System Level Simulator Requirement Specification

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1. Introduction

This document describes the requirement specification for 5G System Level Simulator.

1.1 Purpose

This document is intended for use by software engineers working directly on the system level simulator.

1.2 Scope

The scope of this document includes the following:

- Some backgrounds on simulators
- Some backgrounds on 4G and 5G
- Requirement specification

1.3 Definitions

The following definitions are used for the simulator and this document.

Table 1-1 Definitions

Word	Description
BS	Related to cell Refers to sector (NOT base station site), TRP(transmission reception point), RSU(road side unit), RRH(remote radio head), RU(RF unit), or RRU(remote radio unit)
MS	Refers to mobile station, user, device, UE(user equipment), UT(user terminal)
Site	Related to base station position Base station, site, eNode-B, eNB
BBU	Baseband unit, DU(digital unit)

1.4 Acronyms

The following acronyms are used for the simulator and this document.

Table 1-2 Acronyms

Acronym	Description
MS	Mobile Station
BS	Base Station
RS	Relay Station
BBU	Baseband Unit
RX	Receiver
TX	Transmitter
DL	Downlink
UL	Uplink
FDD	Frequency Division Duplexing
TDD	Time Division Duplexing
TTI	Transmission Time Interval
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access@
RB	Resource Block
ARQ	Automatic Repeat Request
HARQ	Hybrid ARQ
ACK	Acknowledgment
NACK	Negative Acknowledgment
LOS	Line of Sight
NLOS	Non Line of Sight
SNR	Signal to Noise Ratio
SINR	Signal to Interference plus Noise Ratio
ESM	Effective SINR Mapping
FER	Frame Error Rate
CDF	Cumulative Distribution Function
V2X	Vehicular to Anything
D2D	Device to Device Communication
IoT	Internet of Things
CoMP	Coordinate Multi Point
MIMO	Multiple Input Multiple Output
FD-MIMO	Full Dimensional MIMO
MU-MIMO	Multi-User MIMO
ULA	Uniform Linear Arrays
CDL	Clustered Delay Line
TDL	Tapped Delay Line
AoD	Azimuth angle of departure
AoA	Azimuth angle of arrival
ZoD	Zenith angle of departure
ZoA	Zenith angle of arrival
MAC	Media Access Control
RRM	Radio Resource Management
GUI	Graphical User Interface
SLS	System Level Simulation, System Level Simulator
LLS	Link Level Simulation, Link Level Simulator
NS	Network Simulation, Network Simulator
TRP	Transmission Reception Point
TRxP	Transmission Reception Point
eMBB	Enhanced Mobile Broadband
mMTC	Massive Machine Type Communications
URLLC	Ultra-Reliable and Low-Latency Communications
RIT	Radio Interface Technology

SRIT	Set of Radio Interface Technologies
PDU	Protocol Data Unit
SDU	Service Data Unit

2. 4G Features

2.1 4G Channel

The 4G channel considers the following components:

- Large scale channel
  - Path-loss, Delay spread, Angular spread, Indoor/outdoor, LOS/NLOS
  - Correlation of large scale channel parameters
- Small scale channel
  - Delay, Angle(AoD, AoA), (spatial filter using antenna pattern)
  - Implemented with clusters and rays
- Short term channel
  - Fading

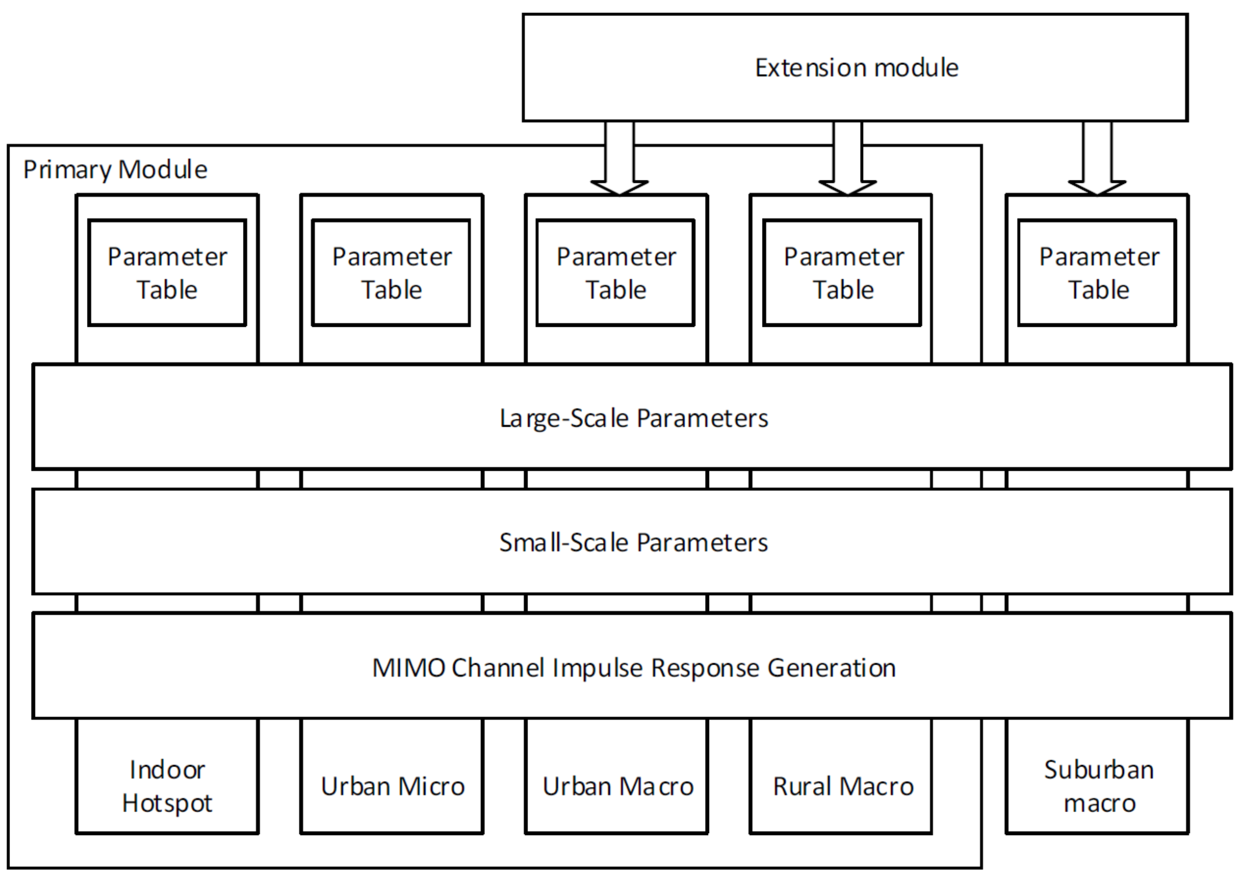


Figure 2-1 4G channel model

2.2 4G Basic Scenarios

The following scenarios may need to be considered.

- Indoor hotspot
- Urban micro-cell
- Urban macro-cell
- Rural macro-cell
- Suburban macro-cell

Figure 2-2 Indoor hot spot environment

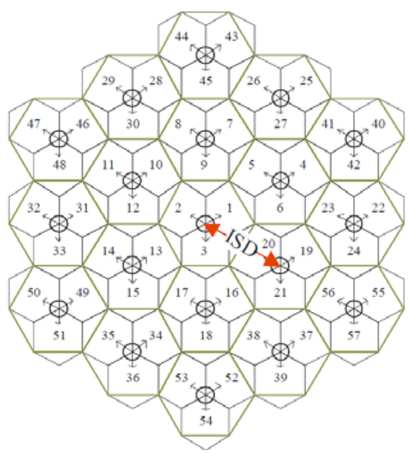


Figure 2-3 Hexagonal cell layout

2.3 4G Key Performance Indicators

The following key performance indicators need to be considered.

- Cell spectral efficiency
- Cell edge user spectral efficiency

2.4 4G Technologies

2.4.1 Carrier Aggregation

2.4.2 Dynamic TDD

TDD offers flexible deployments without requiring a pair of spectrum resources. For TDD deployments in general, interference between UL and DL including both BS-to-BS and MS-to-MS interference needs to be considered. One example includes layered heterogeneous network deployments, where it may be of interest to consider different uplink-downlink configurations in different cells. Also of interest are deployments involving different carriers deployed by different operators in the same band and employing either the same or different uplink-downlink configurations, where possible interference may include adjacent channel interference as well as co-channel interference such as remote BS-to-BS interference.

Obtain the DL/UL geometry and/or throughput to see the performance loss due to different TDD configurations in the network based on the agreed simulation assumptions. The difference of the DL/UL geometry with and without different TDD configurations and the absolute DL/UL geometry with different TDD configurations are used as criteria to evaluate the feasibility of applying different TDD configurations in different cells.

Scenario 1: This scenario assumes multiple Femto cells deployed on the same carrier frequency. The following cases are simulated:

Case 1: Baseline is the transmission directions of all cells are the same

Case 2: The transmission direction of Femto cells is randomly set as DL and UL with a 50% probability.

Scenario 2: This scenario assumes multiple Femto cells deployed on the same carrier frequency and multiple Macro cells deployed on an adjacent carrier frequency where all Macro cells have the same UL-DL configuration and Femto cells can adjust UL-DL configuration. The following cases are simulated:

Case 1: Baseline is the transmission directions of all cells (including Macro and Femto) are the same.

Case 2: All Macro cells are of the same transmission direction (i.e. either DL or UL) and the transmission direction of Femto cells is randomly set as DL and UL with a 50% probability.

Scenario 3:This scenario assumes multiple outdoor Pico cells deployed on the same carrier frequency. The following cases are simulated:

Case 1: Baseline is the transmission directions of all cells are the same

Case 2: The transmission direction of outdoor Pico cells is randomly set as DL or UL with a 50% probability.

Case 3 (optional): Pico with interference management. The transmission direction of outdoor Pico cells shall be controlled by the interference management method.

Scenario 4: This scenario assumes multiple outdoor Pico cells deployed on the same carrier frequency and multiple Macro cells deployed on an adjacent carrier frequency where all Macro cells have the same UL-DL configuration and outdoor Pico cells can adjust UL-DL configuration. The following cases are simulated:

Case 1: Baseline is the transmission directions of all cells are the same

Case 2: The transmission direction of outdoor Pico cells is randomly set as DL or UL with a 50% probability.

Case 3 (optional): Pico with interference management. The transmission direction of outdoor Pico cells shall be controlled by the interference management method

Scenario 5: This scenario assumes multiple Femto cells and multiple Macro cells deployed on the same carrier frequency where all Macro cells have the same UL-DL configuration and Femto cells can adjust UL-DL configuration. The following cases are simulated:

Case 1: Baseline is the transmission directions of all cells (including Macro and Femto) are the same.

Case 2: All Macro cells are of the same transmission direction (i.e. either DL or UL) and the transmission direction of Femto cells is randomly set as DL and UL with a 50% probability.

Scenario 6: This scenario assumes multiple outdoor Pico cells and multiple Macro cells deployed on the same carrier frequency where all Macro cells have the same UL-DL configuration and outdoor Pico cells can adjust UL-DL configuration. The following cases are simulated:

Case 1: Baseline is the transmission directions of all cells are the same

Case 2: The transmission direction of outdoor Pico cells is randomly set as DL or UL with a 50% probability.

Case 3 (optional): Pico with interference management. The transmission direction of outdoor Pico cells shall be controlled by the interference management method

Scenario 7: This scenario assumes multiple Macro cells deployed on the same carrier frequency for one operator and multiple Macro cells deployed on an adjacent carrier frequency for another operator, where all victim Macro cells deployed on the same carrier have the same UL-DL configuration and all aggressor Macro cells deployed on an adjacent carrier frequency can adjust UL-DL configuration. The following cases are simulated:

Case 1: Baseline is the transmission directions of all cells are the same.

Case 2: All Macro cells of one operator are of the same transmission direction (i.e. either DL or UL) and the transmission direction of all Macro cells of another operator is different to the victim system.

To evaluate the benefits of TDD UL-DL reconfiguration based on traffic adaptation at least in terms of performance and energy saving, the following metrics can be used:

- Packet throughput, defined as the packet size over the packet transmission time, including the packet waiting time in the buffer
- UE average packet throughput, defined as the average of packet throughput for the UE
- {5%, 50%, 95%} UE average packet throughput, from the CDF of average packet throughput from all UEs
- Cell average packet throughput, defined as the mean of average packet throughput from all UEs
- Other metrics, e.g.
    - Packet drop statistics
    - Packet delay statistics

- Frequency resource (PRBs) utilizations
- Time resource (subframes) utilizations
- CDF of packet throughput
- Total number of configured DL/UL subframes

2.4.3 Device-to-Device Communication

Following are the layout options that shall be used:

- Option 1: Urban macro (500m ISD) + 1 RRH/Indoor Hotzone per cell
- Option 2: Urban macro (500m ISD) + 1 Dual stripe per cell
- Option 3: Urban macro (500m ISD) (all UEs outdoor)
- Option 4: Urban macro (500m ISD) + 3 RRH/Indoor Hotzone per cell
- Option 5: Urban macro (1732m ISD)
- Option 6: Urban micro (100m ISD)

For evaluation of proposed discovery schemes the following metrics shall be considered.

- The metrics related to performance targets aspect of Open ProSe discovery are
- Number of UEs discovered as a function of time. This shall be a system level metric.
- CDF of number of UEs discovered as a function of time. This shall be a system level metric.
- The metric related to performance targets aspect of Restricted ProSe discovery is
- Probability of discovery as a function of time. Zero time penalty shall be assumed for each false alarm. This shall be a system level metric.
- The metrics related to range and reliability aspects of discovery are
- Probability of discovery vs. pathloss. This shall be both a link & system level metric.
- Probability of false alarm. This shall be both a link & system level metric.
- The metrics related to impact on WAN aspect of discovery are
- Amount of resource used for discovery per cell if in-coverage. This shall be a system level metric.
- FFS metrics related to throughput loss and/or interference.
- The metrics related to power consumption aspect of discovery is
- Power consumption should be calculated using the model described in Section A.2.1.6.

For evaluation of proposed communication schemes the following metrics shall be considered.

The metrics related to D2D throughput aspects of communication are

- For full buffer traffic model; mean, 5%, and CDF of user throughput. This shall be a system level metric.
- For FTP2 traffic model; mean, 5%, and CDF of perceived user throughput. This shall be a system level metric.

- For VOIP traffic model; VOIP system capacity. The VOIP delay requirement shall be 200 ms for Unicast, Broadcast, Groupcast and 100ms per hop for Relays. This shall be a system level metric.

The metrics related to range and reliability aspects of communication are

- Performance versus pathloss or distance. Performance shall be in terms of either user throughput, perceived user throughput, or probability of satisfied VOIP user depending on traffic model. This shall be both a link and system level metric. For link level performance use only full buffer.

The metrics related to call setup latency aspect of communication is

- Physical layer latency for call setup for out-of-coverage only. This should only model L1 related aspects; higher layer aspects should be considered in RAN2. This shall be both a link and system metric.

The metrics related to impact on WAN aspects of communication are

- Change in cell throughput/cell spectral efficiency for full buffer traffic model. This shall be a system level metric.
- CDFs of perceived per-user throughput for FTP2 with and without D2D. This shall be a system level metric.

The metrics related to power aspect of communication is

- Power consumption should be calculated using the model described in Section A.2.1.6.

2.4.4 V2X

Vehicle UEs are dropped on the roads according to spatial Poisson process. The vehicle density is determined by the assumption on the vehicle speed, and the vehicle location should be updated every 100 ms in the simulation.

In Urban case, a vehicle changes its direction at the intersection as follows: Go straight with probability 0.5, Turn left with probability 0.25, Turn right with probability 0.25

Vehicle UEs are dropped one the lanes specified. Average inter-vehicle distance in the same lane is 2.5 sec * absolute vehicle speed.

Pedestrian UEs are dropped using equally spaced along the sidewalk with a fixed inter-pedestrian X m dropped.

For evaluation of proposed schemes for V2V, the following metric(s) shall be considered.

- Packet Reception Ratio (PRR): For one Tx packet, the PRR is calculated by X/Y, where Y is the number of UE/vehicles that located in the range (a, b) from the TX, and X is the number of UE/vehicles with successful reception among Y. CDF of PRR and the following average PRR are used in evaluation
    - CDF of PRR with a = 0, b = baseline of 320 meters for freeway and 150 meters for urban. Optionally, b = 50 meters for urban with 15 km/h vehicle speed .
    - Average PRR, calculated as (X1+X2+X3….+Xn)/(Y1+Y2+Y3…+Yn) where n denotes the number of generated messages in simulation. with a = i*20 meters, b = (i+1)*20 meters for i=0, 1, …, 25
- FFS Packet Inter-Reception (PIR): time elapsed between two successive successful receptions of two different packets transmitted from node A to node B

For evaluation of proposed schemes for V2I, the performance metric is the same as that for V2V except for target communication range.

For pedestrian UE in case of V2P, the following metric(s) shall be considered.

- The power consumption model defined in [4] is used as an additional performance metric to evaluate the power consumption caused by the reception of pedestrian UE.
- To evaluate the reception ratio of Vehicle UE's transmission packet, the existing performance metric of V2V (i.e., PRR) is reused with the following modifications.
  - PRR is calculated under the assumption that Vehicle UE's packet transmitted during the time when pedestrian UE sleeps is regarded as the failure of reception.
  - Target range for CDF of PRR and average PRR is the half of that defined in V2V.
- FFS on whether/how to investigate the impact of bursty reception failure caused by sleep of pedestrian UE over consecutive subframes.

For vehicle UE and pedestrian UE in case of P2V, the following metric(s) shall be considered.

- To evaluate the reception ratio of pedestrian UE's transmission packet, the existing performance metric of V2V (i.e., PRR) is reused with the following modifications.
  - Target range for CDF of PRR and average PRR is the half of that defined in V2V.
- The power consumption model defined in [4] is used as an additional performance metric to evaluate the power consumption caused by the transmission of pedestrian UE.

