22.3 | 19 | -143.3 | 100.8 | | 82.9 |
| 11 | Laplacian | | 3.7136 | -25.6 | 32.7 | -94.7 | 96.4 | | 88 |
| 12 | Laplacian | | 5.4524 | -20.2 | 0.5 | 147 | 98.9 | | 81 |
| 13 | Laplacian | | 12.0034 | -29.8 | 55.9 | -36.2 | 95.6 | | 88.6 |
| 14 | Laplacian | | 20.6419 | -29.2 | 57.6 | -26 | 104.6 | | 78.3 |
| Per-Cluster Parameters | | | | | | | | | |
| Parameter | | *c*ASD in [°] | | *c*ASA in [°] | *c*ZSD in [°] | *c*ZSA in [°] | | XPR in [dB] | |
| Value | | 5 | | 11 | 3 | 7 | | 8 | |

### 7.7.2 Tapped Delay Line (TDL) models

The TDL models for simplified evaluations, e.g., for non-MIMO evaluations, are defined for the full frequency range from 0.5 GHz to 100 GHz with a maximum bandwidth of 2 GHz.

Three TDL models, namely TDL-A, TDL-B and TDL-C, are constructed to represent three different channel profiles for NLOS while TDL-D and TDL-E are constructed for LOS, the parameters of which can be found respectively in Table 7.7.2-1, Table 7.7.2-2 , Table 7.7.2-3, Table 7.7.2-4 and Table 7.7.2-5.

The Doppler spectrum for each tap is characterized by a classical (Jakes) spectrum shape and a maximum Doppler shift *fD* where . Due to the presence of a LOS path, the first tap in TDL-D and TDL-E follows a Ricean fading distribution. For those taps the Doppler spectrum additionally contains a peak at the Doppler shift *fS* = 0.7 *fD* with an amplitude such that the resulting fading distribution has the specified K-factor.

Each TDL model can be scaled in delay so that the model achieves a desired RMS delay spread, according to the procedure described in Clause 7.7.3.

For LOS channel models, the K-factor of TDL-D and TDL-E can be set to a desired value following the procedure described in Clause 7.7.6.

Table 7.7.2-1. TDL-A

|  |  |  |  |
| --- | --- | --- | --- |
| Tap # | Normalized delay | Power in [dB] | Fading distribution |
| 1 | 0.0000 | -13.4 | Rayleigh |
| 2 | 0.3819 | 0 | Rayleigh |
| 3 | 0.4025 | -2.2 | Rayleigh |
| 4 | 0.5868 | -4 | Rayleigh |
| 5 | 0.4610 | -6 | Rayleigh |
| 6 | 0.5375 | -8.2 | Rayleigh |
| 7 | 0.6708 | -9.9 | Rayleigh |
| 8 | 0.5750 | -10.5 | Rayleigh |
| 9 | 0.7618 | -7.5 | Rayleigh |
| 10 | 1.5375 | -15.9 | Rayleigh |
| 11 | 1.8978 | -6.6 | Rayleigh |
| 12 | 2.2242 | -16.7 | Rayleigh |
| 13 | 2.1718 | -12.4 | Rayleigh |
| 14 | 2.4942 | -15.2 | Rayleigh |
| 15 | 2.5119 | -10.8 | Rayleigh |
| 16 | 3.0582 | -11.3 | Rayleigh |
| 17 | 4.0810 | -12.7 | Rayleigh |
| 18 | 4.4579 | -16.2 | Rayleigh |
| 19 | 4.5695 | -18.3 | Rayleigh |
| 20 | 4.7966 | -18.9 | Rayleigh |
| 21 | 5.0066 | -16.6 | Rayleigh |
| 22 | 5.3043 | -19.9 | Rayleigh |
| 23 | 9.6586 | -29.7 | Rayleigh |

Table 7.7.2-2. TDL-B

|  |  |  |  |
| --- | --- | --- | --- |
| Tap # | **Normalized delay** | **Power in [dB]** | **Fading distribution** |
| 1 | 0.0000 | 0 | Rayleigh |
| 2 | 0.1072 | -2.2 | Rayleigh |
| 3 | 0.2155 | -4 | Rayleigh |
| 4 | 0.2095 | -3.2 | Rayleigh |
| 5 | 0.2870 | -9.8 | Rayleigh |
| 6 | 0.2986 | -1.2 | Rayleigh |
| 7 | 0.3752 | -3.4 | Rayleigh |
| 8 | 0.5055 | -5.2 | Rayleigh |
| 9 | 0.3681 | -7.6 | Rayleigh |
| 10 | 0.3697 | -3 | Rayleigh |
| 11 | 0.5700 | -8.9 | Rayleigh |
| 12 | 0.5283 | -9 | Rayleigh |
| 13 | 1.1021 | -4.8 | Rayleigh |
| 14 | 1.2756 | -5.7 | Rayleigh |
| 15 | 1.5474 | -7.5 | Rayleigh |
| 16 | 1.7842 | -1.9 | Rayleigh |
| 17 | 2.0169 | -7.6 | Rayleigh |
| 18 | 2.8294 | -12.2 | Rayleigh |
| 19 | 3.0219 | -9.8 | Rayleigh |
| 20 | 3.6187 | -11.4 | Rayleigh |
| 21 | 4.1067 | -14.9 | Rayleigh |
| 22 | 4.2790 | -9.2 | Rayleigh |
| 23 | 4.7834 | -11.3 | Rayleigh |

Table 7.7.2-3. TDL-C

|  |  |  |  |
| --- | --- | --- | --- |
| **Tap #** | **Normalized delays** | **Power in [dB]** | **Fading distribution** |
| 1 | 0 | -4.4 | Rayleigh |
| 2 | 0.2099 | -1.2 | Rayleigh |
| 3 | 0.2219 | -3.5 | Rayleigh |
| 4 | 0.2329 | -5.2 | Rayleigh |
| 5 | 0.2176 | -2.5 | Rayleigh |
| 6 | 0.6366 | 0 | Rayleigh |
| 7 | 0.6448 | -2.2 | Rayleigh |
| 8 | 0.6560 | -3.9 | Rayleigh |
| 9 | 0.6584 | -7.4 | Rayleigh |
| 10 | 0.7935 | -7.1 | Rayleigh |
| 11 | 0.8213 | -10.7 | Rayleigh |
| 12 | 0.9336 | -11.1 | Rayleigh |
| 13 | 1.2285 | -5.1 | Rayleigh |
| 14 | 1.3083 | -6.8 | Rayleigh |
| 15 | 2.1704 | -8.7 | Rayleigh |
| 16 | 2.7105 | -13.2 | Rayleigh |
| 17 | 4.2589 | -13.9 | Rayleigh |
| 18 | 4.6003 | -13.9 | Rayleigh |
| 19 | 5.4902 | -15.8 | Rayleigh |
| 20 | 5.6077 | -17.1 | Rayleigh |
| 21 | 6.3065 | -16 | Rayleigh |
| 22 | 6.6374 | -15.7 | Rayleigh |
| 23 | 7.0427 | -21.6 | Rayleigh |
| 24 | 8.6523 | -22.8 | Rayleigh |

Table 7.7.2-4. TDL-D.