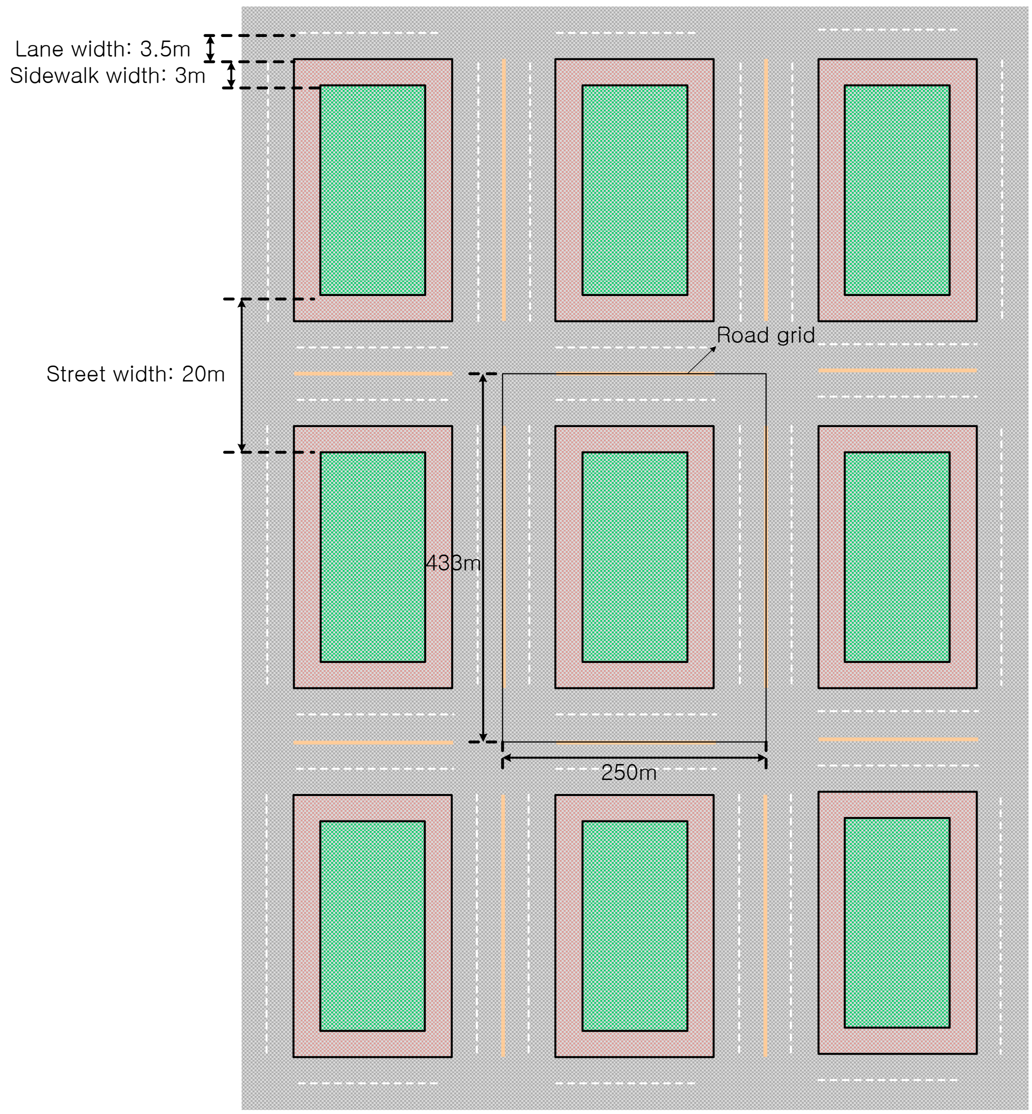


Figure 2-4 Road configuration for urban case

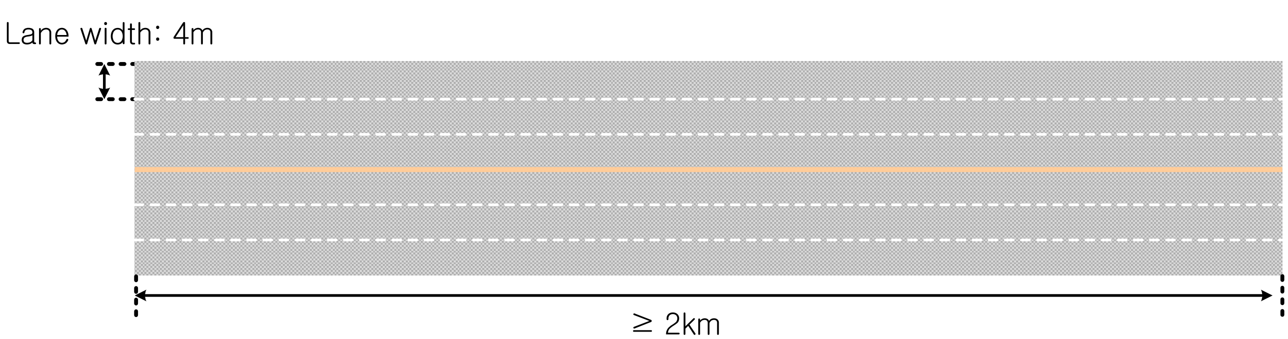


Figure 2-5 Road configuration for freeway case

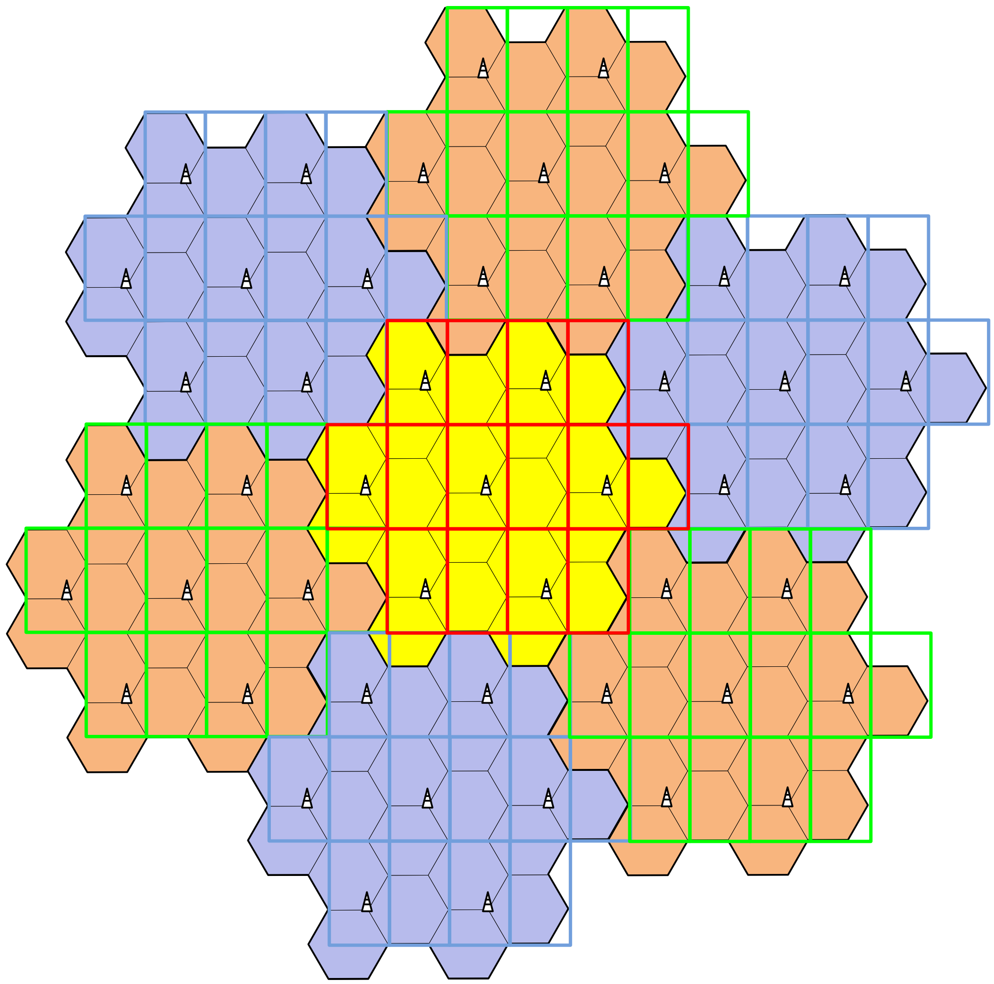


Figure 2-6 Wrap around model for urban case

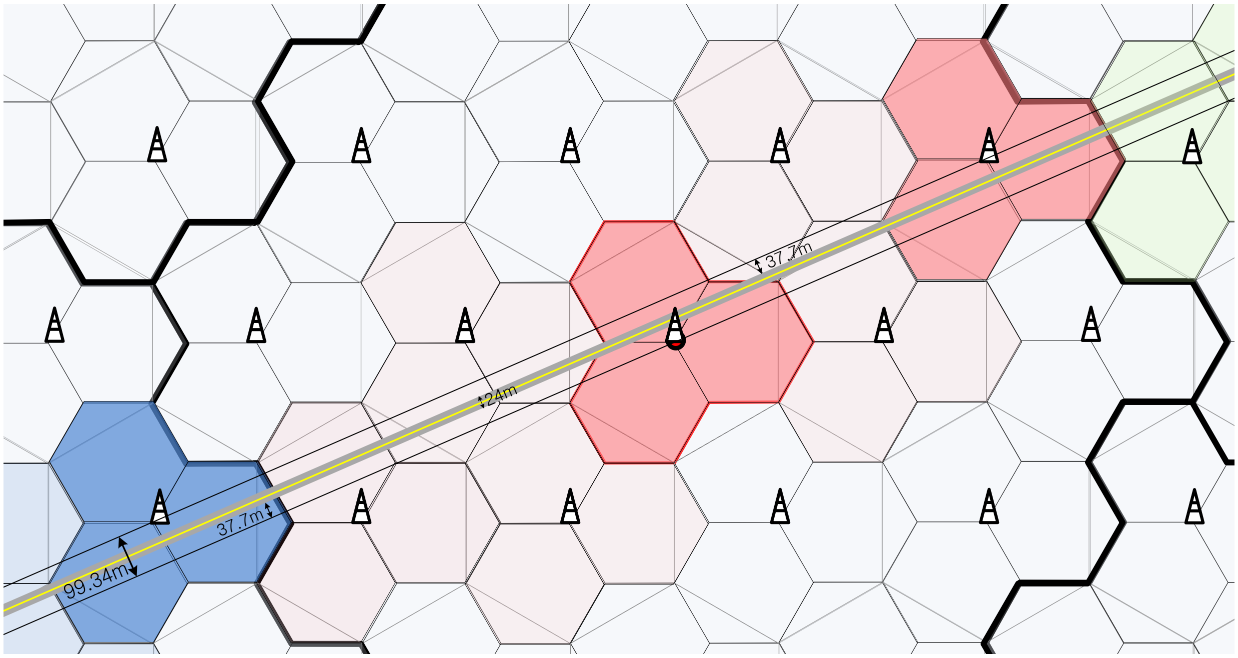


Figure 2-7 Wrap around model for freeway case

2.4.5 Cooperative Multipoint

Following two types of CoMP can be considered:

- Joint Processing (JP): data is available at each of the geometrically separated points, and PDSCH transmission occurs from multiple points.
- Coordinated Scheduling/Beamforming (CS/CB): data is only available at serving cell (data transmission from that point) but user scheduling/beamforming decisions are made with coordination among cells.

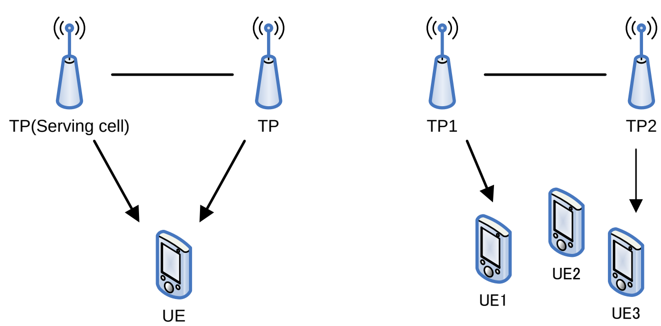


Figure 2-8 Coordinated multi-point transmission

2.4.6 Licensed Assisted Access

The following figure shows four LAA deployment scenarios, where the number of licensed carriers and the number of unlicensed carriers can be one or more.

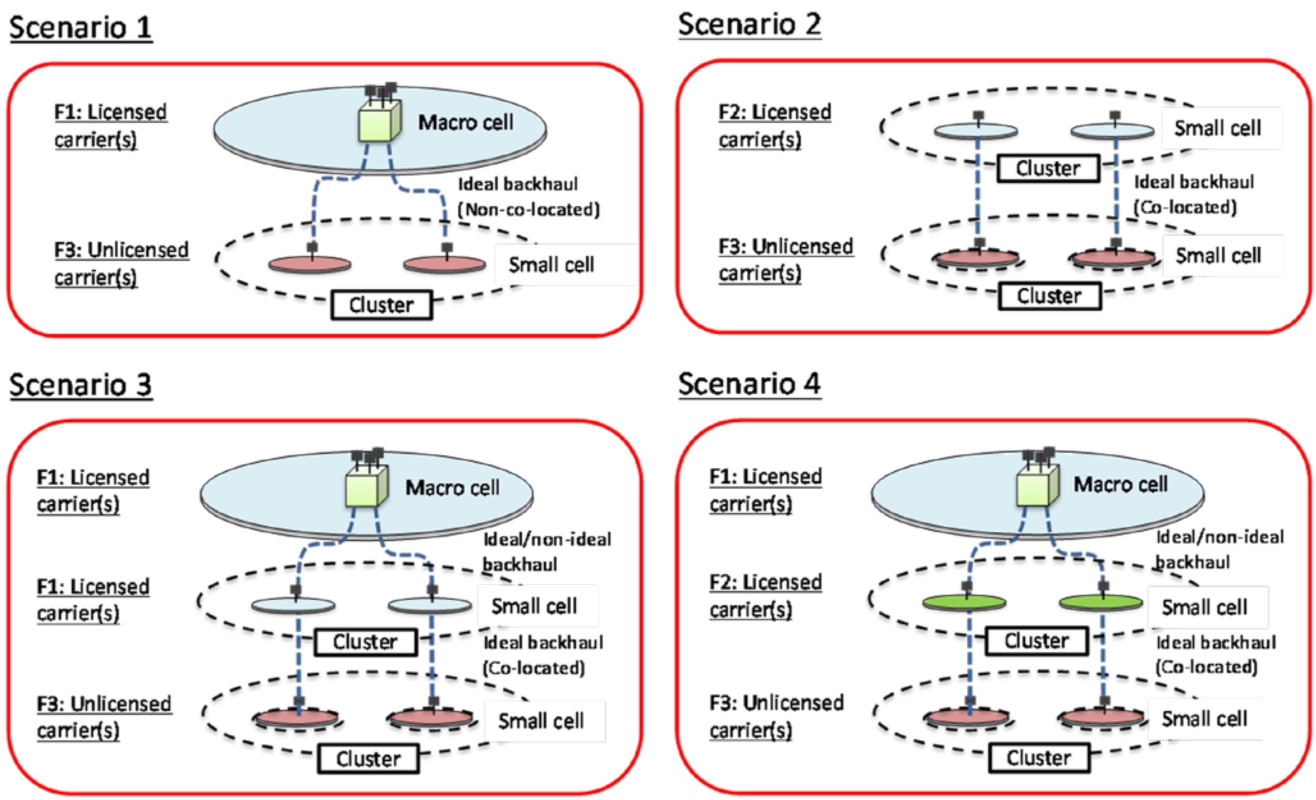


Figure 2-9 LAA deployment scenarios

Indoor scenario:

Two operators deploy 4 small cells each in the single-floor building. The small cells of each operator are equally spaced and centered along the shorter dimension of the building. The distance between two closest nodes from two operators is random. The set of small cells for both operators is centered along the longer dimension of the building.

Performance metric:

- User received throughput
- Latency
- Average buffer occupancy
- Ratio of mean served cell throughput and offered cell throughput

Outdoor scenario:

- Macro cell (hexagonal grid, 3 sectors per site, 19 or 7 macro sites, two networks are collocated)

- Licensed small cell
- Unlicensed small cell

3. 5G Features

3.1 5G Channel

In addition to 4G channel, the 5G channel considers the following issues:

- 3D Channel for FD-MIMO
  - 3D angular spread, 3D angles(AoD, AoA, ZoD, ZoA)
  - Linear/X-pol, vertical antenna pattern as well as horizontal antenna pattern
  - 3D location of MS
  - 3D rotation of MS
- Mmwave
  - Oxygen absorption
  - Blockage
- Multi connections
  - Correlation in multi-frequencies
- Scalability
  - Large bandwidth
  - Large antenna array (large number of antenna panels)
- Fast moving MS
  - Spatial consistency of cluster and ray correlation
  - Spatial consistency of indoor states
  - Time-varying Doppler frequencies
  - Rotational motion of MS

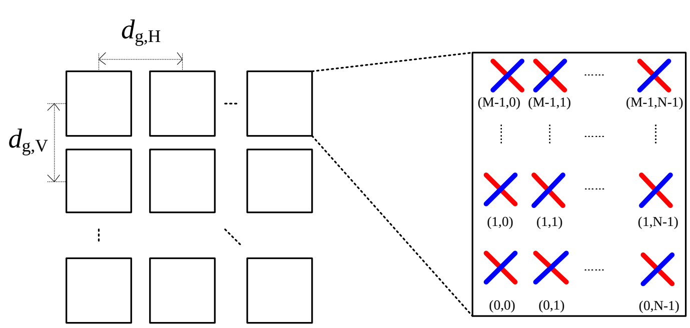


Figure 3-1 Antenna panel

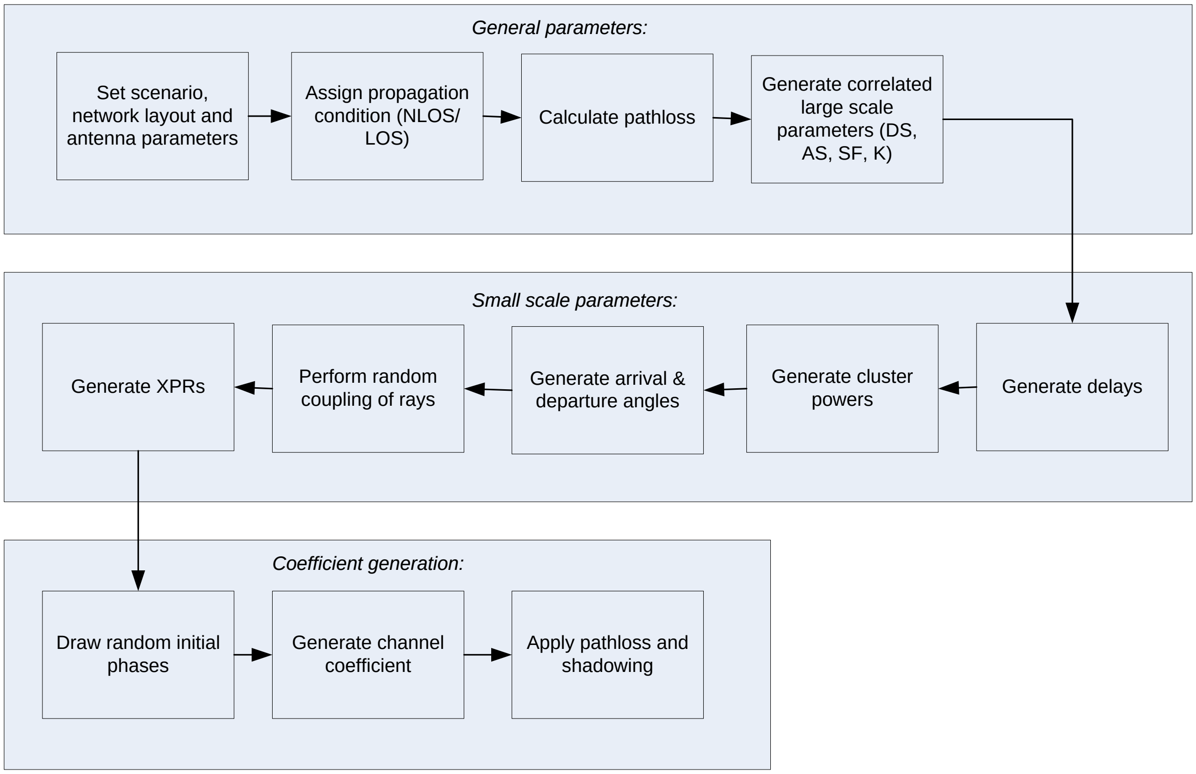
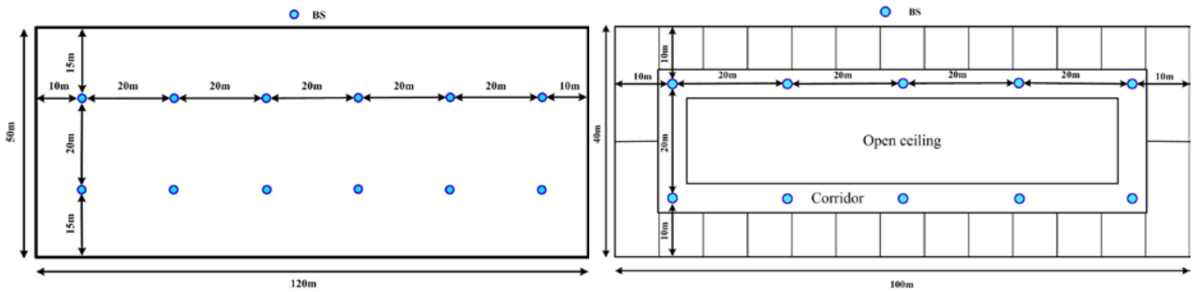


Figure 3-2 Channel coefficient generation procedure

3.2 5G Basic Scenarios

The following scenarios may need to be considered.