|  |  |  |  |
| --- | --- | --- | --- |
| Tap # | Normalized delay | Power in [dB] | Fading distribution |
| 1 | 0 | -0.2 | LOS path |
| 0 | -13.5 | Rayleigh |
| 2 | 0.035 | -18.8 | Rayleigh |
| 3 | 0.612 | -21 | Rayleigh |
| 4 | 1.363 | -22.8 | Rayleigh |
| 5 | 1.405 | -17.9 | Rayleigh |
| 6 | 1.804 | -20.1 | Rayleigh |
| 7 | 2.596 | -21.9 | Rayleigh |
| 8 | 1.775 | -22.9 | Rayleigh |
| 9 | 4.042 | -27.8 | Rayleigh |
| 10 | 7.937 | -23.6 | Rayleigh |
| 11 | 9.424 | -24.8 | Rayleigh |
| 12 | 9.708 | -30.0 | Rayleigh |
| 13 | 12.525 | -27.7 | Rayleigh |
| NOTE: The first tap follows a Ricean distribution with a K-factor of K1 = 13.3 dB and a mean power of 0dB. | | | |

Table 7.7.2-5. TDL-E.

|  |  |  |  |
| --- | --- | --- | --- |
| Tap # | Normalized delay | Power in [dB] | Fading distribution |
| 1 | 0 | -0.03 | LOS path |
| 0 | -22.03 | Rayleigh |
| 2 | 0.5133 | -15.8 | Rayleigh |
| 3 | 0.5440 | -18.1 | Rayleigh |
| 4 | 0.5630 | -19.8 | Rayleigh |
| 5 | 0.5440 | -22.9 | Rayleigh |
| 6 | 0.7112 | -22.4 | Rayleigh |
| 7 | 1.9092 | -18.6 | Rayleigh |
| 8 | 1.9293 | -20.8 | Rayleigh |
| 9 | 1.9589 | -22.6 | Rayleigh |
| 10 | 2.6426 | -22.3 | Rayleigh |
| 11 | 3.7136 | -25.6 | Rayleigh |
| 12 | 5.4524 | -20.2 | Rayleigh |
| 13 | 12.0034 | -29.8 | Rayleigh |
| 14 | 20.6519 | -29.2 | Rayleigh |
| NOTE: The first tap follows a Ricean distribution with a K-factor of K1 = 22 dB and a mean power of 0dB. | | | |

### 7.7.3 Scaling of delays

The RMS delay spread values of both CDL and TDL models are normalized and they can be scaled in delay so that a desired RMS delay spread can be achieved. The scaled delays can be obtained according to the following equation:

 (7.7-1)

in which

 is the normalized delay value of the *n*th cluster in a CDL or a TDL model

 is the new delay value (in [ns]) of the *n*th cluster

 is the wanted delay spread (in [ns])

The example scaling parameters are selected according to Table 7.7.3-1 where the values have been chosen such that the RMS delay spreads span the range observed in measurements corresponding to the typical 5G evaluation scenarios. For information purposes, examples of such RMS delay spreads for the different scenarios are given in Table 7.7.3-2 where the "short-delay profile" corresponds to the median RMS delay spread for LOS scenarios, while "normal-delay profile" and "long-delay profile" correspond to the median and the 90th percentile RMS delay spread for NLOS scenarios according to the channel parameters in Table 7.5-6. It can therefore be understood that a particular RMS delay spread in Table 7.7.3-1 may occur in any scenario; however certain values may be more likely in some scenarios than in others.

The example parameters given in Table 7.7.3-1 does not preclude the use of other scaling values if this is found appropriate, for instance if additional scenarios are introduced or if e.g. the effect of beamforming needs to be captured in a TDL. Both of these examples can potentially result in an increased range of experienced RMS delay spreads.

Table 7.7.3-1. Example scaling parameters for CDL and TDL models.

|  |  |
| --- | --- |
| Model |  |
| Very short delay spread | 10 ns |
| Short delay spread | 30 ns |
| Nominal delay spread | 100 ns |
| Long delay spread | 300 ns |
| Very long delay spread | 1000 ns |

Table 7.7.3-2. Scenario specific scaling factors - for information only

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Proposed Scaling Factor  in [ns] | | Frequency [GHz] | | | | | | |
| 2 | 6 | 15 | 28 | 39 | 60 | 70 |
| Indoor office | Short-delay profile | 20 | 16 | 16 | 16 | 16 | 16 | 16 |
| Normal-delay profile | 39 | 30 | 24 | 20 | 18 | 16 | 16 |
| Long-delay profile | 59 | 53 | 47 | 43 | 41 | 38 | 37 |
| UMi Street-canyon | Short-delay profile | 65 | 45 | 37 | 32 | 30 | 27 | 26 |
| Normal-delay profile | 129 | 93 | 76 | 66 | 61 | 55 | 53 |
| Long-delay profile | 634 | 316 | 307 | 301 | 297 | 293 | 291 |
| UMa | Short-delay profile | 93 | 93 | 85 | 80 | 78 | 75 | 74 |
| Normal-delay profile | 363 | 363 | 302 | 266 | 249 | 228 | 221 |
| Long-delay profile | 1148 | 1148 | 955 | 841 | 786 | 720 | 698 |
| RMa & RMa O2I | Short-delay profile | 32 | 32 | N/A | N/A | N/A | N/A | N/A |
| Normal-delay profile | 37 | 37 | N/A | N/A | N/A | N/A | N/A |
| Long-delay profile | 153 | 153 | N/A | N/A | N/A | N/A | N/A |
| UMi / UMa O2I | Normal-delay profile | 240 | | | | | | |
| Long-delay profile | 616 | | | | | | |

### 7.7.4 Spatial filter for generating TDL channel model

The TDL models described in Clause 7.7.2 are generated from the CDL models assuming ideal isotropic antennas at both Tx and Rx. It is also possible to generate TDL models by assuming non-isotropic antennas like directive horn antennas or array antennas.

The basic idea to generate a TDL model based on a filtered CDL model is shown in Figure 7.7.4-1 below.

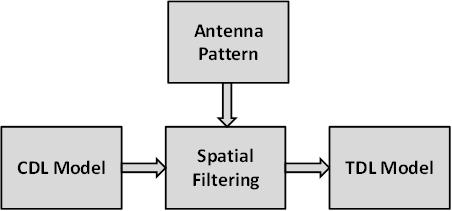


Figure 7.7.4-1 The basic idea for filtering the CDL model to TDL model.

#### 7.7.4.1 Exemplary filters/antenna patterns

Note that any filter/pattern can be applied on a CDL to derive a TDL for evaluating directional algorithms.

**Example 1:** Isotropic pattern

 (7.7-2)

**Example 2:** Rectangular mask

 (7.7-3)

with  denotes beamwidth.

**Example 3:** Simplified antenna pattern given in [ITU-R M.2135]



Figure 7.7.4-2 Simplified antenna pattern [ITU-R M.2135].

#### 7.7.4.2 Generation procedure

1. The following steps are needed to generate tapped delay line (TDL) models:Choose a CDL model (e.g. CDL-A). Note that the models may be scaled according to Clause 7.7.5.1 prior to the filtering in order to represent different angular spreads.