- Indoor hotspot
- Dense urban single layer
- Dense urban two layer
- Rural
- Urban macro
- High speed train macro only
- High speed train macro + relay
- Urban grid for eV2X macro only
- Urban grid for eV2X macro + RSU
- Highway for eV2X macro only
- Highway for eV2X macro + RSU
- Urban coverage for massive connection
- Extreme long range



(a) Indoor office (b) Indoor shopping mall

Figure 3-3 Indoor office and indoor shopping mall scenarios

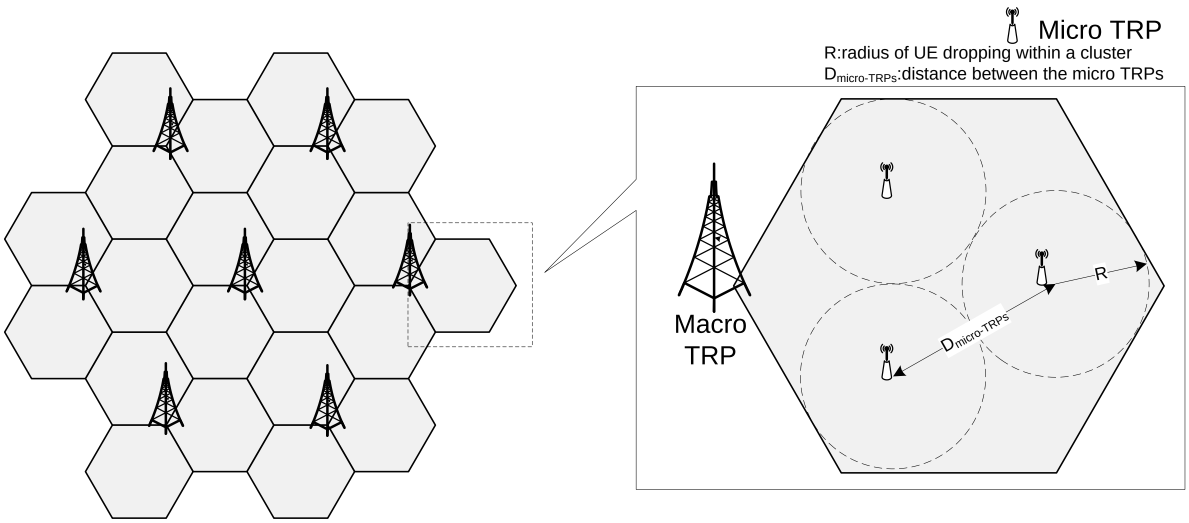


Figure 3-4 Cell Layout for dense urban

3.3 5G Key Performance Indicators

The following key performance indicators may need to be considered.

- Average spectral efficiency
- 5th percentile user spectral efficiency
- User experienced data rate
- Areal capacity
- Connection density
- Energy efficiency
- Mobility

3.4 5G Technologies

3.4.1 Mmwave and Dual Connectivity

Association

Scheduling

3.4.2 High Speed Train

MS movement

Periodic recalculation of long-term parameters

Handover

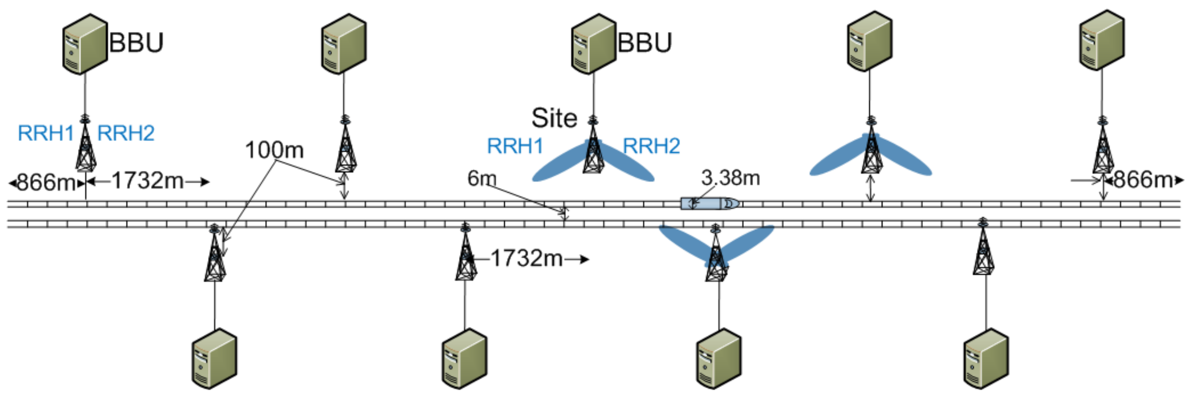


Figure 3-5 Cell layout for high speed train (4GHz)

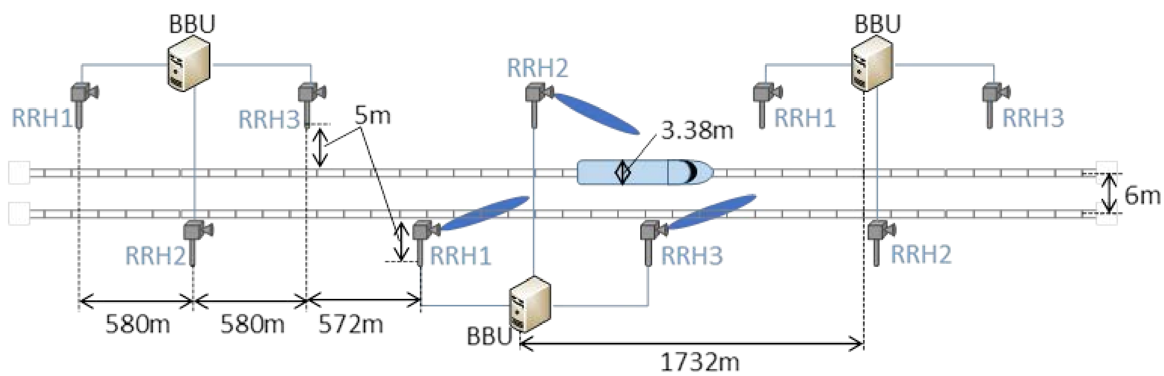


Figure 3-6 Cell layout for high speed train (30GHz)

3.4.3 Massive Connectivity

3.4.4 Ultra Reliable and Low Latency Communication

System level simulation can be used to evaluate URLLC capacity in order to capture the interference variation, UE pathloss/geometry difference, scheduling aspect, etc.

Only one cell is loaded with URLLC UE.

The rest 56 cells are loaded with 1 full buffer user.

Latency metric should capture control channel, data transmission, processing, retransmission and queuing latency.

For each packet, latency can be defined as the duration from the time when the packet arrives at MAC scheduler buffer till the time when all bits of the packet are successfully decoded at MAC.

A UE is in outage iff it cannot meet the reliability requirement of R at latency L.

The following KPIs can be used for eMBB capacity

- Full buffer: 5% user spectrum efficiency and mean cell spectrum efficiency
- FTP mode: 5% and 50% user experienced data rate

3.4.5 Moving Cells

4. ITU-R Evaluation for 5G

4.1 Vision

4.1.1 Observation of Trends

User and application trends

- Supporting very low latency and high reliability human-centric communication
- Supporting very low latency and high reliability machine-centric communication
- Maintaining high quality at high mobility
- Enhanced multimedia services
- Internet of things
- Convergence of applications
- Ultra-accurate positioning applications

Growth in traffic

- Global traffic will grow in the range of 10-100 times from 2020 to 2030
- It is observed that the current average traffic asymmetry ratio of mobile broadband is in favor of the downlink, and this is expected to increase due to growing demand for audio-visual content

Technology trends

- Technologies to enhance the radio interface
- Network technologies
- Technologies to enhance mobile broadband scenarios
- Technologies to enhance massive machine type communications
- Technologies to enhance ultra-reliable and low latency communications
- Technologies to improve network energy efficiency
- Terminal technologies
- Technologies to enhance privacy and security
- Technologies enabling higher data rates

4.1.2 Usage Scenarios

The usage scenarios for IMT for 2020 and beyond include:

- Enhanced Mobile Broadband
- Ultra-reliable and low latency communications
- Massive machine type communications

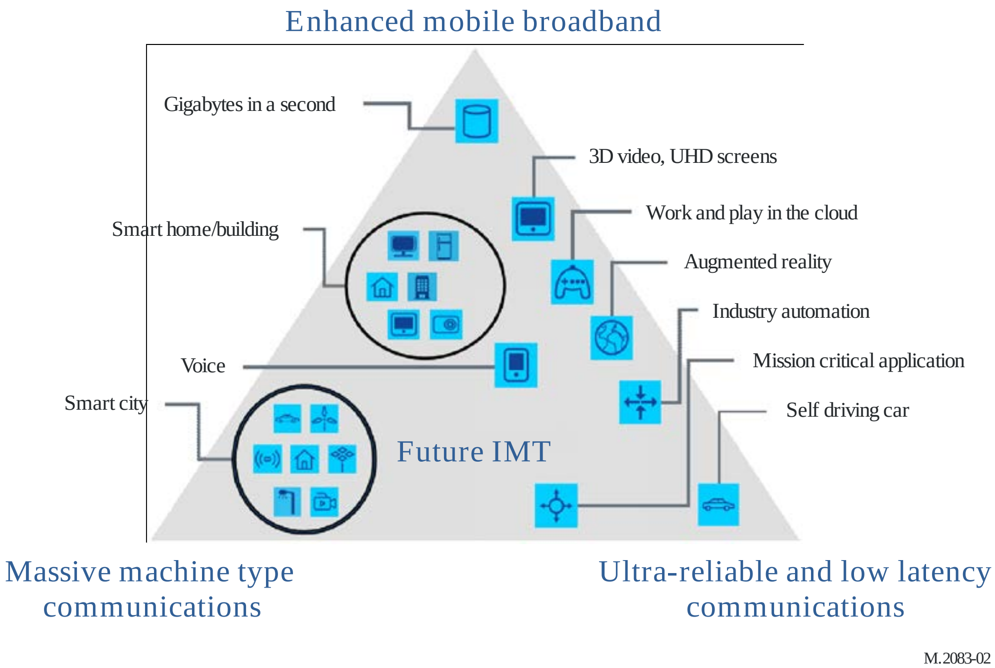


Figure 4-1 Usage scenarios of IMT-2020

4.1.3 Key Capabilities

Peak data rate

- Maximum achievable data rate under ideal conditions per user/device (in Gbit/s).

User experienced data rate

- Achievable data rate that is available ubiquitously across the coverage area to a mobile user/device (in Mbit/s or Gbit/s).

Latency

- The contribution by the radio network to the time from when the source sends a packet to when the destination receives it (in ms).

Mobility

- Maximum speed at which a defined QoS and seamless transfer between radio nodes which may belong to different layers and/or radio access technologies (multi-layer/-RAT) can be achieved (in km/h).

Connection density

- Total number of connected and/or accessible devices per unit area (per km2).

Network energy efficiency

- ➢ The quantity of information bits transmitted to/ received from users, per unit of energy consumption of the radio access network (RAN) (in bit/Joule)

Device energy efficiency

- ➢ The quantity of information bits per unit of energy consumption of the communication module (in bit/Joule).

Spectrum efficiency

- ➢ Average data throughput per unit of spectrum resource and per cell (bit/s/Hz).

Area traffic capacity

- ➢ Total traffic throughput served per geographic area (in Mbit/s/m2).

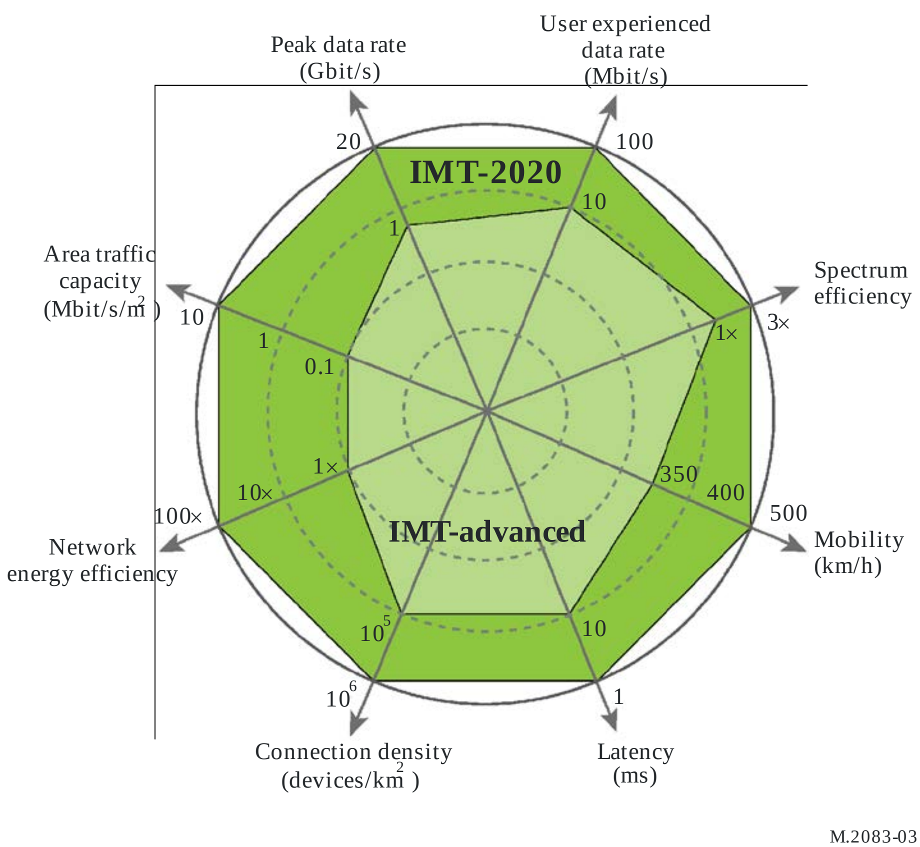


Figure 4-2 Key capabilities

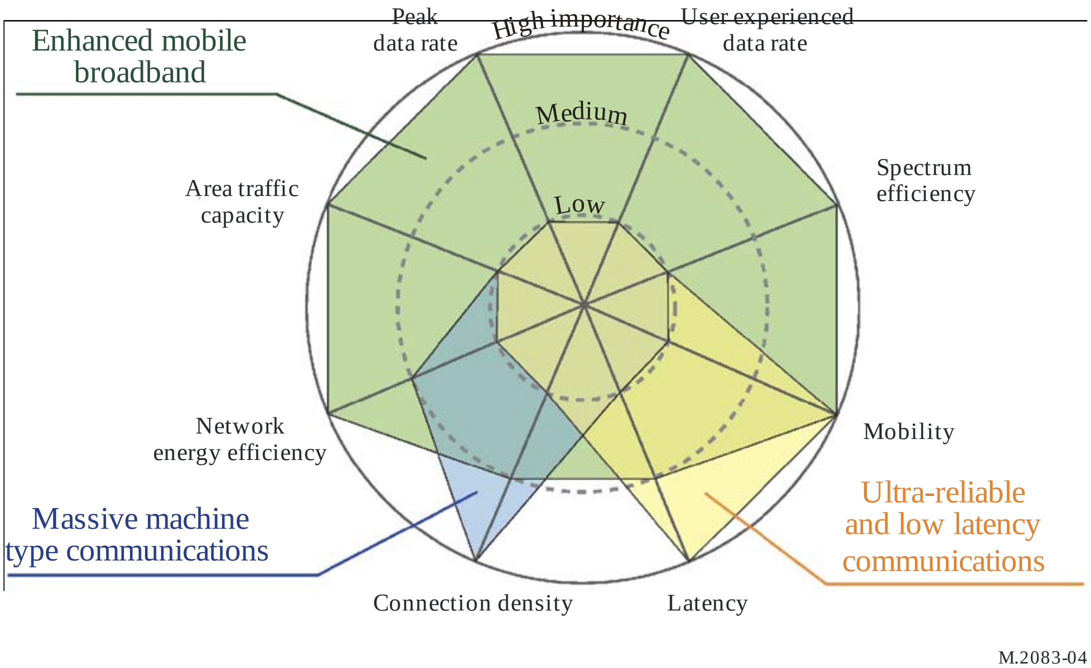


Figure 4-3 The importance of key capabilities in different usage scenarios

4.2 Technical Performance Requirements

4.2.1 Peak Data Rate

Peak data rate is the maximum achievable data rate under ideal conditions (in bit/s), which is the received data bits assuming error-free conditions assignable to a single mobile station, when all assignable radio resources for the corresponding link direction are utilized.