2. Choose spatial filters  and  defined in LCS

3. Transform the spatial filter into GCS to obtain  and  such that the pointing direction  is centered within the filter. The pointing direction may be defined



a. by the dominant path  with , where  denotes the CDL cluster power values



b. Or an arbitrary direction

4. Calculate TDL cluster power values  given the following equation



 (7.7-4)

### 7.7.5 Extension for MIMO simulations

Extended MIMO link-level channel models can be constructed according to two alternative methods described in the following.

#### 7.7.5.1 CDL extension: Scaling of angles

The angle values of CDL models are fixed, which is not very suitable for MIMO simulations for several reasons; The PMI statistics can become biased, and a fixed precoder may perform better than open-loop and on par with closed-loop or reciprocity beamforming. Furthermore, a CDL only represents a single channel realization. The predefined angle values in the CDL models can be generalized by introducing angular translation and scaling. By translation, mean angle can be changed to  and angular spread can be changed by scaling. The translated and scaled ray angles can be obtained according to the following equation:

 (7.7-5)

in which:

 is the tabulated CDL ray angle



 is the rms angular spread of the tabulated CDL including the offset ray angles, calculated using the angular spread definition in Annex A



 is the mean angle of the tabulated CDL, calculated using the definition in Annex A



 is the desired mean angle



 is the desired rms angular spread



 is the resulting scaled ray angle.



The angular scaling is applied on the ray angles including offsets from the tabulated cluster angles. Typical angular spreads for different scenarios can be obtained from the system-level model.

Example scaling values are:

- AOD spread (ASD) for each CDL model: {5, 10, 15, 25} degrees.

- AOA spread (ASA) for each CDL model: {30, 45, 60} degrees.

- ZOA spread (ZSA) for each CDL model: {5, 10, 15} degrees.

- ZOD spread (ZSD) for each CDL model: {1, 3, 5} degrees.

The angular scaling and translation can be applied to some or all of the azimuth and zenith angles of departure and arrival.

Note: The azimuth angles may need to be wrapped around to be within [0, 360] degrees, while the zenith angles may need to be clipped to be within [0, 180] degrees.

#### 7.7.5.2 TDL extension: Applying a correlation matrix

The TDLs and the spatial-filtered TDLs can be used with the correlation matrices for MIMO link-level simulations. Typical correlation parameters can be derived from 1) delay & angular scaled CDLs with antenna array assumptions, 2) system-level model with antenna array assumptions, or 3) by selecting extreme cases, e.g. uncorrelated, highly correlated etc. For example, these following options can be considered:

1) Zero correlation (IID channel coefficients) can be used for any number of antenna elements

2) The correlation matrix construction method from 3GPP TS36.101/104 [15][16] can be used for linear and planar (single- or dual-polarized) arrays.

- Other correlation parameters α, β, γ than those specified in 3GPP TS36.101/104 [15][16] and extensions to larger antenna arrays can be considered. For typical scenarios, α and β will be in the range 0-1

- A representative set of values is {0,0.7,0.9,0.99}

Note: This approach can be applied to TDLs derived from spatially filtered CDLs to emulate hybrid BF system

Note: Other methodologies could also be developed, e.g.

- extending the 3GPP TS36.101/104 [15][16] procedure to planar arrays or more elements

- using CDLs in combination with array assumptions to derive per-tap correlation matrices as in [17].

- using the system-level model in combination with array assumptions to derive per-tap or per-channel correlation matrices

### 7.7.6 K-factor for LOS channel models

For the LOS channel models of CDL/TDL-D and CDL/TDL-E, the K-factor values may be changed by the user. Mean and standard deviation of K-factor values can be found in Table 7.5-6, although other values may also be used.

If the K-factor of a model shall be changed to  [dB], the cluster powers for the Laplacian clusters (in case of CDL) or the tap powers for the Rayleigh fading taps (in case of TDL) are determined by

, (7.7.6-1)

where  and  denote the scaled and the model path power (as given in the tables) of tap/cluster . The model's K-factor  is defined as

. (7.7.6-2)

After scaling the powers, the delay spread needs to be re-normalized. This is done through the two steps below.

1) Calculate the actual RMS delay spread after the K-factor adjustment.

2) Divide the delays by that value to obtain DS = 1.

## 7.8 Channel model calibration

### 7.8.1 Large scale calibration

For large scale calibration, fast fading is not modeled. The calibration parameters can be found in Table 7.8-1. The calibration results based on TR 38.900 V14.0.0 can be found in R1-165974.

Table 7.8-1: Simulation assumptions for large scale calibration

|  |  |
| --- | --- |
| Parameter | Values |
| Scenarios | UMa, UMi-Street Canyon, Indoor-office (open office) |
| Sectorization | 3 sectors per cell site: 30, 150 and 270 degrees  cid:image004.png@01D19614.C45E6D10 |
| BS antenna configurations | Mg = Ng = 1; (M,N,P) = (10, 1, 1), dV = 0.5λ |
| BS port mapping | The 10 elements are mapped to a single CRS port |
| BS antenna electrical downtilting | 102 degrees for UMa and UMi Street Canyon  110 degrees for indoor |
| Antenna virtualization | DFT precoding according to TR 36.897 with application of panning and tilting angles |
| BS Tx power | 44 dBm for UMi-Street Canyon, 49 for UMa at 6GHz  35 dBm at 30GHz and 70 GHz for UMa and UMi-Street canyon  24 dBm for Indoor for all carrier frequencies |
| Bandwidth | 20MHz for 6GHz, and 100MHz for 30GHz and 70 GHz |
| UT antenna configurations | 1 element (vertically polarized), Isotropic antenna gain pattern |
| Handover margin (for calibration) | 0dB |
| UT distribution | Following TR36.873 for UMa and UMi, (3D dropping)  uniform dropping for indoor with minimum distance (2D) of 0 m |
| UT attachment | Based on pathloss considering LOS angle |
| UT noise figure | 9 dB |
| Fast fading channel | Fast fading channel is not modelled |
| O2I penetration loss | 50% low loss and 50% high loss |
| Carrier Frequency | 6 GHz, 30 GHz, 70GHz |
| Wrapping method for UMa and UMi | geographical distance based wrapping (mandatory)  radio distance (optional) |
| Metrics | 1) Coupling loss – serving cell (based on LOS pathloss) |
| 2) Geometry (based on LOS pathloss) with and without white noise |

### 7.8.2 Full calibration

The calibration parameters for full calibration including the fast fading modelling can be found in Table 7.8-2. Unspecified parameters in Table 7.8-2 are the same as those in Table 7.8-1. When P=2, X-pol (+/-45 degree) is used for BS antenna configuration 1 and X-pol (0/+90 degree) is used for UT antenna configuration. The calibration results based on TR 38.900 V14.0.0 can be found in R1-165975.