The minimum requirements for peak data rate are as follows:

- Downlink peak data rate is 20 Gbit/s.
- Uplink peak data rate is 10 Gbit/s.

4.2.2 Peak Spectral Efficiency

Peak spectral efficiency is the maximum data rate under ideal conditions normalized by channel bandwidth (in bit/s/Hz), where the maximum data rate is the received data bits assuming error-free conditions assignable to a single mobile station, when all assignable radio resources for the corresponding link direction are utilized.

The minimum requirements for peak spectral efficiencies are as follows:

- Downlink peak spectral efficiency is 30 bit/s/Hz.
- Uplink peak spectral efficiency is 15 bit/s/Hz.

4.2.3 User Experienced Data Rate

User experienced data rate is the 5% point of the cumulative distribution function (CDF) of the user throughput. User throughput (during active time) is defined as the number of correctly received bits, i.e. the number of bits contained in the service data units (SDUs) delivered to Layer 3, over a certain period of time.

The target values for the user experienced data rate are as follows in the Dense Urban – eMBB test environment:

- Downlink user experienced data rate is 100 Mbit/s.
- Uplink user experienced data rate is 50 Mbit/s.

4.2.4 5th Percentile User Spectral Efficiency

The 5th percentile user spectral efficiency is the 5% point of the CDF of the normalized user throughput. The normalized user throughput is defined as the number of correctly received bits, i.e., the number of bits contained in the SDUs delivered to Layer 3, over a certain period of time, divided by the channel bandwidth and is measured in bit/s/Hz.

The minimum requirements for 5th percentile user spectral efficiency for various test environments are as follows.

- Indoor Hotspot - eMBB: downlink 0.3 bit/s/Hz, Uplink 0.21 bit/s/Hz
- Dense Urban - eMBB: downlink 0.225 bit/s/Hz, Uplink 0.115 bit/s/Hz
- Rural - eMBB: downlink 0.12 bit/s/Hz, Uplink 0.045 bit/s/Hz

4.2.5 Average Spectral Efficiency

Average spectral efficiency is the aggregate throughput of all users (the number of correctly received bits, i.e. the number of bits contained in the SDUs delivered to Layer 3, over a certain period of time) divided by the channel bandwidth of a specific band divided by the number of TRxPs and is measured in bit/s/Hz/TRxP.

The minimum requirements for average spectral efficiency are as follows:

- Indoor Hotspot - eMBB: downlink 0 bit/s/Hz/TRxP, Uplink 6.75 bit/s/Hz/TRxP
- Dense Urban - eMBB: downlink 7.8 bit/s/Hz/TRxP, Uplink 5.4 bit/s/Hz/TRxP
- Rural - eMBB: downlink 3.3 bit/s/Hz/TRxP, Uplink 1.6 bit/s/Hz/TRxP

4.2.6 Area Traffic Capacity

Area traffic capacity is the total traffic throughput served per geographic area (in Mbit/s/m2). The throughput is the number of correctly received bits, i.e. the number of bits contained in the SDUs delivered to Layer 3, over a certain period of time.

The target value for Area traffic capacity in downlink is 10 Mbit/s/m^2 in the Indoor Hotspot – eMBB test environment.

4.2.7 User Plane Latency

User plane latency is the contribution of the radio network to the time from when the source sends a packet to when the destination receives it (in ms). It is defined as the one-way time it takes to successfully deliver an application layer packet/message from the radio protocol layer 2/3 SDU ingress point to the radio protocol layer 2/3 SDU egress point of the radio interface in either uplink or downlink in the network for a given service in unloaded conditions, assuming the mobile station is in the active state.

The minimum requirements for user plane latency are as follows:

- 4ms for eMBB
- 1ms for URLLC

4.2.8 Control Plane Latency

Control plane latency refers to the transition time from a most “battery efficient” state (e.g. Idle state) to the start of continuous data transfer (e.g. Active state).

The minimum requirement for user plane latency is 20ms.

4.2.9 Connection Density

Connection density is the total number of devices fulfilling a specific quality of service (QoS) per unit area (per km^2). This requirement is defined for the purpose of evaluation in the mMTC usage scenario.

The minimum requirement for connection density is 1,000,000 devices per km^2.

4.2.10 Energy Efficiency

Energy efficiency of the network and the device can relate to the support for the following two aspects: (a) Efficient data transmission in a loaded case and (b) Low energy consumption when there is no data.

Efficient data transmission in a loaded case is demonstrated by the average spectral efficiency. Low energy consumption when there is no data can be estimated by the sleep ratio.

4.2.11 Reliability

Reliability is the success probability of transmitting a layer 2/3 packet within a required maximum time, which is the time it takes to deliver a small data packet from the radio protocol layer 2/3 SDU ingress point to the radio protocol layer 2/3 SDU egress point of the radio interface at a certain channel quality. This requirement is defined for the purpose of evaluation in the URLLC usage scenario.

The minimum requirement for the reliability is $1\text{-}10^{-5}$ success probability of transmitting a layer 2 PDU (protocol data unit) of 32 bytes within 1 ms in channel quality of coverage edge for the Urban Macro-URLLC test environment, assuming small application data (e.g. 20 bytes application data + protocol overhead).

4.2.12 Mobility

Mobility is the maximum mobile station speed at which a defined QoS can be achieved (in km/h).

The following classes of mobility are defined:

- Stationary: 0 km/h
- Pedestrian: 0 km/h to 10 km/h
- Vehicular: 10 km/h to 120 km/h
- High speed vehicular: 120 km/h to 500 km/h

A mobility class is supported if the traffic channel link data rate on the uplink, normalized by bandwidth, is as shown in the following table. This assumes the user is moving at the maximum speed in that mobility class in each of the test environments.

Table 4-1 Traffic channel link data rates normalized by bandwidth

Test environment	Mobility classes supported	Normalized traffic channel link data rate (bit/s/Hz)	Mobility (km/h)
Indoor Hotspot - eMBB	Stationary, Pedestrian	1.5	10
Dense Urban - eMBB	Stationary, Pedestrian, Vehicular (up to 30km/h)	1.12	30
Rural - eMBB	Pedestrian, Vehicular, High speed vehicular	0.8	120
		0.45	500

4.2.13 Mobility Interruption Time

Mobility interruption time is the shortest time duration supported by the system during which a user terminal cannot exchange user plane packets with any base station during transitions.

The minimum requirement for mobility interruption time is 0 ms.

4.2.14 Bandwidth

Bandwidth is the maximum aggregated system bandwidth. The bandwidth may be supported by single or multiple radio frequency (RF) carriers.

The requirement for bandwidth is at least 100 MHz.

4.3 Test Environments

4.3.1 Test Environments

- Indoor Hotspot-eMBB: an indoor isolated environment at offices and/or in shopping malls based on stationary and pedestrian users with very high user density.
- Dense Urban-eMBB: an urban environment with high user density and traffic loads focusing on pedestrian and vehicular users.
- Rural-eMBB: a rural environment with larger and continuous wide area coverage, supporting high speed vehicles.
- Urban Macro–mMTC: an urban macro environment targeting continuous coverage focusing on a high number of connected machine type devices
- Urban Macro–URLLC: an urban macro environment targeting ultra reliable and low latency communications

4.3.2 Network Layout

- Indoor Hotspot: It consists of one floor of a building. The height of the floor is 3m. The floor has a surface of 120m × 5m and 12 BSs/sites which are placed in 20 meter spacing. In the figure, internal walls are not explicitly shown but are modeled via the stochastic LOS probability model.
- Dense Urban: The deployment consists of two layers, a macro layer and a micro layer. The macro-layer base stations are placed in a regular grid, following hexagonal layout with three sectors each. For the micro layer, there are 3 micro sites randomly dropped in each macro TRxP area.
- Rural: The BSs/sites are placed in a regular grid, following hexagonal layout with three TRxPs each. For evaluation of the mobility, the same topographical details of hexagonal layout are applied to both 120 km/h and 500 km/h mobility. For 500 km/h mobility, additional evaluations are encouraged using linear cell layout configurations.
- Urban: The base stations are placed in a regular grid, following hexagonal layout with three sectors each, as in the dense urban macro layer and rural case.

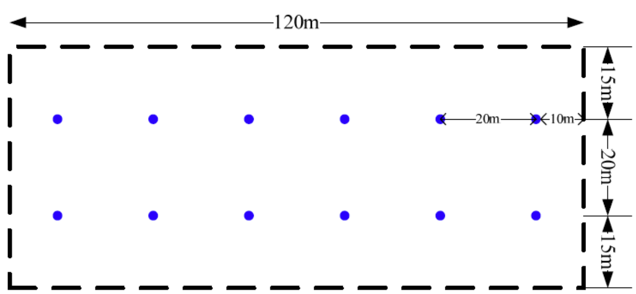


Figure 4-4 Indoor hotspot sites layout

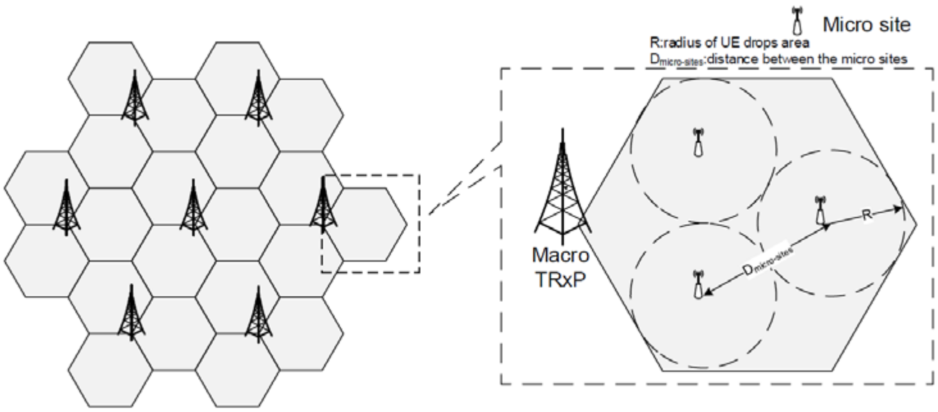


Figure 4-5 Dense urban-eMBB layout

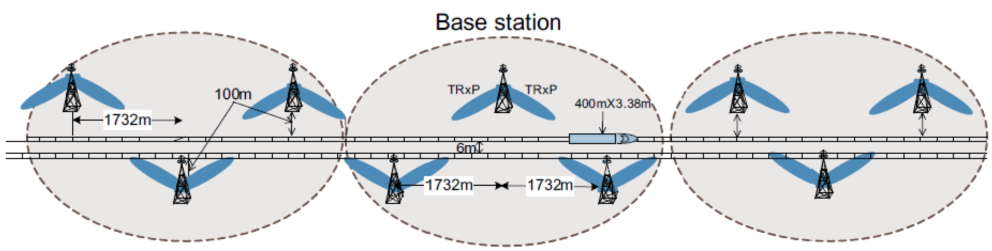


Figure 4-6 Linear cell layout for high speed vehicular mobility (4 GHz/without relay)

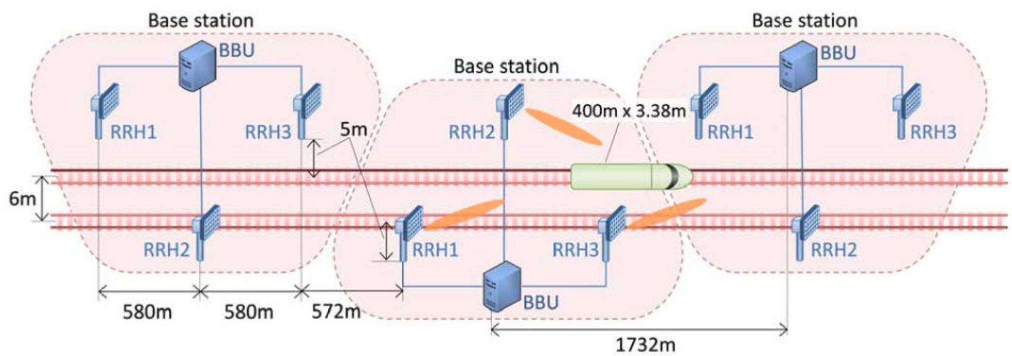


Figure 4-7 Linear cell layout for high speed vehicular mobility (30 GHz/with relay)

4.4 Channel Model

4.4.1 Channel Model

The channel model consists of a Primary Module, and Extension Module, and a Map-based Hybrid Channel Module.

The primary channel module is a geometry-based stochastic channel model. It does not explicitly specify the locations of the scatterers, but rather the directions of rays. Geometry based modeling of the radio channel enables separation of propagation parameters and antennas. The channel parameters for individual snapshots are determined stochastically based on statistical distributions extracted from channel measurements. Channel realizations are generated through the application of the geometrical principle by summing contributions of rays with specific small-scale parameters link delay, power, azimuth angles of arrival and departure, elevation angles of arrival and departure. Superposition results to correlation between antenna elements and temporal fading with geometry dependent Doppler spectrum.

The extension module below 6 GHz provides an alternative method of generating the channel parameters below 6 GHz in the primary module. It provides additional level of parameter variability. Module provides new parameter values for the Primary Module based on environment-specific parameters. It is based on the time-spatial propagation model which is geometry-based double directional channel model with closed-form functions. It calculates the large-scale parameters for the channel realization by taking into account the following key parameters such as city structures (street width, average building height), BS height, bandwidth and the distance between the BS and the UE.

The map-based hybrid channel module is an optimal module, which is based on a digital map, and consists of a deterministic component and a stochastic component. It can be used if the system performance is desired to be evaluated or predicted with the adoption of digital map to take into account the impacts from environmental structures and materials. The implementation of the map-based hybrid channel module starts with the definitions of scenario and digitized map. Based on the imported configurations, the ray-tracing is applied to each pair of link Tx/Rx end with the output including LOS state/deterministic power, delay, angular information etc. Then, the large-scale parameters except for shadow fading, are adopted to generate the delay and virtual power for random clusters based on the similar procedures of primary model, where the threshold of probability for cluster inter-arrival interval is considered in the selection of random clusters. The real powers of the selected random clusters are calculated based on deterministic results. After merging the random and deterministic clusters, the generations of the channel coefficients are conducted through the similar procedures as the primary module except for the inherited mean value of cross polarization ratio for dominant paths from the corresponding deterministic results.

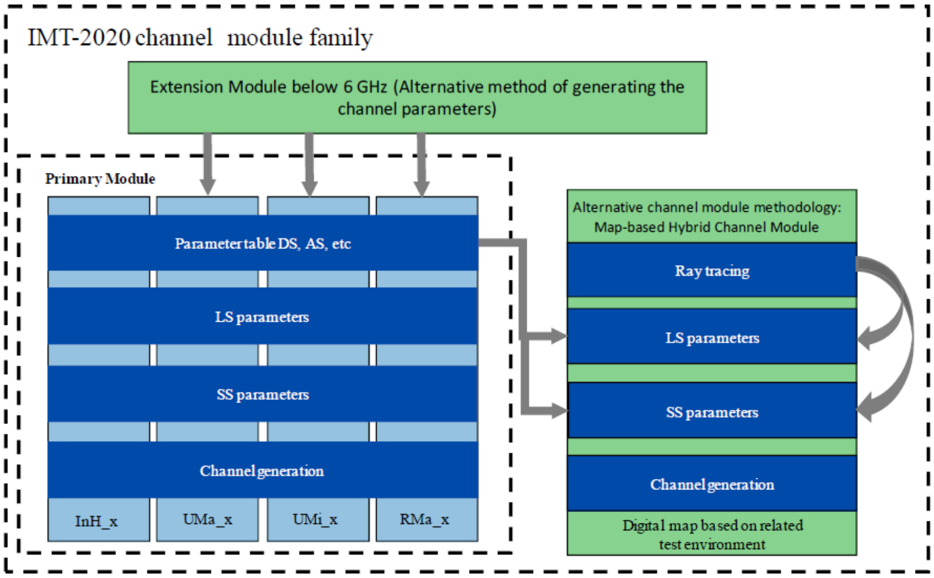


Figure 4-8 IMT-2020 channel model

4.4.2 Mapping to Channel Model Scenario

The primary module includes channel model A and B, which are both based on field measurements and are equally valid for evaluation. Either of them can be used for the evaluation.

Table 4-2 Mapping of channel models to test environments

Test environment	Indoor Hotspot - eMBB	Dense urban - eMBB	Rural - eMBB	Urban macro - mMTC	Urban macro - URLLC
Channel model	InH_A, InH_B	Macro layer: UMa_A, UMa_B Micro layer: UMi_A, UMi_B	RMa_A, RMa_B	UMa_A, UMa_B	UMa_A, UMa_B

4.4.3 New Capabilities of Channel Modeling

3D modeling

3D modeling describes the channel propagation both in azimuth and elevation dimensions at both Tx and Rx.

Spatial consistency and clusters

The spatial consistency of channel, on one hand, means that the channel evolves smoothly without discontinuities when the Tx and/or Rx moves or turns; on the other hand, means that channel characteristics are highly correlated in closely located links, e.g., two close-by mobile stations seen by the same base station.

Large bandwidth and large antenna arrays

To support the evaluation of large bandwidth and large antenna array, the channel model should be specified with sufficiently high resolution in the delay and angular domain.

Blockage modeling

The blockage model describes the phenomenon where the stationary or moving objects standing between the transmitter and receivers dramatically changes the channel characteristics when the signal is blocked, especially for high frequency bands, since mm-waves do not effectively penetrate or diffract around human bodies and other objects.

Gaseous absorption

The electromagnetic wave may be partially or totally absorbed by an absorbing medium due to atomic and molecular interactions.

Ground reflection

Measurements in millimeter wave frequency bands have shown that ground reflection in millimeter wave has significant effect which can produce a strong propagation path that superimposes with the direct LOS path and induces severe fading effects.

Vegetation effects

Radio waves are affected by foliage and this effect increases with frequency. The main propagation phenomena involved are: attenuation of the radiation through the foliage, diffraction above/below and sideways around the canopy, and diffuse scattering by the leaves.