Table 7.8-2: Simulation assumptions for full calibration

|  |  |
| --- | --- |
| Parameter | Values |
| Scenarios | UMa, UMi-street Canyon, Indoor-office (open office) |
| Carrier Frequency | 6 GHz, 30 GHz, 60GHz, 70GHz |
| Bandwidth | 20MHz for 6GHz, and 100MHz for 30GHz, 60 GHz and 70 GHz |
| BS Tx power | 44 dBm for UMi-Street Canyon, 49 for UMa at 6GHz  35 dBm at 30GHz, 60 GHz and 70 GHz for UMa and UMi-Street canyon  24 dBm for Indoor for all carrier frequencies |
| BS antenna configurations | Config 1: M = 4,N = 4,P = 2, Mg = 1, Ng = 2, dH = dV = 0.5λ, dH,g = dV,g = 2.5λ … calibration metrics 1), 2), 3) are calibrated  Config 2: Mg = Ng = 1, M = N = 2, P = 1 … calibration metrics 1), 2), 4) are calibrated |
| BS port mapping | Config 1: all 16 elements for each polarization on each panel are mapped to a single CRS port; panning angles of the two subarrays: (0,0) degs; same downtilt angles as used for the large-scale calibrations  Config 2: each antenna element is mapped to one CRS port |
| UT antenna configurations | Mg = Ng = 1, M = N = 1, P = 2 |
| UT distribution | Following TR36.873 for UMa and UMi, (3D dropping)  uniform dropping for indoor with minimum distance (2D) of 0 m |
| UT attachment | Based on RSRP (formula) from CRS port 0 |
| Polarized antenna modelling | Model-2 in TR36.873 |
| UT array orientation | Ω*UT,* uniformly distributed on [0,360] degree, Ω*UT,*= 90 degree, Ω*UT,* = 0 degree |
| UT antenna pattern | Isotropic |
| Metrics | 1) Coupling loss – serving cell |
| 2) Wideband SIR before receiver without noise |
| 3) CDF of Delay Spread and Angle Spread (ASD, ZSD, ASA, ZSA) from the serving cell (according to circular angle spread definition of TR 25.996) |
| 4)  CDF of largest (1st) PRB singular values (serving cell) at t=0 plotted in 10\*log10 scale.  CDF of smallest (2nd) PRB singular values (serving cell) at t=0 plotted in 10\*log10 scale.  CDF of the ratio between the largest PRB singular value and the smallest PRB singular value (serving cell) at t=0 plotted in 10\*log10 scale.  Note: The PRB singular values of a PRB are the eigenvalues of the mean covariance matrix in the PRB. |

### 7.8.3 Calibration of additional features

The calibration parameters for the calibration of oxygen absorption, large bandwidth and large antenna array, spatial consistency, and blockage can be respectively found in Table 7.8-3, 7.8-4, 7.8-5, and 7.8-6. Unspecified parameters in these tables are the same as those in Tables 7.8-1 and 7.8-2. When P=2, X-pol (+/-45 degree) is used for BS antenna configuration 1 and X-pol (0/+90 degree) is used for UT antenna configuration. The calibration results based on TR 38.900 V14.0.0 can be found in R1-1700990.

Table 7.8-3: Simulation assumptions for calibration for oxygen absorption

|  |  |
| --- | --- |
| Parameter | Values |
| Scenarios | UMi-street Canyon |
| Carrier Frequency | 60 GHz |
| BS antenna configurations | M = 4, N = 4, P = 2, Mg = 1, Ng = 2, dH = dV = 0.5λ, dH,g = dV,g = 2.5λ |
| BS port mapping | all 16 elements for each polarization on each panel are mapped to a single CRS port; panning angles of the two subarrays: (0,0) degs; same downtilt angles as used for the large-scale calibrations |
| Calibration method | Drop multiple users in the multiple cells randomly, and collect the following metrics for each user after attachment. |
| Metrics | 1) CDF of coupling loss (serving cell)  2) Wideband SINR before receiver – determined from RSRP (formula) from CRS port 0  3) CDF of Delay Spread from the serving cell |

Table 7.8-4: Simulation assumptions for calibration for large bandwidth and large antenna array

|  |  |
| --- | --- |
| Parameter | Values |
| Scenarios | UMi-street Canyon |
| Carrier Frequency | 30GHz |
| Bandwidth | 2GHz |
| BS antenna configurations | M = 8, N = 8, P = 2, Mg = 1, Ng = 4, dH = dV = 0.5λ, dH,g = dV,g = 4λ |
| BS port mapping | all 64 elements for each polarization on each panel are mapped to a single CRS port; panning angles of the two subarrays: (0,0) degs; same downtilt angles as used for the large-scale calibrations |
| The number of rays per cluster | *N*MPC = 40 |
| Calibration method | Drop multiple users in the multiple cells randomly, and collect the following metrics for each user after attachment. |
| Metrics | 1) CDF of coupling loss (serving cell)  2) Wideband SINR before receiver – determined from RSRP (formula) from CRS port 0  3) CDF of largest (1st) PRB singular values (serving cell) at t=0 plotted in 10\*log10 scale |

Table 7.8-5: Simulation assumptions for calibration for spatial consistency

|  |  |
| --- | --- |
| Parameter | Values |
| Scenarios | UMi-street Canyon |
| Carrier Frequency | 30 GHz |
| BS antenna configurations | M = 4, N = 4, P = 2, Mg = 1, Ng = 2, dH = dV = 0.5λ, dH,g = dV,g = 2.5λ |
| BS port mapping | all 16 elements for each polarization on each panel are mapped to a single CRS port; panning angles of the two subarrays: (0,0) degs; same downtilt angles as used for the large-scale calibrations |
| UE distribution | Following TR36.873, 3D dropping  uniform dropping for indoor with minimum distance of 0 m  For Config1: 100% UE indoor and in the 1st floor  For Config2: 100% UE outdoor |
| Mobility | Config1: UE is stationary  Config2: UE is moving with random direction and fixed speed, e.g., 30 km/h |
| Calibration method | For Config1:  Drop multiple UEs in a single cell, determine all permutations of pairs of UEs, collect the variables for each pair and bin them into certain distance ranges, e.g., 1m/2m/10m, to get enough samples. Collect the following metrics 1) –6).  For Config2:  Drop multiple users in the single cell, and collect metric 1)-2) and 7)-9) for each user after attachment. |
| Metrics | 1) CDF of coupling loss (serving cell)  2) Wideband SINR before receiver – determined from RSRP (formula) from CRS port 0  3) Cross-correlation coefficient of delay for the third cluster between paired UEs, see note 1  4) Cross-correlation coefficient of AOA for the third cluster between paired UEs  5) Cross-correlation coefficient of LOS/NLOS status between paired UEs  6) Cross correlation coefficient of the channel response in Step 11 on the first non-DC subcarrier in an OFDM symbol on antenna port 0 received on the first UE antenna over multiple realizations between paired UEs  7) CDF of average varying rate of power for the third cluster, see note 2  8) CDF of average varying rate of delay for the third cluster (ns)  9) CDF of average varying rate of AOA for the third cluster (degree) |
| NOTE 1 For the UT pair at a certain distance range, the variables collected by two UEs can be denoted as X and Y, respectively, then the cross-correlation coefficient for real number can be written as [E(XY)-E(X)E(Y)] /sqrt([E(X^2)-E(X)^2])/ sqrt([E(Y^2)-E(Y)^2]), the cross-correlation coefficient for complex number can be written as |[E(XY\*)-E(X)E(Y)\*]/sqrt([E(XX\*)-E(X)E(X)\*])/sqrt([E(YY\*)-E(Y)E(Y)\*])|.  NOTE 2 For the average varying rate, we assume the collecting interval, e.g., 100ms, and then get the samples for a certain UE, the varying rate can be written as the standard variance of the samples per 100ms. | |