4.4.4 Fast Fading Model

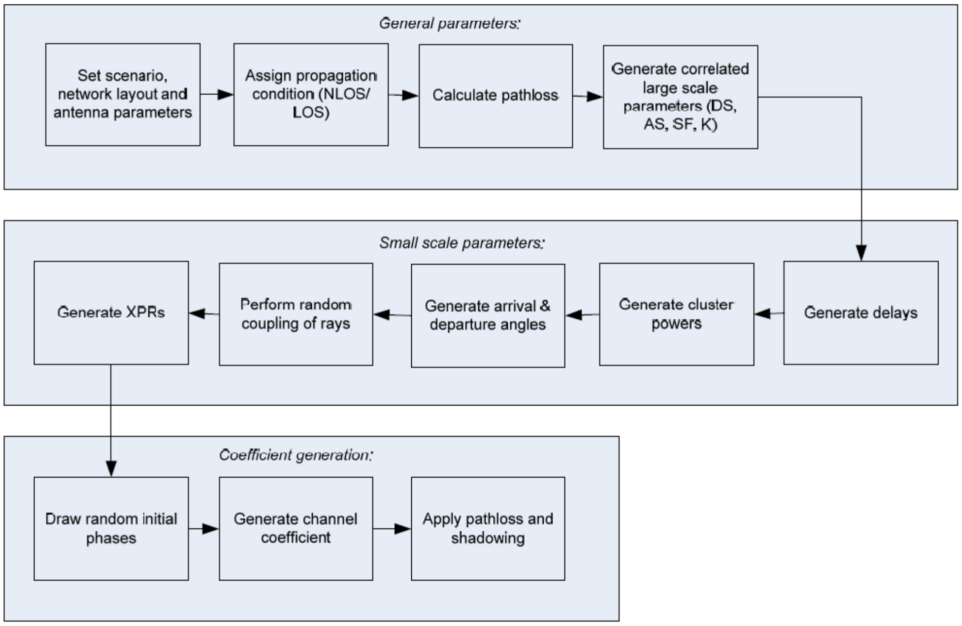


Figure 4-9 Channel coefficient generation

General parameter generation

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

Large scale parameter generation

- Step 2: Assign propagation condition (LOS/NLOS) and indoor/outdoor state for each user.
- Step 3: Calculate pathloss for each link.
- Step 4: Generate large scale parameters, e.g., root-mean-square delay spread (DS), root-mean-square angular spreads (ASA, ASD, ZSA, ZSD), Ricean K-factor (K) and shadow fading (SF) taking into account cross correlation.

Small scale parameter generation

- Step 5: Generate delays. Delays are drawn randomly from the delay distribution.
- Step 6: Generate cluster powers. Cluster powers are calculated assuming a single slope exponential power delay profile. In the case of LOS condition, an additional specular component is added to the first cluster.
- Step 7: Generate arrival angles and departure angles for both azimuth and elevation.
- Step 8: Coupling of rays within a cluster for both azimuth and elevation. Couple randomly AOD angles to AOA angles, and ZOD angles to ZOA angles.
- Step 9: Generate the cross polarization power ratios for each ray of each cluster.

Channel coefficient generation

- Step 10: Draw initial random phases for each ray of each cluster.
- Step 11: Generate channel coefficients for each cluster and each receiver and transmitter element pair.
- Step 12: Apply pathloss and shadowing for the channel coefficients.

The use of the following advanced modeling components is optional and up to the proponents to decide.

Table 4-3 Advanced modeling components

Advanced modeling component	Corresponding steps	Recommended condition
Oxygen absorption	Step 11	From 52 to 68 GHz
Large bandwidth and large antenna array - Modeling of propagation delay	Step 11	When the bandwidth B is greater than c/D Hz, where D is the max antenna aperture C is the speed of light
Large bandwidth and large antenna array - Modeling of intra-cluster angular and delay spread	Step 7	When inverse of bandwidth is smaller than the per-cluster delay spread or angular resolution of the antenna array is better than per-cluster angular spread
Spatial consistency procedure	Step 5 - 11	To ensure that the channel evolves smoothly without discontinuities which can be important when evaluating the system performance, including beam tracking or MU-MIMO performance
Spatial consistent user mobility modeling	Step 5 - 7	
Spatial consistent LOS/NLOS, indoor states O-I parameters	Step 2 - 12	
Blockage	Step between 9 and 10	When the transmitter and receiver are blocked by the stationary or moving objects, especially for the higher frequency bands
Modeling of inter-frequency correlation of large scale parameters	Step 1, 2, 4 - 11	For simulations in multiple frequency band simultaneously
Time-varying Doppler frequencies	Step 11	For nonlinear user movement or when direction of arrival is time-varying
User rotation	Step 1	For simulation that user rotation is considered
Ground reflection	Step 11	To increase the model accuracy in LOS conditions, especially in higher frequency band
Random cluster number	Step 5, 7	To better capture the cluster characteristics of the channel

4.5 Evaluation of Radio Interface Technologies

4.5.1 Characteristics of Evaluation

The technical characteristics chosen for evaluation are summarized in the following table.

Table 4-4 Summary of evaluation methodologies

Technical Requirements	Method
Peak data rate	Analytical
Peak spectral efficiency	Analytical
User experienced data rate	Analytical for single band and single layer; Simulation for multi-layer
5^{th} percentile user spectral efficiency	Simulation
Average spectral efficiency	Simulation
Area traffic capacity	Analytical
User plane latency	Analytical

Control plane latency	Analytical
Connection density	Simulation
Energy efficiency	Inspection
Reliability	Simulation
Mobility	Simulation
Mobility interruption time	Analytical
Bandwidth	Inspection

Table 4-5 Simulations for test environments

Technical Requirements	Hotspot eMBB	Dense Urban eMBB	Rural eMBB	Urban Macro mMTC	Urban Macro URLLC
User experienced data rate		SLS			
5th percentile user spectral efficiency	SLS	SLS	SLS		
Average spectral efficiency	SLS	SLS	SLS		
Connection density				SLS + LLS	
Reliability					SLS + LLS
Mobility	SLS + LLS	SLS + LLS	SLS + LLS		

4.5.2 System Simulation Procedures

The following principles shall be followed in system simulation:

- Users are dropped independently over the predefined area of the network layout throughout the system. Each mobile corresponds to an active user session that runs for the duration of the drop.
- Mobiles are randomly assigned LoS and NLoS channel conditions according to the channel model
- Cell assignment to a user is based on a cell selection scheme
- The minimum distance between a user and a base station maintained.
- Fading signal and interference are computed from each transmitter into each receiver (on an aggregated basis).
- The interference over thermal (IoT) parameter is an uplink design constraint that the proponent must take into account when designing the system such that the average IoT value experienced in the evaluation is equal to or less than 10 dB.
- In simulations based on the full-buffer traffic model, packets are not blocked when they arrive into the system (i.e. queue depths are assumed to be infinite).
- Users with a required traffic characteristic shall be modeled according to the traffic models.
- Packets are scheduled with an appropriate packet scheduler for full buffer and other traffic models separately. Channel quality feedback delay, feedback errors, PDU (protocol data unit) errors and real channel estimation effects inclusive of channel estimation error are modeled and packets are retransmitted as necessary.
- The overhead channels (i.e., the overhead due to feedback and control channels) should be realistically modeled.
- For a given drop the simulation is run and then the process is repeated with the users dropped at new random locations. A sufficient number of drops are simulated to ensure convergence in the user and system performance metrics.

- Performance statistics are collected taking into account the wrap-around configuration in the network layout, noting that wrap-around is not considered in the indoor case.
- All cells in the system shall be simulated with dynamic channel properties using a wrap-around technique, noting that wrap-around is not considered in the indoor case.

In order to perform less complex system simulations, often the simulations are divided into separate ‘link’ and ‘system’ simulations with a specific link-to-system interface. Another possible way to reduce system simulation complexity is to employ simplified interference modeling.

4.5.3 Spectral Efficiency

The average spectral efficiency is evaluated by system level simulation using the evaluation configuration parameters of Indoor Hotspot-eMBB, Dense Urban-eMBB, and Rural-eMBB test environments. It should be noted that the average spectral efficiency is evaluated by system level simulation only using a single-layer layout configuration even if a test environment comprises a multi-layer layout configuration.

The 5th percentile user spectral efficiency is evaluated by system level simulation using the evaluation configuration parameters of Indoor Hotspot-eMBB, Dense Urban-eMBB, and Rural-eMBB test environments. It should be noted that the 5th percentile user spectral efficiency is evaluated by system level simulation only using a single-layer layout configuration even if a test environment comprises a multi-layer layout configuration. The 5th percentile user spectral efficiency shall be evaluated using identical simulation assumptions as the average spectral efficiency for that test environment.

4.5.4 Connection Density

There are two possible evaluation methods to evaluate connection density requirement.

- Non-full buffer system-level simulation
- Full-buffer system-level simulation followed by link-level simulation

[Option 1: Non-full buffer system-level simulation]

Old description: (can be ignored)

Given a certain number of devices N in the simulation area with average inter-packet time interval T_{packet}, the average number of packets arrival in one second could be derived (denoted as $N_{\text{packet}} = N/T_{\text{packet}}$). The system should guarantee that the packet outage rate (percentage of packets in outage) is less than 1%, where a packet is defined to have experienced of outage if the packet failed to be delivered to the destination receiver within a permissible packet delay bound of [XX] seconds. The packet delay is the overall latency from the time when the packet arrival at the transmitter to the time when successful source decoding accomplishes at the receiver. The evaluator shall perform the following steps in order to evaluate the connection efficiency.

- Step 1: Set a certain system device number N, and then get system packet arrival rate N_{packet}. Set the system TRxP number as M and simulation bandwidth as W.
- Step 2: Generate the UE traffic packet according to the small packet model at packet arrival rate N_{packet}.
- Step 3: Run simulation and obtain the packet outage rate.

- Step 4: Change the system device number, repeat step 1-3 to find the system UE number N_{capacity} satisfying the packet outage rate [1%].
- Step 5: Calculate UE connection efficiency by $N_{\text{capacity}}/M/W$.

New description:

- Step 1: Set system user number per TRxP as N
- Step 2: Generate the user packet according to the traffic model
- Step 3: Run non-full buffer system-level simulation to obtain the packet outage rate. The outage rate is defined as the ratio of the number of packets that to be delivered to the destination receiver within a transmission delay of less than or equal to 10s to the total number of packets generated in Step 2
- Step 4: Change the value of N and repeat Step 2-3 to obtain the system user number per TRxP N' satisfying the packet outage rate of 1%
- Step 5: Calculate connection density by equation C = N' / A, where the TRxP area A is calculated as A = $ISD^2 \times \text{sqrt}(3)/6$, and ISD is the inter-site distance

The requirement is fulfilled if the connection density C is greater than or equal to the connection density requirement

[Option 2: Full-buffer system-level simulation followed by link-level simulation]

Old description: (can be ignored)

The connection density refers to the total number of devices fulfilling a target QoS per unit area (per km^2), where the target QoS is to deliver within 10 s an amount of data of 200 bytes with 99% success probability. The evaluator shall perform the following steps in order to evaluate the connection density requirement. Analysis, system level simulation and link level simulation are used for evaluation.

- Step 1: Derive the required data rate per TRxP.
  - Step 1-1: Derive number of devices/TRxP.
  - Step 1-2: Derive average message per device per day and the mean size of each message
  - Step 1-3: Derive bit rate per TRxP.
- Step 2: Determine median SINR from uplink system level simulation using Urban Macro – mMTC evaluation parameters.
- Step 3: Perform link level simulation to show that at this SINR, the derived uplink bitrate per (Z kbps) can be supported over the aggregated system bandwidth of the corresponding test environment (i.e., Urban Macro – mMTC).

New description:

- Perform full-buffer system-level simulation using the evaluation parameters for Urban Macro-mMTC test environment, determine the uplink $SINR_i$ for each percentile i = 1, ..., 99 of the distribution over users, and record the average allocated user bandwidth W_{user}; In case user multiplexing on the same time/frequency resource is modeled in this step, record the average number of multiplexed users N_{mux}. N_{mux} = 1 for no user multiplexing
- Perform link-level simulation and determine the achievable user data rate R_i for the recoded $SINR_i$ and W_{user} values; In case user multiplexing on the same time/frequency resource is modeled in this step, record the average number of multiplexed users $n_{mux,i}$ under $SINR_i$; The achievable data rate for this case is derived by $R_i = Z_i/n_{mux,i}$, where aggregated bit rate Z_i is the summed bit rate of $n_{mux,i}$ users on W_{user}; $n_{mux,i}$ = 1 for no user multiplexing
- Calculate the packet transmission delay of a user as $D_i = S / R_i$, where S is the packet size
- Calculate the traffic generated per user as $T = S / T_{inter\text{-}arrival}$, where $T_{inter\text{-}arrival}$ is the inter-packet arrival time

- Calculate the long-term frequency resource requested under $SINR_i$ as $B_i = T / (R_i / W_{user})$
- Calculate the number of supported connections per TRxP, $N = W / mean(B_i)$; W is the simulation bandwidth; The mean of B_i may be taken over the best 99% of the $SINR_i$ conditions; In case user multiplexing is modeled in Step 1, $N = N_{mux} \times W / mean(B_i)$; In case user multiplexing is modeled in Step 2, $N = W / mean(B_i / n_{mux,i})$
- Calculate the connection density as $C = N / A$, where the TRxP area A is calculated as $A = ISD^2 \times sqrt(3)/6$, and ISD is the inter-site distance

The requirement is fulfilled if the 99th percentile of the delay per user D_i is less than or equal to 10s, and the connection density is greater than or equal to the connection density requirement.

4.5.5 Mobility

Mobility shall be evaluated under Indoor Hotspot-eMBB, Dense Urban-eMBB, and Rural-eMBB test environments.

The evaluator shall perform the following steps in order to evaluate the mobility requirement.

- Step 1: Run system simulations, identical to those for average spectral efficiency and 5th percentile user spectral efficiency, except for speeds, using link level simulations and a link-to-system interface appropriate for these speed values, for the set of selected test environment(s) associated with the candidate RIT/SRIT proposal and collect overall statistics for uplink SINR values, and construct cumulative distribution function (CDF) over these values for each test environment.
- Step 2: Use the CDF for the test environment(s) to save the respective 50%-percentile SINR value.
- Step 3: Run new uplink link-level simulations for the selected test environment(s) for either NLoS or LoS channel conditions using the associated speeds, as input parameters, to obtain link data rate and residual packet error rate as a function of SINR. The link-level simulation shall use air interface configuration(s) supported by the proposal and take into account retransmission, channel estimation and phase noise impact.
- Step 4: Compare the link spectral efficiency values (link data rate normalized by channel bandwidth) obtained from Step 3 using the associated SINR value obtained from Step 2 for selected test environments, with the corresponding threshold values.
- Step 5: The proposal fulfils the mobility requirement if the spectral efficiency value is larger than or equal to the corresponding threshold value and if also the residual decoded packet error rate is less than 1%, for all selected test environments. For the selected test environment it is sufficient if one of the spectral efficiency values (of either NLoS or LoS channel conditions) fulfill the threshold.

Similar methodology can be used for downlink.

4.5.6 Reliability

Old description (can be ignored):

The evaluator shall perform the following steps in order to evaluate the reliability requirement.

- Step 1: Run system simulations, identical to those for average spectral efficiencies, using link level simulations and a link-to-system interface appropriate for the assumed speed values, for the set of selected test environment(s) associated with the candidate RIT/SRIT proposal and collect overall statistics for [downlink and/or uplink] SINR values, and construct cumulative distribution function (CDF) over these values for each test environment.

- Step 2: Use the CDF for the test environment(s) to save the respective 5%-percentile [downlink and/or uplink] SINR value.
- Step 3: Run new [downlink and/or uplink] link-level simulations using the associated to obtain residual packet error rate within maximum delay time as a function of SINR taking into account retransmission.
- Step 4: The proposal fulfils the reliability requirement if the fraction of messages that are correctly delivered within the required delay is larger than or equal to the required success probability.

New description:

The evaluator shall perform the following steps in order to evaluate the reliability requirement using system-level simulation followed by link-level simulations.

- Step 1: Run downlink or uplink full buffer system-level simulations of candidate RITs/SRITs using the evaluation parameters of Urban Macro-URLLC test environment and collect overall statistics for downlink or uplink SINR values, and construct CDF over these values
- Step 2: Use the CDF for Urban Macro-URLLC test environment to save the respective 5th percentile downlink or uplink SINR value
- Step 3: Run corresponding link-level simulations for either NLOS or LOS channel conditions using the associated parameters to obtain success probability, which equals to (1 - P_e), where P_e is the residual packet error ratio within maximum delay time as a function of SINR taking into account retransmission
- Step 4: The proposal fulfils the reliability requirement if at the 5th percentile downlink or uplink SINR value of Step 2 and within the required delay, the success probability derived in Step 3 is larger than or equal to the required success probability. It is sufficient to fulfill the requirement in either downlink or uplink in either NLOS or LOS channel conditions.

5. 5G NR

5.1 Physical Layer General Description

5.1.1 Relation to Other Layers

The following figure shows the NR radio interface protocol architecture around the physical layer (Layer 1). The physical layer interfaces the Medium Access Control (MAC) sub-layer of Layer 2 and the Radio Resource Control (RRC) Layer of Layer 3. The circles between different layer/sub-layers indicate Service Access Points (SAPs). The physical layer offers a transport channel to MAC. The transport channel is characterized by how the information is transferred over the radio interface. MAC offers different logical channels to the Radio Link Control (RLC) sub-layer of Layer 2. A logical channel is characterized by the type of information transferred.

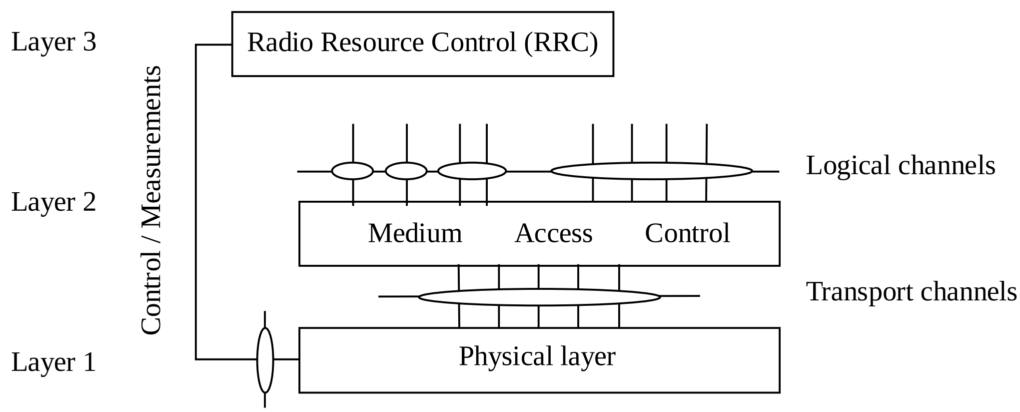


Figure 5-1 Radio interface protocol architecture around the physical layer

The physical layer offers data transport services to higher layers. The access to these services is through the use of a transport channel via the MAC sub-layer.