Table 7.8-6: Simulation assumptions for calibration for blockage

|  |  |
| --- | --- |
| Parameter | Values |
| Scenarios | UMi-street Canyon |
| Carrier Frequency | 30 GHz |
| BS antenna configurations | M = 4, N = 4, P = 2, Mg = 1, Ng = 2, dH = dV = 0.5λ, dH,g = dV,g = 2.5λ |
| BS port mapping | all 16 elements for each polarization on each panel are mapped to a single CRS port; panning angles of the two subarrays: (0,0) degs; same downtilt angles as used for the large-scale calibrations |
| Calibration method | For Model A:  Drop multiple users in the multiple cells, and collect the following metrics 1) – 3) for each user after attachment. Optional self-blocking feature is made mandatory in the Landscape mode only for calibration purposes.  For Model B:  Drop a BS in (0,0,30) and a UT in (100,0,1.5),  Jump directly to Step 11 and replace the channel with CDL-E.  Drop a blocking screen of size h=10m, w = 2m in (80,10,1.5)  Move the UT from (100,0,1.5) to (100,20,1.5) in small increments. For each UT position, translate all the AODs and AOAs of CDL-E such that the specular (LOS path) of CDL-E is pointing along the direct path between the BS and UT.  Collect metric 4) |
| Metrics | 1) CDF of coupling loss (serving cell)  2) Wideband SINR before receiver – determined from RSRP (formula) from CRS port 0  3) CDF of ASA from the serving cell  4) RSRP as a function of UT position |

### 7.8.4 Calibration of the indoor factory scenario

For the InF, the calibration parameters can be found in Table 7.8-7. The calibration results can be found in R1-1909704.

It should be noted absolute delay model had not been agreed by the deadline, so companies were not able to submit CDF of first path excess delay for serving cell.

Table 7.8-7: Simulation assumptions for large scale calibration for the indoor factory scenario

|  |  |
| --- | --- |
| Parameter | Values |
| Scenario | InF-SL, InF-DL, InF-SH, InF-DH |
| Hall size | InF-SL: 120x60 m  InF-DL: 300x150 m  InF-SH: 300x150 m  InF-DH: 120x60 m |
| Room height | 10 m |
| Sectorization | None |
| BS antenna configurations | 1 element (vertically polarized), Isotropic antenna gain pattern |
| UT antenna configurations | 1 element (vertically polarized), Isotropic antenna gain pattern |
| Handover margin (for calibration) | 0dB |
| BS deployment | 18 BSs on a square lattice with spacing D, located D/2 from the walls.  - for the small hall (L=120m x W=60m): D=20m  - for the big hall (L=300m x W=150m): D=50m    BS height = 1.5 m for InF-SL and InF-DL  BS-height = 8 m for for InF-SH and InF-DH |
| UT distribution | uniform dropping for indoor with minimum 2D distance of 1 m  UT height = 1.5 m |
| UT attachment | Based on pathloss |
| UT noise figure | 9 dB |
| Carrier frequency | 3.5 GHz, 28 GHz |
| Bandwidth | 100 MHz |
| Clutter density: | Low clutter density: 20%  High clutter density: 60% |
| Clutter height: | Low clutter density: 2 m  High clutter density: 6 m |
| Clutter size: | Low clutter density: 10 m  High clutter density: 2 m |
| Metrics | 1) Coupling loss – serving cell |
| 2) Geometry with and without noise |
| 3) CDF of delay spread and angle spread (ASD, ZSD, ASA, ZSA) according to the definition in Annex A.1 |
| 4) CDF of first path excess delay for serving cell |

# 8 Map-based hybrid channel model (Alternative channel model methodology)

Map-based hybrid model is composed of a deterministic component following, e.g., METIS work [6] and a stochastic component following mainly the model described in clause 7. The channel model methodology described in this clause is an alternative to the methodology specified in clause 7, and can be used if:

- The system performance is desired to be evaluated or predicted with the use of digital map to take into account the impacts from environmental structures and materials.

The map-based hybrid model defined in this clause is not calibrated and can be used per company basis.

## 8.1 Coordinate system

The same coordinate system as defined in Clause 7.1 is applied.

## 8.2 Scenarios

The same scenarios as in Clause 7.2 can be applied.

## 8.3 Antenna modelling

The same antenna modelling as defined in Clause 7.3 can be applied.

## 8.4 Channel generation

The radio channels are created using the deterministic ray-tracing upon a digitized map and emulating certain stochastic components according to the statistic parameters listed in Tables 7.5-6 to 7.5-11 [Note: Not all parameters listed in these tables are used in hybrid model]. The channel realizations are obtained by a step-wise procedure illustrated in Figure 8.4-1 and described below. In the following steps, downlink is assumed. For uplink, arrival and departure parameters have to be swapped.



Figure 8.4-1: Channel coefficient generation procedure

**Step-wise procedure:**

Step 1: Set environment and import digitized map accordingly

a) Choose scenario. Choose a global coordinate system and define zenith angle *θ*, azimuth angle *ϕ*, and spherical basis vectors ,  as shown in Figure 7.5-2.

b) Import digitized map according to the chosen scenario. The digitized map should at least contain the following information:

- The 3D geometric information for each of major structures involving with buildings or rooms. The external building walls and internal room walls are represented by surfaces and identified by the coordinates of the vertices on each wall.

- The material and thickness of each wall as well as the corresponding electromagnetic properties including permittivity and conductivity.

- Random small objects in certain scenarios (e.g, UMi outdoor)

The format of digitized map, including additional information besides above-mentioned, is per implementation wise and out of scope of this description.

Step 2: Set network layout, and antenna array parameters

a) Give number of BS and UT.

b) Give 3D locations of BS and UT, and calculate LOS AOD (*ϕLOS,AOD*), LOS ZOD (*θLOS,ZOD*), LOS AOA (*ϕLOS,AOA*), LOS ZOA (*θLOS,ZOA*) of each BS and UT in the global coordinate system

c) Give BS and UT antenna field patterns *Frx* and *Ftx* in the global coordinate system and array geometries

d) Give BS and UT array orientations with respect to the global coordinate system. BS array orientation is defined by three angles Ω*BS,α* (BS bearing angle), Ω*BS,β* (BS downtilt angle) and Ω*BS,γ* (BS slant angle). UT array orientation is defined by three angles Ω*UT,α* (UT bearing angle), Ω*UT,β* (UT downtilt angle) and Ω*UT,γ* (UT slant angle). Give rotational motion of UT in terms of its bearing angle, downtilt angle and slant angle if UT rotation is modelled.

e) Give speed and direction of motion of UT in the global coordinate system for virtual motion.

f) Give system centre frequency/frequencies and bandwidth(s) for each of BS-UT links

If the bandwidth (denoted as ) is greater than *c/D* Hz, where *c* is the speed of light and *D* is the maximum antenna aperture in either azimuth or elevation, the whole bandwidth is split into  equal-sized frequency bins, where  is a per-implementation parameter taking into account the channel constancy as well as other potential evaluation needs, and the bandwidth of each frequency bin is . Within *k*-th frequency bin, the channel power attenuation, phase rotation, Doppler are assumed constant, whose corresponding values are calculated based on the centre frequency of *k*-th frequency bin for , where  is the centre frequency of the corresponding BS-UT link.