5.1.2 General Description of Layer 1

The multiple access scheme for the NR physical layer is based on Orthogonal Frequency Division Multiplexing (OFDM) with a cyclic prefix (CP). For uplink, Discrete Fourier Transform-spread-OFDM (DFT-s-OFDM) with a CP is also supported. To support transmission in paired and unpaired spectrum, both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) are enabled.

The Layer 1 is defined in a bandwidth agnostic way based on resource blocks, allowing the NR Layer 1 to adapt to various spectrum allocations. A resource block spans 12 sub-carriers with a given sub-carrier spacing.

The radio frame has a duration of 10ms and consists of 10 sub-frames with a sub-frame duration of 1ms. A sub-frame is formed by one or multiple adjacent slots, each having 14 adjacent symbols.

The physical channels defined in the downlink are:

- the Physical Downlink Shared Channel (PDSCH),
- the Physical Downlink Control Channel (PDCCH),
- the Physical Broadcast Channel (PBCH),

The physical channels defined in the uplink are:

- the Physical Random Access Channel (PRACH),
- the Physical Uplink Shared Channel (PUSCH),
- and the Physical Uplink Control Channel (PUCCH).

In addition, signals are defined as reference signals, primary and secondary synchronization signals.

The modulation schemes supported are

- in the downlink, QPSK, 16QAM, 64QAM, and 256QAM,
- in the uplink, QPSK, 16QAM, 64QAM and 256QAM for OFDM with a CP and π/2-BPSK, QPSK, 16QAM, 64QAM and 256QAM for DFT-s-OFDM with a CP

The channel coding scheme for transport blocks is quasi-cyclic LDPC codes with 2 base graphs and 8 sets of parity check matrices for each base graph, respectively. One base graph is used for code blocks larger than certain sizes or with initial transmission code rate higher than thresholds; otherwise, the other base graph is used. Before the LDPC coding, for large transport blocks, the transport block is segmented into multiple code blocks with equal size. The channel coding scheme for PBCH and control information is Polar coding based on nested sequences. Puncturing, shortening and repetition are used for rate matching.

There are several Physical layer procedures involved. Such procedures covered by the physical layer are;

- Cell search
- Power control
- Uplink synchronization and Uplink timing control
- Random access related procedures
- HARQ related procedures
- Beam management and CSI related procedures

Through the control of physical layer resources in the frequency domain as well as in the time and power domains, implicit support of interference coordination is provided in NR.

5.2 Services Provided by the Physical Layer

5.2.1 Services and Functions of the Physical Layer

The physical layer offers data transport services to higher layers.

The access to these services is through the use of transport channels via the MAC sub-layer.

A transport block is defined as the data delivered by MAC layer to the physical layer and vice versa.

The physical layer is expected to perform the following functions to provide the data transport service:

- Error detection on the transport channel and indication to higher layers;
- FEC encoding/decoding of the transport channel;
- Hybrid ARQ soft-combining;
- Rate matching of the coded transport channel to physical channels;
- Mapping of the coded transport channel onto physical channels;
- Power weighting of physical channels;
- Modulation and demodulation of physical channels;
- Frequency and time synchronization;
- Radio characteristics measurements and indication to higher layers;
- Multiple Input Multiple Output (MIMO) antenna processing;
- RF processing.

5.2.2 Uplink Model of Physical Layer

The physical-layer model for Uplink Shared Channel transmission is described based on the corresponding PUSCH physical-layer-processing chain. Processing steps that are relevant for the physical-layer model, e.g. in the sense that they are configurable by higher layers, are highlighted in blue.

- Higher-layer data passed to/from the physical layer
- CRC and transport-block-error indication
- FEC and rate matching
- Data modulation
- Mapping to physical resource
- Multi-antenna processing
- Support of L1 control and Hybrid-ARQ-related signaling

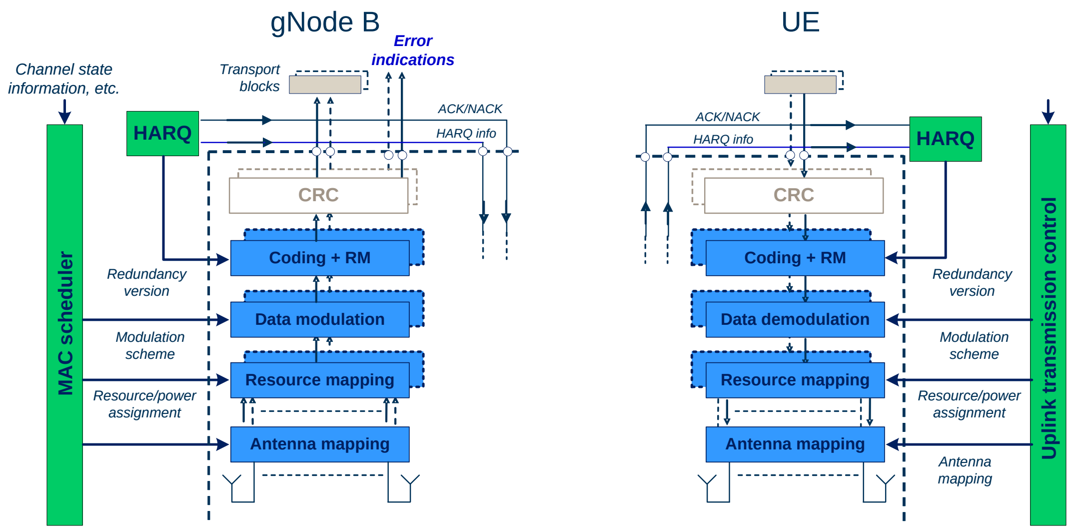


Figure 5-2 Physical-layer model for UL-SCH transmission

The physical-layer model for RACH transmission is characterized by a PRACH preamble format that consists of a cyclic prefix, a preamble, and a guard time during which nothing is transmitted.

5.2.3 Downlink Model of Physical Layer

The physical-layer model for Downlink Shared Channel transmission is described based on the corresponding PDSCH physical-layer-processing chain. Processing steps that are relevant for the physical-layer model, e.g. in the sense that they are configurable by higher layers, are highlighted in blue.

- Higher-layer data passed to/from the physical layer;
- CRC and transport-block-error indication;
- FEC and rate matching;
- Data modulation;
- Mapping to physical resource;
- Multi-antenna processing;
- Support of L1 control and Hybrid-ARQ-related signaling.

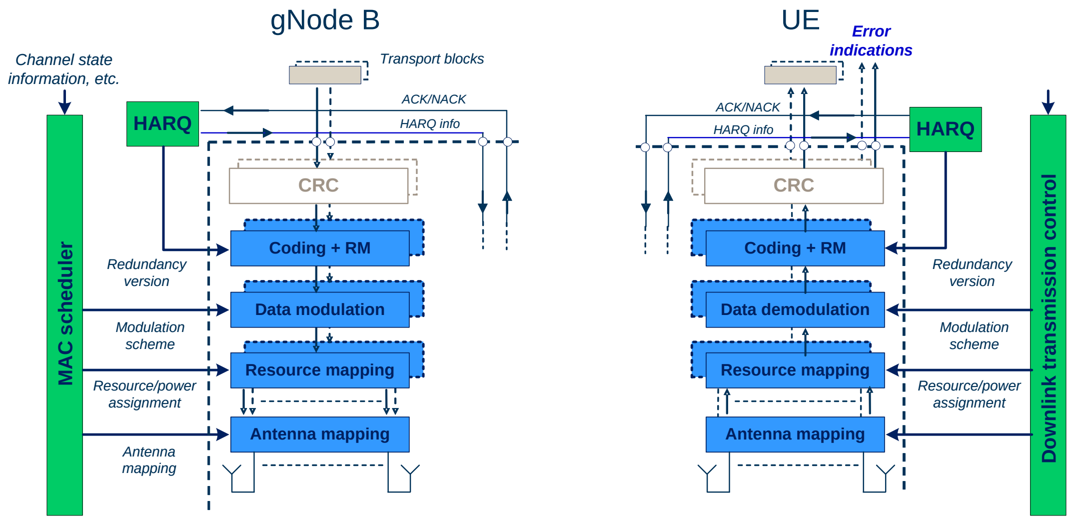


Figure 5-3 Physical-layer model for DL-SCH transmission

The physical-layer model for BCH transmission is characterized by a fixed pre-defined transport format. There is one transport block for the BCH every 80ms. The BCH physical-layer model is described based on the corresponding PBCH physical-layer-processing chain:

- Higher-layer data passed to/from the physical layer;
- CRC and transport-block-error indication;
- FEC and rate matching;
- Data modulation;
- Mapping to physical resource;
- Multi-antenna processing.

The physical-layer model for PCH transmission is described based on the corresponding physical-layer-processing chain. The PCH is carried on PDSCH.

- Higher-layer data passed to/from the physical layer;
- CRC and transport-block-error indication;
- FEC and rate matching;
- Data modulation;
- Mapping to physical resource;
- Multi-antenna processing.

5.3 Physical Channels and Modulation

5.3.1 Numerologies

Multiple OFDM numerologies are supported as given by the following table where μ and the cyclic prefix for a carrier bandwidth part are given by the higher-layer parameters *DL-BWP-mu* and *DL-BWP-cp* for the downlink and *UL-BWP-mu* and *UL-BWP-cp* for the uplink.

Table 5-1 Supported transmission numerologies

μ	$\Delta f = 2^{\mu} \cdot 15\,[\text{kHz}]$	**Cyclic prefix**
0	15	Normal
1	30	Normal
2	60	Normal, Extended
3	120	Normal
4	240	Normal

5.3.2 Frame Structure

Downlink and uplink transmissions are organized into frames with $T_{\mathrm{f}} = (\Delta f_{\max} N_{\mathrm{f}} / 100) \cdot T_{\mathrm{c}} = 10\,\mathrm{ms}$ duration, consisting of ten subframes of $T_{\mathrm{sf}} = (\Delta f_{\max} N_{\mathrm{f}} / 1000) \cdot T_{\mathrm{c}} = 1\,\mathrm{ms}$ duration each. The number of consecutive OFDM symbols per subframe is $N_{\mathrm{symb}}^{\mathrm{subframe},\mu} = N_{\mathrm{symb}}^{\mathrm{slot}} N_{\mathrm{slot}}^{\mathrm{subframe},\mu}$. Each frame is divided into two equally-sized half-frames of five subframes each with half-frame 0 consisting of subframes 0 – 4 and half-frame 1 consisting of subframes 5 – 9.

For subcarrier spacing configuration μ, slots are numbered $n_{\mathrm{s}}^{\mu} \in \{0,..., N_{\mathrm{slot}}^{\mathrm{subframe},\mu} - 1\}$ in increasing order within a subframe and $n_{\mathrm{s,f}}^{\mu} \in \{0,..., N_{\mathrm{slot}}^{\mathrm{frame},\mu} - 1\}$ in increasing order within a frame. There are $N_{\mathrm{symb}}^{\mathrm{slot}}$ consecutive OFDM symbols in a slot where $N_{\mathrm{symb}}^{\mathrm{slot}}$ depends on the cyclic prefix.

Table 5-2 Number of OFDM symbols per slot, slots per frame, and slots per subframe for normal cyclic prefix

μ	$N_{\mathrm{symb}}^{\mathrm{slot}}$	$N_{\mathrm{slot}}^{\mathrm{frame},\mu}$	$N_{\mathrm{slot}}^{\mathrm{subframe},\mu}$
0	14	10	1
1	14	20	2
2	14	40	4
3	14	80	8
4	14	160	16
5	14	320	32

5.3.3 Physical Resources

An antenna port is defined such that the channel over which a symbol on the antenna port is conveyed can be inferred from the channel over which another symbol on the same antenna port is conveyed.

Two antenna ports are said to be quasi co-located if the large-scale properties of the channel over which a symbol on one antenna port is conveyed can be inferred from the channel over which a symbol on the other antenna port is conveyed. The large-scale properties include one or more of delay spread, Doppler spread, Doppler shift, average gain, average delay, and spatial Rx parameters.

A resource block is defined as $N_{\mathrm{sc}}^{\mathrm{RB}} = 12$ consecutive subcarriers in the frequency domain.

5.3.4 Uplink Channels and Signals

An uplink physical channel corresponds to a set of resource elements carrying information originating from higher layers. The following uplink physical channels are defined:

- Physical Uplink Shared Channel, PUSCH
- Physical Uplink Control Channel, PUCCH
- Physical Random Access Channel, PRACH

An uplink physical signal is used by the physical layer but does not carry information originating from higher layers. The following uplink physical signals are defined:

- Demodulation reference signals, DM-RS
- Phase-tracking reference signals, PT-RS
- Sounding reference signal, SRS

5.3.5 Downlink Channels and Signals

A downlink physical channel corresponds to a set of resource elements carrying information originating from higher layers. The following downlink physical channels are defined:

- Physical Downlink Shared Channel, PDSCH
- Physical Broadcast Channel, PBCH
- Physical Downlink Control Channel, PDCCH.

A downlink physical signal corresponds to a set of resource elements used by the physical layer but does not carry information originating from higher layers. The following downlink physical signals are defined:

- Demodulation reference signals, DM-RS, for PDSCH and PBCH
- Phase-tracking reference signals, PT-RS
- Channel-state information reference signal, CSI-RS
- Primary synchronization signal, PSS
- Secondary synchronization signal, SSS

5.4 Multiplexing and Channel Coding

Data and control streams from/to MAC layer are encoded /decoded to offer transport and control services over the radio transmission link. Channel coding scheme is a combination of error detection, error correcting, rate matching, interleaving and transport channel or control information mapping onto/splitting from physical channels.

5.5 Physical Layer Procedures for Control

Cell search is the procedure by which a UE acquires time and frequency synchronization with a cell and detects the physical layer Cell ID of that cell.

Upon reception of a timing advance command for a TAG containing the primary cell or PSCell, the UE shall adjust uplink transmission timing for PUCCH/PUSCH/SRS of the primary cell or PSCell based on the received timing advance command.

The downlink radio link quality of the primary cell shall be monitored by a UE for the purpose of indicating out-of-sync/in-sync status to higher layers. The UE is not required to monitor the downlink radio link quality in DL BWPs other than the active DL BWP on the primary cell.

Uplink power control determines the transmit power of the different uplink physical channels or signals.

Prior to initiation of the physical random access procedure, Layer 1 shall receive from higher layers a set of SS/PBCH block indexes and shall provide to higher layers a corresponding set of RSRP measurements.

From the physical layer perspective, the L1 random access procedure encompasses the transmission of random access preamble (Msg1) in a PRACH, random access response (RAR) in a PDSCH (Msg2), Msg3 PUSCH, and PDSCH for contention resolution.

5.6 Physical Layer Procedures for Data

The gNodeB determines the downlink transmit energy per resource element.

For downlink, a maximum of 16 HARQ processes in supported. The number of processes the UE may assume will at most be used for the downlink is configured to the UE for each cell separately by higher layer parameter nrofHARQ-processesForPDSCH.

A UE shall upon detection of a PDCCH with a configured DCI format decode the corresponding PDSCHs as indicated by that DCI.

The time and frequency resources that can be used by the UE to report CSI are controlled by the gNB. CSI consists of Channel Quality Indicator (CQI), precoding matrix indicator (PMI), CSI-RS resource indicator (CRI), strongest layer indication (SLI), rank indication (RI) and/or and L1-RSRP.

If a UE is configured by higher layers to decode PDCCH with the CRC scrambled by the C-RNTI, the UE shall decode the PDCCH and transmit the corresponding PUSCH.

5.7 Physical Layer Measurements

With the measurement specifications L1 provides measurement capabilities for the UE and NG-RAN. These measurements can be classified in different reported measurement types: intra-frequency, inter-frequency, inter-system, traffic volume, quality and UE internal measurements.

6. Type of Simulators

6.1 Type of Simulators

6.1.1 Link Level Simulator

In order to evaluate the performance of cellular communication systems, several types of simulations can be performed, including link level simulation, system level simulation, and network level simulation.

Link level simulation can measure the error probabilities according to channel environments with accurate physical layer models including modulation and channel coding.

6.1.2 System Level Simulator

In system level simulation, a large number of base stations and terminals are placed to obtain average or cell-edge system performance.

6.1.3 Network Level Simulator

Network level simulation considers various network elements and the protocol operations of core networks as well as radio access networks. It can be used to measure the network or end-to-end performance, while link level and system level simulations focuses on the performance evaluation of the wireless section.

6.2 Relationship of Simulators

6.2.1 Integration of Simulators

An example of an integrated simulator is shown in the following figure. Although the integration of LLS, SLS, and NS has been seriously considered, it is decided that the integration will not be performed.

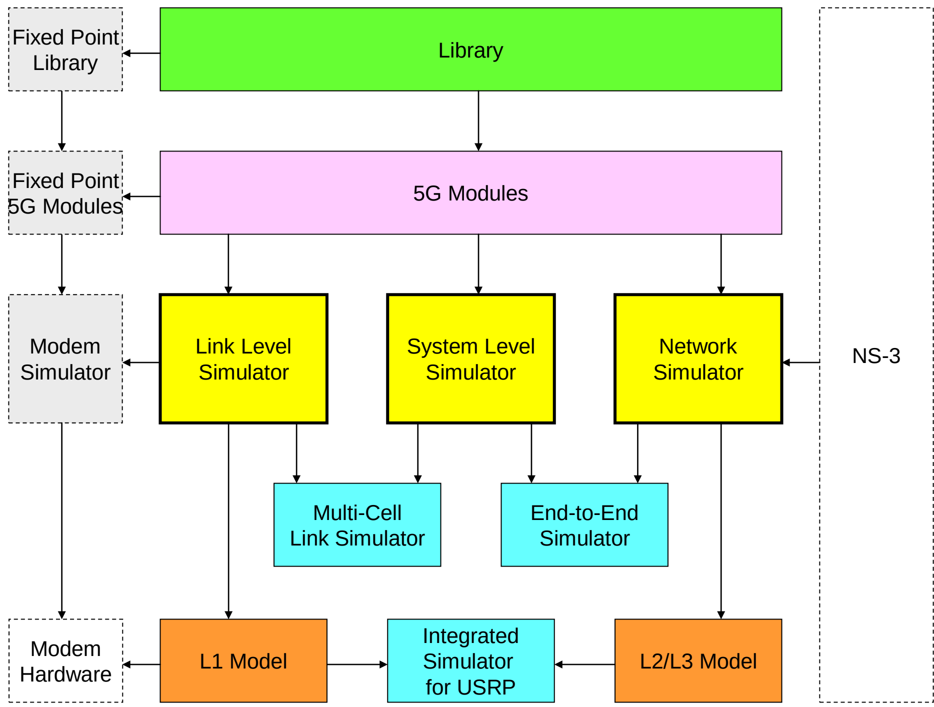


Figure 6-1 Integration of simulators

6.2.2 Interworking of Simulators

Instead, some forms of interworking will be implemented. The details of interworking level are TBD.