Step 3: Apply ray-tracing to each pair of link ends (i.e., end-to-end propagation between pair of Tx/Rx arrays).

a) Perform geometric calculations in ray-tracing to identify propagation interaction types, including LOS, reflections, diffractions, penetrations and scattering (in case the digitized map contains random small objects), for each propagation path. In general, some maximum orders of different interaction types can be set.

- The theoretical principles and procedures of geometric tracing calculations can be found in [6]~[10][12]. This description does not intend to mandate new concepts and/or procedures to the conventional ray-tracing algorithms; on the other hand, the implementation-based variations aiming to reduce computation complexity are allowed within limits of acceptable calibration tolerances.

- The same geometric calculation is shared among all  frequency bins.

b) Perform electric field calculations over propagation path, based on identified propagation interaction types (LOS, reflection, diffraction, penetration and scattering) and centre frequencies of frequency bins.

The details of electric field calculation can be found in [6]~[13].

The modelling algorithms in geometry and electric field calculations for different propagation interactions are summarized in the table below.

Table 8.4-1 Principles applied in ray-tracing

|  |  |  |
| --- | --- | --- |
|  | Geometry calculation | Electric field calculation |
| LOS | Free space LOS | Friis equation [11] |
| Reflection | Snell's law with image-based method [7] | Fresnel equation [7] |
| Diffraction | Fermat's principle [12] | UTD [13] |
| Penetration | Snell's law for transmission through slab [8] | Fresnel equation [7] |
| Scattering (upon small objects) | Isotropic scattering [6] | RCS-based scattering coefficient [6] |

Note: For reasons of simplicity and simulation speed, the maximum order of reflection on a path without diffraction is configurable from {1,2,3}; the maximum order of diffraction on a path without reflection is configurable from {1,2}; the path containing both reflection and diffraction has 1-order reflection and 1-order diffraction, besides any potential penetrations; and the maximum order of penetration on a path is configurable, with the recommended value equal to 5.

The outputs from Step 3 should at least contain following for each pair of link ends:

- the LOS/NLOS flag to indicate whether a LOS propagation mechanism exists;

- the number of deterministic propagation paths  (also referred as deterministic clusters in Step 8. To avoid the unnecessary computation complexity, these deterministic paths only include those paths whose powers are higher than 25dB below the maximum deterministic path power, where the path power is denoted as  and defined below);

- for each deterministic path (-th path sorted in ascending order of path delay):

- the flag indicating whether the deterministic path is generated with scattering upon random small objects;

- the normalized path delay  and the first arrival absolute delay (with  to be the real absolute propagation delay of the path);

- angles of arrival and departure [,,,];

- the power  for k-th frequency bin, and the path power 

- the XPR of the path, where  with  being the XPR for k-th frequency bin.

- to support for true motion, i.e. the case when a trajectory is specified for UT, a path ID is associated for each deterministic path. The same ID is associated for a path across a number of UT locations as far as 1) it has same interaction types in the same order and 2) its interactions occur in same walls or other surfaces.

The  deterministic paths are sorted by normalized path delay () in ascending order. That is to say, = 0.

If =0 for a pair of link ends, the channel gain for this pair of link ends is assumed to be zero and the remaining steps are skipped with none of random cluster.

Step 4: Generate large scale parameters e.g. delay spread, angular spreads and Ricean K factor for random clusters.

The generation of large scale parameters takes into account cross correlation according to Table 7.5-6 and uses the procedure described in Clause 3.3.1 of [14] with the square root matrixbeing generated using the Cholesky decomposition and the following order of the large scale parameter vector: **s***M* = [*sK, sDS, sASD, sASA, sZSD, sZSA*]*T*. Limit random RMS azimuth arrival and azimuth departure spread values to 104 degrees, i.e., ASA= min(ASA,104°), ASD= min(ASD,104°). Limit random RMS zenith arrival and zenith departure spread values to 52 degrees, i.e., ZSA= min(ZSA,52°), ZSD= min(ZSD,52°). For the parameter selection from Table 7.5-6, the LOS/NLOS condition determined in Step 3 is applied.

Step 5: Generate delays (denoted as {**) for random clusters**

Delays are drawn randomly according to the exponential delay distribution

 (8.4-1)

where , *Xn* ~ uniform(0,1), and cluster index *n* = 0,…,  with  to be configurable. A recommended value for  is the number of clusters given in Table 7.5-6.

, where *rτ* is the delay distribution proportionality factor given in Table 7.5-6.

Normalise the delays by subtracting the minimum delay and sort the normalised delays to ascending order:

 (8.4-2)

where  is the additional scaling of delays to compensate for the effect of LOS peak addition to the delay spread, and is depending on the heuristically determined Ricean K-factor [dB] as generated in Step 4:

 (8.4-3)

For the delay used in cluster power generation in Step 6, the scaling factor  is always 1.

The *n*-th random cluster is removed if *n=0* or  for any of *1≤lRT≤LRT*, where *τth* is given by , and is the configurable probability for cluster inter-arrival interval to be less than *τth*. For example, set =0.2 to obtain *τth*=0.223.

Denote  for *1≤n≤LRC* as the delays of the *LRC* random clusters that remain after the cluster removal.

As an add-on feature, the absolute time of arrival of a cluster is derived as:

- , if the cluster is the -th deterministic path obtained in Step 3 for *1≤lRT≤LRT*;

- +, if the cluster is the n-th random cluster for *1≤n≤LRC.*

Step 6: Generate powers (denoted as for *1≤i≤LRC*) for random clusters.

Cluster powers for the random clusters are calculated assuming a single slope exponential power delay profile. First, the virtual powers (denoted as  for *1≤i≤LRC*) of random clusters and virtual powers (denoted as  for *1≤j≤LRT*) of deterministic clusters are calculated as following.

Denote:

 (8.4-4)

 (8.4-5)

where *i,RC* and *j,RT* are the per cluster shadowing terms in [dB] and meet distribution of *N(0,)*. Then,

 (8.4-6)

 (8.4-7)

*In the case of LOS condition*, *A=KR* with *KR* being the Ricean *K*-factor obtained in Step 4 and converted to linear scale; otherwise, *A=0*. The real power (including effects of pathloss) per random cluster in *k*-th frequency bin is given by

 (8.4-8)

for *1≤i≤LRC* and . Similar to path power of deterministic cluster, the path power of *i*-th random cluster is calculated as

. (8.4-9)

Step 7: Generate arrival angles and departure angles for both azimuth and elevation, for each random cluster.

*For azimuth angles of the n-th random cluster:*

The composite PAS in azimuth of all random clusters is modelled as wrapped Gaussian (see Table 7.5-6). The AOAs are determined by applying the inverse Gaussian function with input parameters and RMS angle spread ASA

 (8.4-10)

with constant  defined as

 (8.4-11)

where  is defined as a scaling factor related to the total number of clusters and is given in Table 7.5-2.

In the LOS case, constant  also depends on the Ricean K-factor *K* in [dB], as generated in Step 4. Additional scaling of the angles is required to compensate for the effect of LOS peak addition to the angle spread.

Assign positive or negative sign to the angles by multiplying with a random variable *Xn* with uniform distribution to the discrete set of {1,–1}, and add component  to introduce random variation

 (8.4-12)

where is calculated as

 (8.4-13)

Note that  shall be given in radians here.

The generation of AOD *(φn,AOD*) follows a procedure similar to AOA as described above.

*For zenith angles of the n-th random cluster:*

The generation of ZOA assumes that the composite PAS in the zenith dimension of all random clusters is Laplacian (see Table 7.5-6). The ZOAs are determined by applying the inverse Laplacian function with input parameters  and RMS angle spread ZSA

 (8.4-14)

with  defined as

, (8.4-15)

where  is a scaling factor related to the total number of clusters and is given in Table 7.5-4.

*In the LOS case*, constant  also depends on the Ricean K-factor K in [dB], as generated in Step 4. Additional scaling of the angles is required to compensate for the effect of LOS peak addition to the angle spread.

Assign positive or negative sign to the angles by multiplying with a random variable *Xn* with uniform distribution to the discrete set of {1,–1}, and add component  to introduce random variation

 (8.4-16)

where  if the UT is located indoors and  if the UT is located outdoors, where  is calculated as

 (8.4-17)

Note that  shall be given in radians here.

The generation of ZOD follows the same procedure as ZOA described above except equation (8.4-16) is replaced by

 (8.4-18)

where variable *Xn* is with uniform distribution to the discrete set of {1,–1}, , is given in Tables 7.5-7 to 7.5-11.

Step 8: Merge deterministic clusters and random clusters.

First, remove any deterministic or random cluster with less than -25 dB power compared to max{,} for all *1≤j≤LRT* and *1≤i≤LRC*. Then, simply put the remaining deterministic clusters and random clusters into single set of clusters, and meanwhile maintain an attribute for each cluster to indicate whether the cluster is a deterministic cluster or a random cluster.

Step 9: Generate ray delays and ray angle offsets inside each cluster, where the cluster can be either random or deterministic.

Denote *M* as the number of rays per cluster, where *M=1* if the cluster corresponds to n=1 in the LOS case, otherwise the value of *M* is given in Table 7.5-6.

*When* *:*

The relative delay of *m*-th ray within *n*-th cluster is given by  for *m* = 1,…,*M*.

The azimuth angle of arrival (AOA) for the *m*-th ray in *n*-th cluster is given by

 (8.4-19)

where  is the cluster-wise rms azimuth spread of arrival angles (cluster ASA) in Table 7.5-6, and offset angle *m* is given in Table 7.5-3.  equals to the AOA angle output from Step 3 if *n*-th cluster is deterministic cluster, and equals to the AOA angle (8.4-12) in Step 7 if *n*-th cluster is random cluster.

The generation of AOD (*φn,m,AOD*) follows a procedure similar to AOA as described above.

The zenith angle of arrival (ZOA) for the *m*-th ray in *n*-th cluster is given by

 (8.4-20)

where  is the cluster-wise rms spread of ZOA (cluster ZOA) in Table 7.5-6, and offset angle *m* is given in Table 7.5-3. Assuming that  is wrapped within [0, 360°], if , thenis set to .  equals to the ZOA angle output from Step 3 if *n*-th cluster is deterministic cluster, and equals to the ZOA angle (8.4-16) in Step 7 if *n*-th cluster is random cluster.

The zenith angle of departure (ZOD) for the *m*-th ray in *n*-th cluster is given by

 (8.4-21)

where  is the mean of the ZSD log-normal distribution.  equals to the ZOD angle output from Step 3 if *n*-th cluster is deterministic cluster, and equals to the ZOD angle (8.4-18) in Step 7 if *n*-th cluster is random cluster.

*When* *:*

The relative delay of *m*-th ray within *n*-th cluster is given by  that are sorted in ascending order, where , with the cluster delay spread as given in Table 7.5-6.  denotes the continuous uniform distribution on the interval . Note that  shall be the independently generated.

The azimuth angles (AOA and AOD) and zenith angles (ZOA and ZOD) for the *m*-th ray in *n*-th cluster in each frequency bin is given by

 (8.4-22)

for *m* = 1,…,*M*, where and  equal to the {AOA,AOD} and {ZOA, ZOD} angle outputs from Step 3 if *n*-th cluster is deterministic cluster, and equal to the {AOA,AOD} and {ZOA, ZOD} angle in Step 7 if *n*-th cluster is random cluster; and

 (8.4-23)

with the respective cluster angular spreads as given in Tables 7.5-6 to 7.5-11.

Assuming that is wrapped within [0, 360°], if , thenis set to .

Step 10: Generate power of rays in each cluster, where coupling of rays within a cluster for both azimuth and elevation could be needed.

Given  as the real power in *k*-th frequency bin for the *n*-th cluster (either deterministic or random) obtained from Step 8,

*When* *:*

Couple randomly AOD angles *φn,m,AOD* to AOA angles *φn,m,AOA* within a cluster *n*. Couple randomly ZOD angles  with ZOA angles using the same procedure. Couple randomly AOD angles *φn,m,AOD* with ZOD angles within a cluster *n*.

The power of *m*-th ray in *n*-th cluster and in *k*-th frequency bin is given by  for *m* = 1,…,*M*.

*When* *:*

The power of *m*-th ray in *n*-th cluster and in *k*-th frequency bin is given by  for *m* = 1,…,*M*, where

 (8.4-24)

and , , , and  are respectively the intra-cluster delay spread and the corresponding intra-cluster angular spreads that are given in Table 7.5-6. The cluster zenith spread of departure is given by

, (8.4-25)

with  being defined in Tables 7.5-7, 7.5-8, 7.5-9, 7.5-10 and 7.5-11.

Step 11: Generate XPRs

Generate the cross polarization power ratios (XPR) **for each ray *m* of each cluster *n*. XPR is log-Normal distributed. Draw XPR values as

 (8.4-26)

where  is Gaussian distributed with given from Table 7.5-6. If *n*-th cluster is a deterministic cluster, ; otherwise,  is given in Table 7.5-6.

Note:  is independently drawn for each ray and each cluster.

Step 12: Draw initial random phases

Draw random initial phase  for each ray *m* of each cluster *n* and for four different polarisation combinations (*θθ*, *θϕ,* *ϕθ,* *ϕϕ*). The distribution for initial phases is uniform within (-**).

*In the LOS case,* calculate an initial phase  for both *θθ* and *ϕϕ* polarisations, where *d3D* is the 3D distance between transmitter and receiver and *λ0=c/fc* is the wavelength of the modelled propagation link.

Step 13: Generate channel coefficients for each cluster *n* and each receiver and transmitter element pair *u, s*.

*In case of NLOS,* the channel coefficients of ray *m* in cluster *n* for a link between Rx antenna *u* and Tx antenna *s* at time *t* in *k*-th frequency bin can be calculated as

 (8.4-27)

where *Frx,u,θ* and *Frx,u,ϕ* are the receive antenna element *u* field patterns in the direction of the spherical basis vectors,  and  respectively, *Ftx,s,θ* and *Ftx,s,ϕ* are the transmit antenna element *s* field patterns in the direction of the spherical basis vectors,  and  respectively. The delay (TOA) for ray *m* in cluster *n* for a link between Rx antenna *u* and Tx antenna *s* is given by:

 (8.4-28)

For the *m*-th ray within *n*-th cluster,  is the spherical unit vector with azimuth arrival angle  and elevation arrival angle , given by

 (8.4-29)

 is the spherical unit vector with azimuth departure angle  and elevation departure angle , given by

 (8.4-30)

Also, is the location vector of receive antenna element *u* and is the location vector of transmit antenna element *s*, *n,m* is the cross polarisation power ratio in linear scale. If polarisation is not considered, the 2x2 polarisation matrix can be replaced by the scalar  and only vertically polarised field patterns are applied.