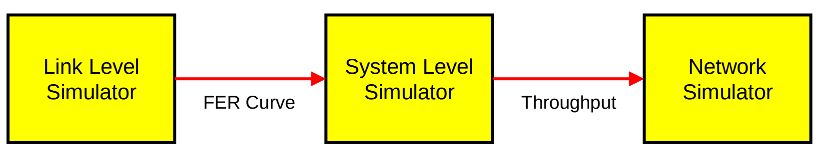


Figure 6-2 Interworking of simulators

6.2.3 Extended Capability

The system level simulator may include a simplified version of a link level simulator in order to extend the capability. In this case, multi-cell link level simulations can be performed in the system level simulation environments. Note that a full version of a link level simulator exists independently outside the system level simulator and the simplified version is not related to the full version.

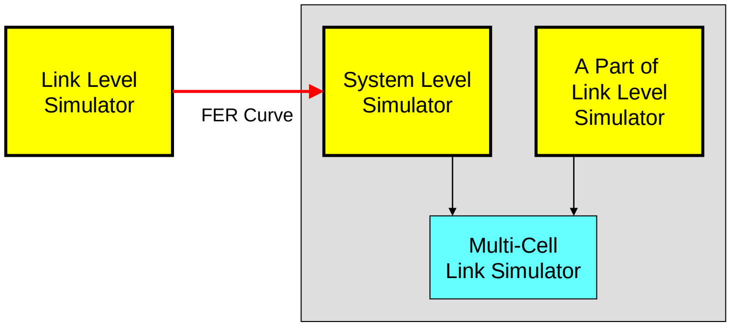


Figure 6-3 Extended capability

7. 4G Simulators

7.1 Link Level Simulator

7.1.1 Vienna Link Level Simulator

The simulator comprises by one or more transmitter blocks, channel modeling for each link, and receiver blocks. The feedback channel is implemented as a delayed error-free signaling channel.

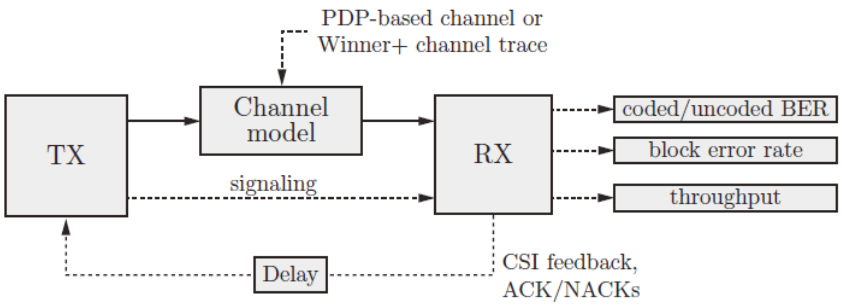


Figure 7-1 Link Level Simulator

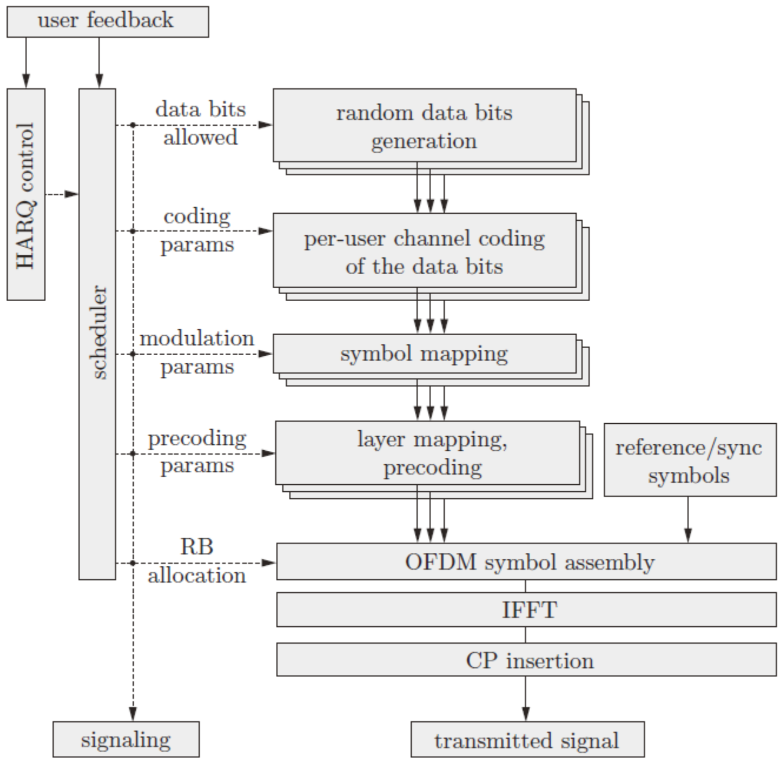


Figure 7-2 Downlink transmitter implementation

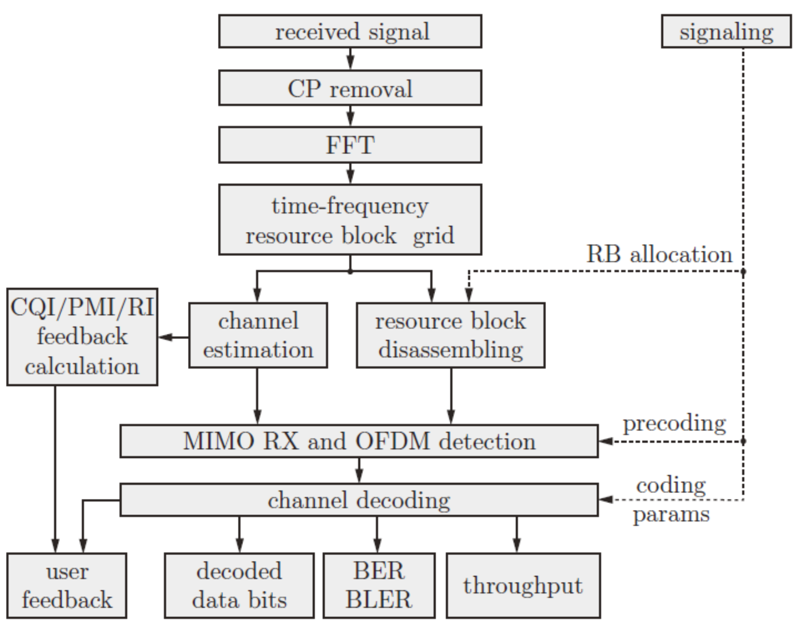


Figure 7-3 Downlink receiver structure

It is possible to adjust the scale of the simulation to the specific needs. This is achieved by introducing three different simulation types with largely different computational complexity.

- Single downlink
- Single-cell multi-user
- Multi-cell multi-user

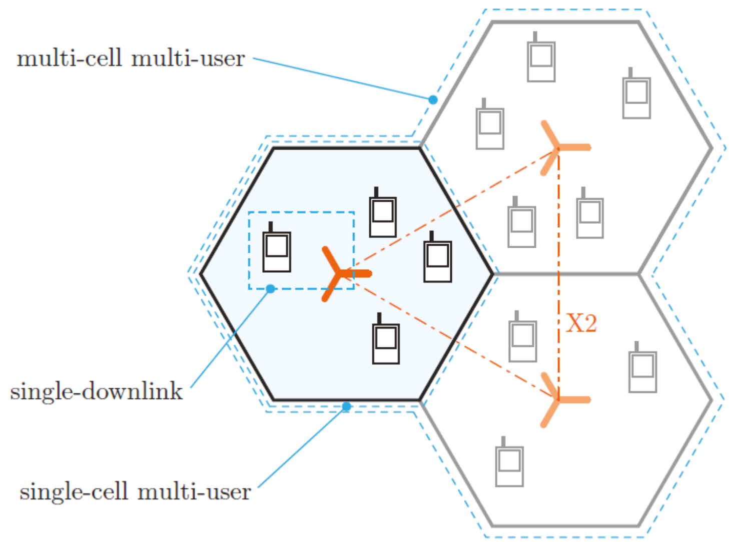


Figure 7-4 Three possible scenarios: single-downlink, single-cell multi-user, and multi-cell multi-user

Multi-cell multi-user link level simulation allows for the realistic investigation of interference-aware receiver techniques, interference management (including cooperative transmissions and interference alignment), and network-based algorithms such as joint resource allocation and scheduling. Furthermore, such simulations are crucial to verify system level simulations.

7.1.2 LTE-LPS

LTE-LPS (long term evolution physical layer performance simulator) is an open-source simulator for educational purposes, developed for MATLAB. LTE-LPS implements both downlink and uplink connections, and can evaluate the bit error rate performance as function of E_b/N_0. This simulator may be used as a tool for studying signal processing and digital communications techniques such as channel estimation, channel coding, equalization, multiple access schemes, multiple-input multiple-output (MIMO) transmissions (diversity, spatial multiplexing, and beamforming), and MUI effects.

7.1.3 PUT Simulator

A set of software simulation tools entitled MACHINE was developed at Poznan University of Technology for performance valuation of mobile wireless networks and radio access technologies. Basic structure of the MACINE is shown in the following figure. It consists of two major parts: the simulated system model (SSM) and radio environment model (REM). The REM is an abstraction of the wireless networks and radio waves propagation effects. The SSM module of the MACHINE consists of three major parts. The first one is a link level simulator that is based on the physical layer of the LTE system. It implements both uplink and downlink data and control channels. The abstraction model of the LTE link facilitates the second major part of SSM - the link to system interface. This interface is utilized by the system level simulator which is the third major part of SSM.

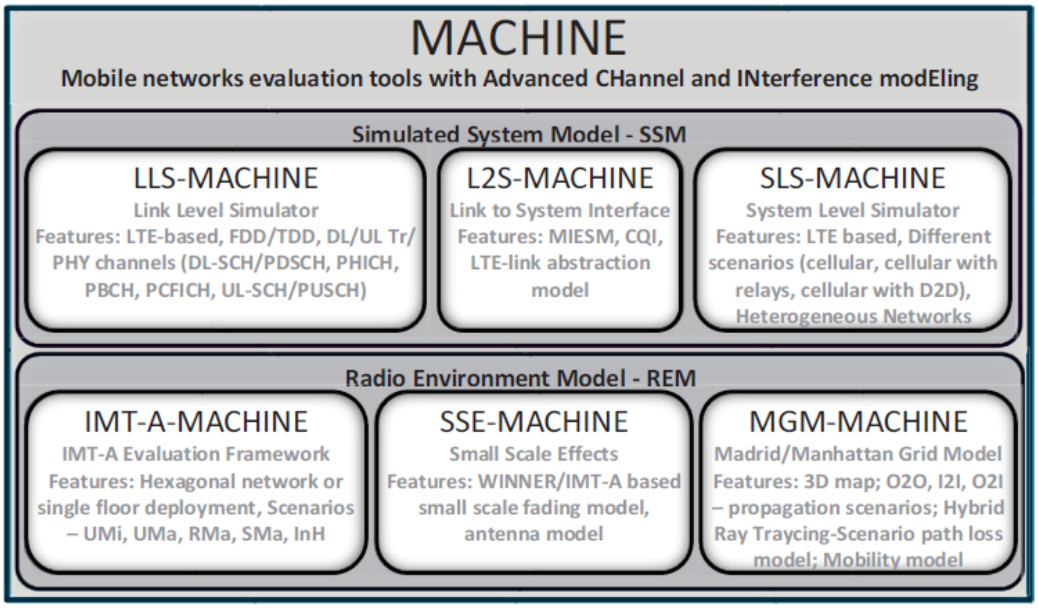


Figure 7-5 High level structure of the MACHINE

For the programming point of view the core processing in MACHINE is written in C++ with the help of IT++ library. Post processing of the obtained results is implemented mainly in Python with the help of matplotlib and numpy libraries. The tools can be developed and executed at least on the MS windows and Linux platforms.

The link level simulator implements a complete LTE transport and physical layer processing procedures.

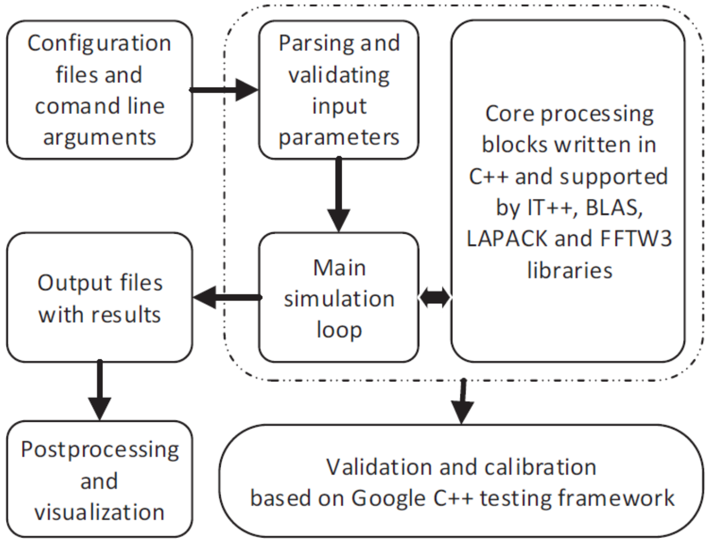


Figure 7-6 LTE link level simulation package structure

7.2 System Level Simulator

7.2.1 Vienna System Level Simulator

In system level simulations, the performance of a whole network is analyzed. The physical layer has to be abstracted by simplified models capturing its essential dynamics with high accuracy at low complexity.

Link quality is evaluated by means of the link-measurement model, while the link-performance model maps it to BLER and outputs link throughput and error distribution.