The Doppler frequency component is calculated from the arrival angles (AOA, ZOA), and the UT velocity vector  with speed *v*, travel azimuth angle *ϕv*, elevation angle *θv* and is given by

, (8.4-31)

*In case of LOS,* the channel coefficient is calculated in the same way as in (8.4-27) except for n=1:

 (8.4-32)

where the corresponding delay (TOA) for cluster *n*=1 for a link between Rx antenna *u* and Tx antenna *s* is given by .

In (8.4-27) and (8.4-32), the oxygen absorption loss, OL*n,m*(*f*), for each ray *m* in cluster *n* at carrier frequency *f* is modelled as

OL*n,m*(*f*) = *α*(*f*)/1000 · *c* ·  [dB] (8.4-33)

where:

*- α*(*f*) is the frequency dependent oxygen loss per distance (dB/km) characterized in Clause 7.6.1;

- *c* is speed of light (m/s); and

-  is the delay (s) obtained from Step 3 for deterministic clusters and from Step 5 for random clusters.  is from the output of Step 3.

In (8.4-27) and (8.4-32), blockage modelling is an add-on feature. If the blockage model is applied, the blockage loss, BL*n,m*(*f,t*) in unit of dB, for each ray *m* in cluster *n* at carrier frequency *f* and time *t* is modelled in the same way as given in Clause 7.6.4; otherwise BL*n,m*(*f,t*)=0dB for all *f* and *t*.

Annex A:  
Further parameter definitions

## A.1 Calculation of angular spread

Based on the circular standard deviation in directional statistics, the following expression for the angular spread AS in radians is proposed

 (A-1)

where  is the power for the *m*th subpath of the *n*th path and  is the subpaths angle (either AOA, AOD, ZOA, ZOD) given in radians.

## A.2 Calculation of mean angle

The power weighted mean angle is given by

 (A-2)

where  is the power for the *m*th subpath of the *n*th path and  is the subpaths angle (either AOA, AOD, ZOA, ZOD) given in radians.

Annex B: Change history

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Change history** | | | | | | | |
| **Date** | **Meeting** | **TDoc** | **CR** | **Rev** | **Cat** | **Subject/Comment** | **New version** |
| 2017-02 | RAN1#88 | R1-1703641 |  |  |  | Skeleton TR based on TR 38.900 v14.2.0, adding new changes (from R1-1701231, R1-1701406, R1-1701410, R1-1701411, R1-1701412, R1-1701413, R1-1701414, R1-1701416, R1-1701417 and R1-1701425) to have a TR applicable for the frequency range 0.5 to 100 GHz | 0.0.1 |
| 2017-02 | RAN1#88 | R1-1704145 |  |  |  | Adding new agreements (from R1-1702701, R1-1703635, R1-1703873, R1-1703358, R1-1702703, R1-1703637, R1-1703354, R1-1703458, R1-1703647, R1-1701936) and reflecting comments from RAN1 e-mail discussions [88-17]. | 0.1.0 |
| 2017-02 | RAN#75 | RP-170394 |  |  |  | Submitted to RAN for information | 1.0.0 |
| 2017-03 | RAN#75 | RP-170737 |  |  |  | Add TR number further to the approval of revised SID in RP-170379. Submitted to RAN for one step approval | 1.0.1 |
| 2017-03 | RAN#75 |  |  |  |  | MCC clean-up – Further to RAN#75 decision, TR goes under change control as Rel-14 | 14.0.0 |
| 2017-06 | RAN#76 | RP-171208 | 0001 | - | F | Correction on site specific effective height for TR38.901 | 14.1.0 |
| 2017-06 | RAN#76 | RP-171208 | 0003 | - | F | Correction for LOS probability | 14.1.0 |
| 2017-06 | RAN#76 | RP-171208 | 0004 | - | F | Correction for scaling factor for ZOD generation | 14.1.0 |
| 2017-06 | RAN#76 | RP-171208 | 0005 | - | F | Correction for modelling of intra-cluster angular and delay spreads | 14.1.0 |
| 2017-06 | RAN#76 | RP-171208 | 0007 | - | F | TR38.901\_CR\_LCS\_Radiation\_Field\_Notation | 14.1.0 |
| 2017-06 | RAN#76 | RP-171208 | 0008 | - | F | TR38.901\_CR\_Mean\_angle\_definition | 14.1.0 |
| 2017-06 | RAN#76 | RP-171208 | 0009 | - | F | TR38.901\_CR\_O2I\_penetration\_loss | 14.1.0 |
| 2017-06 | RAN#76 | RP-171208 | 0010 | 1 | F | TR38.901\_CR\_Correction\_on\_Rural\_LSP | 14.1.0 |
| 2017-06 | RAN#76 | RP-171208 | 0011 | 1 | F | Clarification for spatial consistency procedure | 14.1.0 |
| 2017-06 | RAN#76 | RP-171208 | 0013 | - | F | TR38.901\_CR\_Scenarios\_in\_Simulation\_Assumptions | 14.1.0 |
| 2017-06 | RAN#76 | RP-171208 | 0014 | - | F | TR38.901\_CR\_TDL\_Spatial\_Filter | 14.1.0 |
| 2017-06 | RAN#76 | RP-171208 | 0015 | - | F | Correction of spatial-consistency UE mobility modelling Procedure A | 14.1.0 |
| 2017-07 |  |  |  |  |  | MCC: UMa LOS probability in Table 7.4-2 is made fully visible | 14.1.1 |
| 2017-09 | RAN#77 | RP-171648 | 0016 | - | F | Correction on the formula of Annex A | 14.2.0 |
| 2017-09 | RAN#77 | RP-171648 | 0018 | 2 | F | Correction on cross polarization power ratios in TR 38.901 | 14.2.0 |
| 2017-09 | RAN#77 | RP-171648 | 0019 | 1 | F | TR38.901\_CR\_Spatially-consistent\_UT\_modelling | 14.2.0 |
| 2017-09 | RAN#77 | RP-171648 | 0020 | 1 | F | TR38.901\_CR\_Calibraiton\_Results | 14.2.0 |
| 2017-12 | RAN#78 | RP-172687 | 0022 | - | F | Correction on 3D-InH channel model in TR 38.901 | 14.3.0 |
| 2018-06 | SA#80 | - | - | - | - | Update to Rel-15 version (MCC) | 15.0.0 |
| 2019-09 | RAN#85 | RP-191944 | 0023 | - | B | Addition of indoor industrial channel model – version created in error – withdrawn | 15.1.0 |
| 2019-10 | RAN#85 | RP-191944 | 0023 | - | B | Addition of indoor industrial channel model – creation of rel-16 report | 16.0.0 |
| 2019-12 | RAN#86 | RP-192629 | 0024 | - | F | CR to TR 38.901 for remaining open issues in IIOT channel modelling | 16.1.0 |