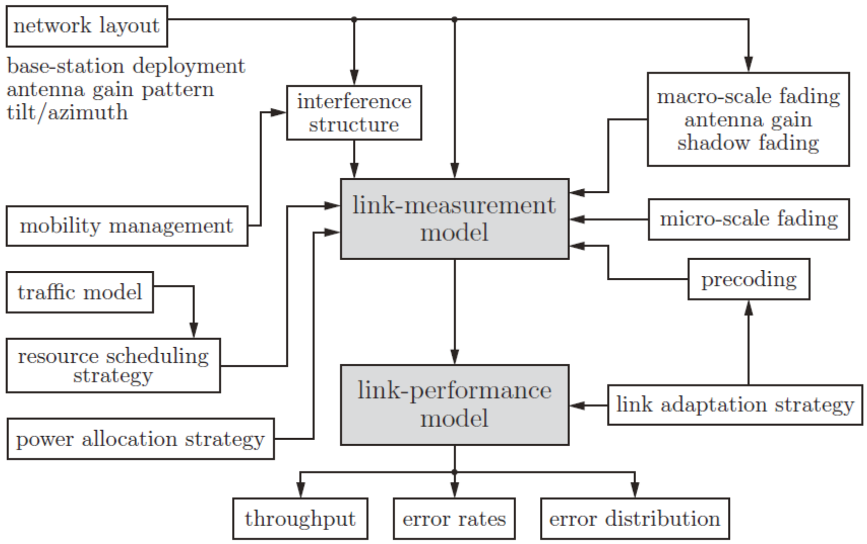


Figure 7-7 Schematic block diagram of the system level simulator

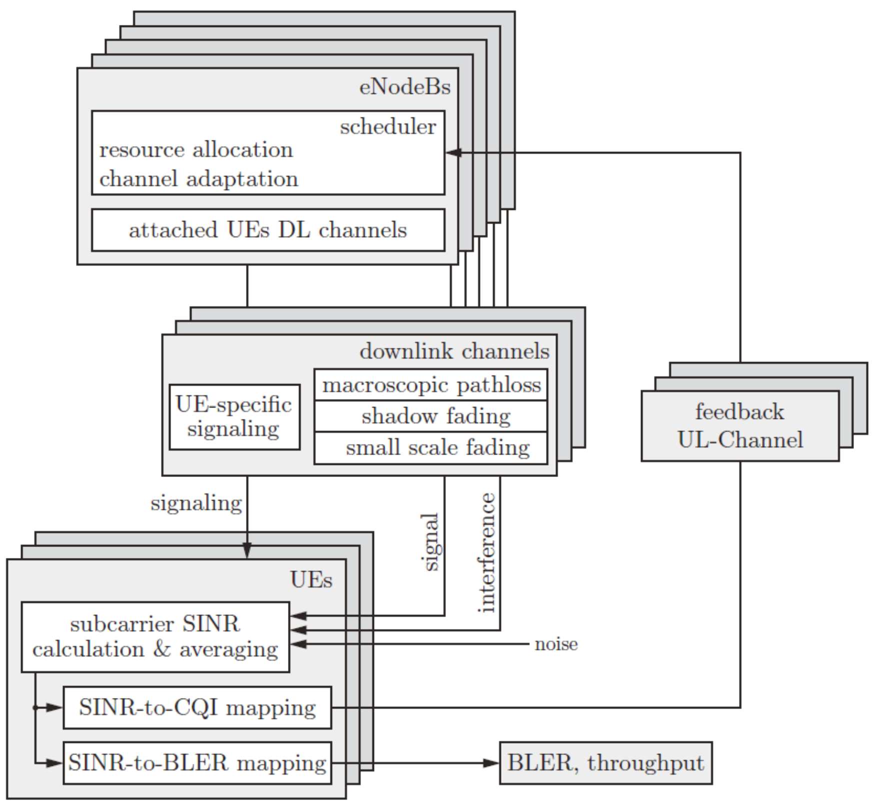


Figure 7-8 Schematic class diagram

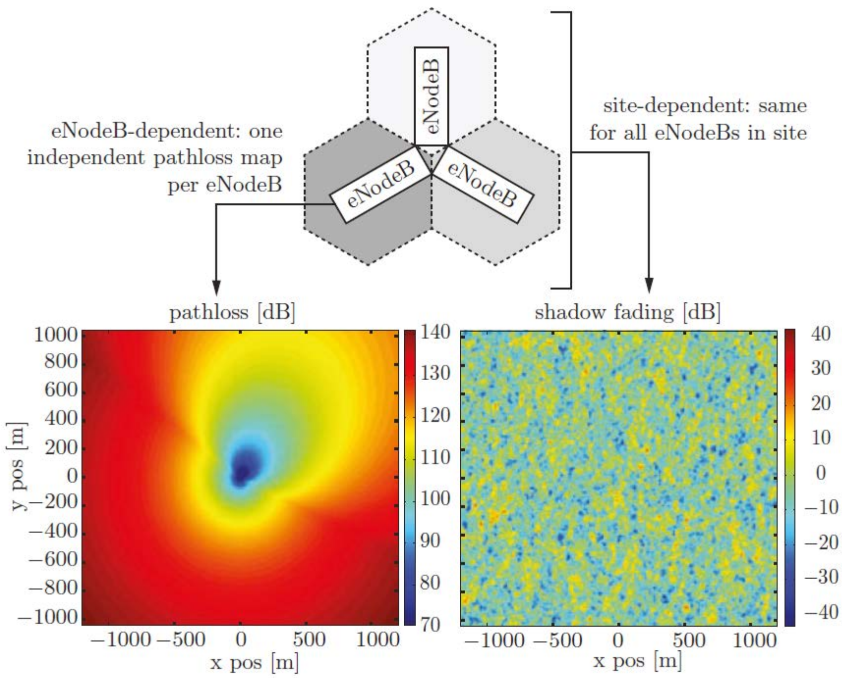


Figure 7-9 Large scale path-loss and shadow fading

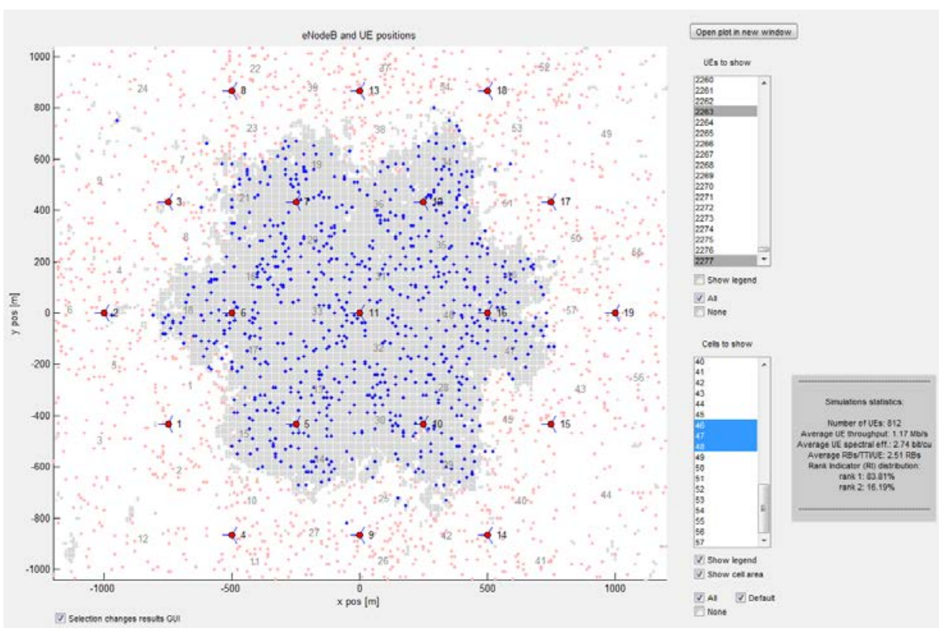


Figure 7-10 Positions of BSs and MSs

7.2.2 SLS by WINGS

The simulation tool is a discrete event simulation environment for the simulation of LTE-A heterogeneous networks. The main modules supported are macro cells, pico cells, and UE nodes.

Measurements

- eNodeB, LTE Pico cell load measurements
- UE SNR/SINR measurements
- SNR/SINR probability density function per cell
- SNR/SINR cumulative distribution function
- eNodeB, LTE Pico cell energy consumption
- eNodeB, LTE Pico cell aggregate (total) throughput (uplink, downlink)
- UE achieved throughput (uplink, downlink)

7.2.3 LTE-SIM

LTE-Sim is the tool provided by POLIBA for running system level simulations in the FANTASTIC-5G project.

In order to ensure modularity, polymorphism, flexibility, and high performance, LTE-Sim has been written in object-oriented C++, as an event-driven simulator. At the present, the software is approximately composed by 100 classes, 450 files, and 67,000 lines of code. Moreover, supported platforms include Linux i386, Linux amd64, Mac OS X. A limited support for Windows is provided too.

LTE-Sim integrates four main components that orchestrate the execution of the simulation. They are: Simulator, NetworkManager, FlowsManager, and FrameManager. For each of them, a dedicated class has been developed. When a simulation starts, only one object for each of the aforementioned components is created. Furthermore, to ensure that each of these classes will have only one instance during the simulation (with a global point of access) a singleton design pattern has been used.

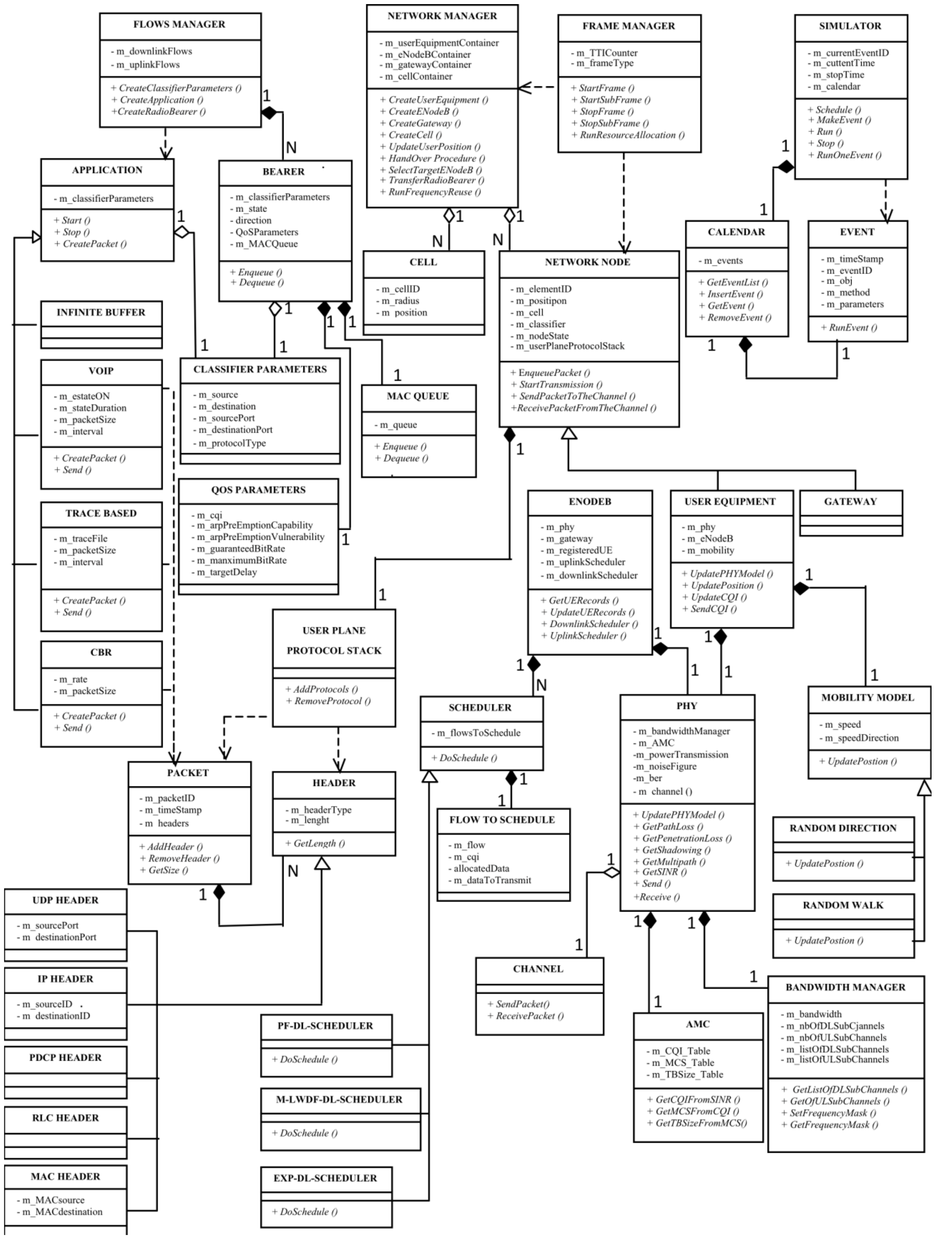


Figure 7-11 Class diagram

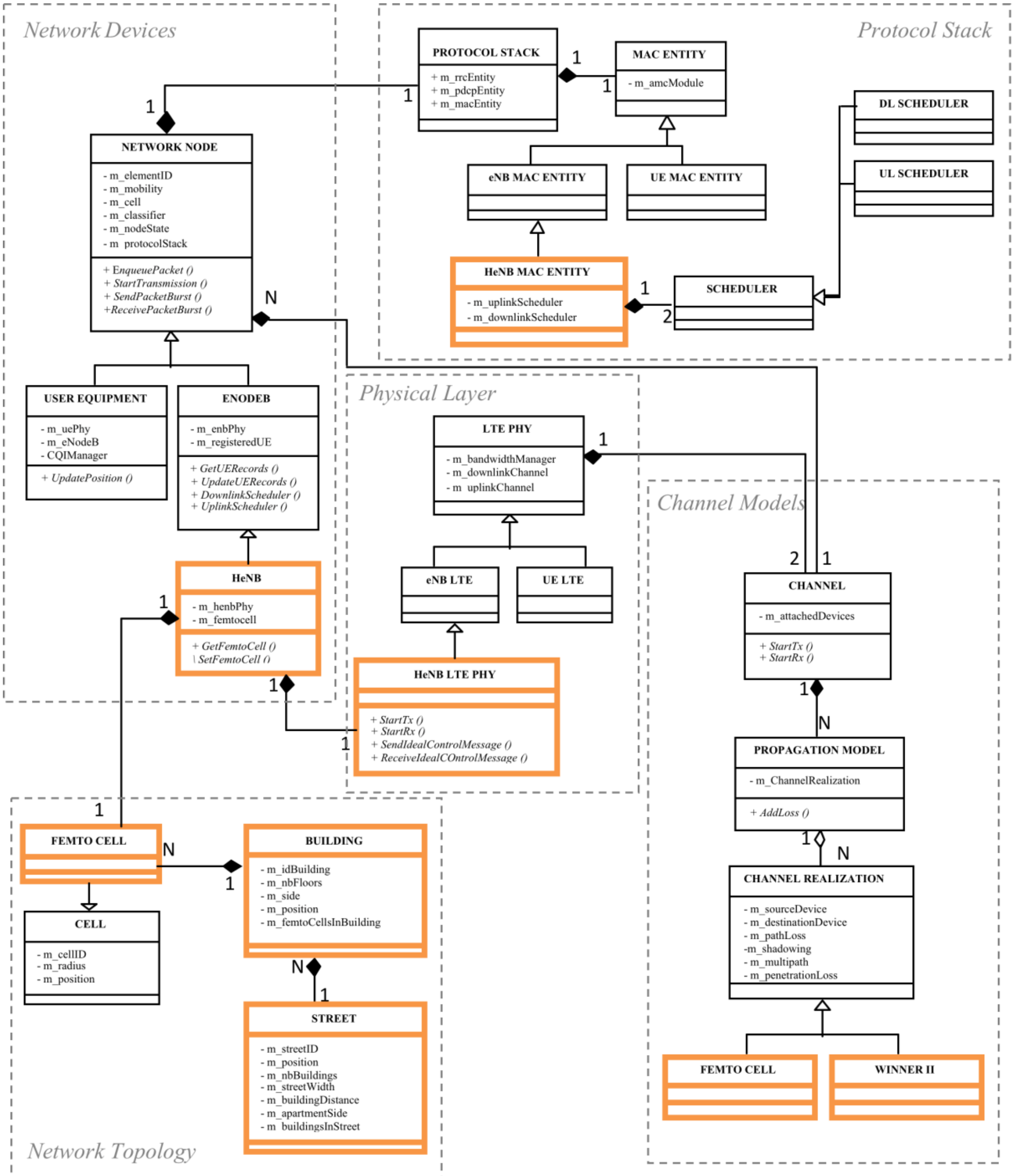


Figure 7-12 Class diagram related to the femtocell extension

Table 7-1 Main components of the LTE-SIM

Component	Functionalities	Important Methods	Method description
Simulator	- Creates/Handles/Ends an event	Schedule()	Creates a new event and insert it into the calendar.
		RunOneEvent()	Executes an event.
		Run() / Stop()	Starts / ends the simulation.
FrameManager	- Defines LTE frame structure - Schedules frames and sub-frames	StartFrame() and StopFrame()	Handles the start and the end of the LTE frame.
		StartSubFrame() and StopSubFrame()	Handles the start and the end of the LTE sub-frame.
FlowsManager	- Handles applications	CreateApplication()	Creates an application
NetworkManager	- Creates devices - Handles UE position - Manages the hand over - Implements frequency reuse techniques	CreateUserEquipment()	Creates an UE device
		CreateCell()	Creates a LTE Cell
		UpdateUserPosition()	Updates the UE position
		HandOverProcedure()	Handles the hand over procedure
		RunFrequecyReuse()	Implements frequency reuse techniques

7.2.4 PUT Simulator

There is one main C++ class that stores various parameters of modes and provides model instantiation, configuration, initialization, and finally execution. Besides the main class, there is a set of classes representing various nodes of wireless networks link base stations, relay stations, and user equipments.

Owing to the complexity of the model, a language with sufficient code structuring capabilities that supports high level data management had to be used. The selection of C++ was an obvious solution because of the two main features of this language: object-oriented programming and code reusability through inheritance.

The top level architecture of the simulator is presented in the following figure.

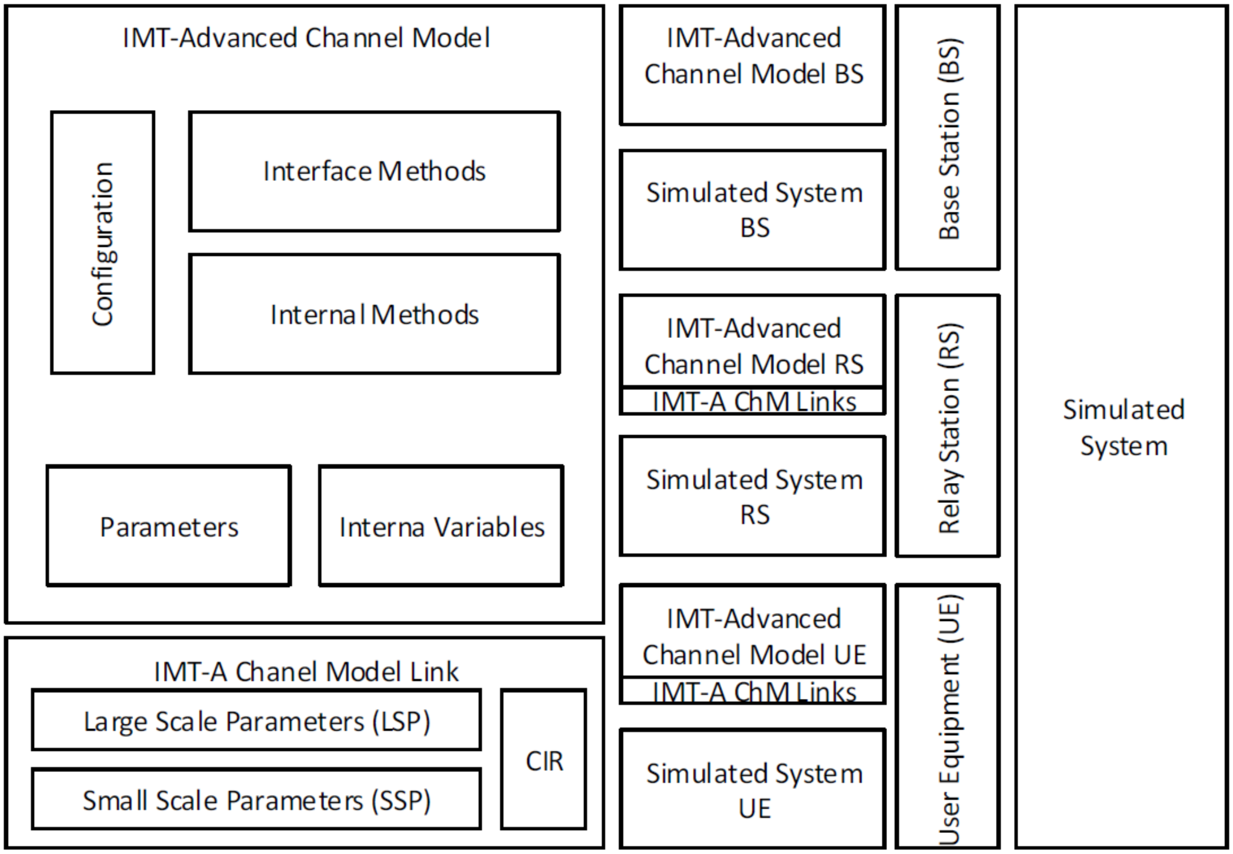


Figure 7-13 Top level architecture of the simulator

7.2.5 IMTAphy

IMTAphy is a A C++ open source LTE / LTE-Advanced system-level simulator with an efficient and fully calibrated ITU IMT-Advanced channel model implementation and a MIMO-capable link-to-system interface. Features of the simulator include:

- LTE / LTE-Advanced system level simulator and full IMT-Advanced channel model implementation
- Available as open-source software free of charge under the GNU GPLv3 license
- Highly efficient C++ implementation relying on openMP and Intel MKL for parallelization
- Calibrated against reference results from 3GPP and other sources (see below)
- Allows simultaneous simulation of uplink and downlink (full duplex) in all ITU IMT-Advanced deployment scenarios
- Round-robin scheduling with power control in the uplink
- Round-robin and proportional fair schedulers based on full closed-loop LTE Rel-8 MIMO feedback (CQI, PMI, and RI)
- Link-to-system model supports linear MIMO MRC, IRC, and MMSE receivers and linear precoding
- Available at https://launchpad.net/imtaphy, installation instructions below.

7.3 Network Simulator

7.3.1 SimulLTE

SimulLTE is an open-source system-level simulator for LTE and LTE-advanced networks. SimulLTE is based on OMNet++ simulation framework.

SimuLTE simulates the data plane of the LTE/LTE-A Radio Access Network and Evolved Packet Core.

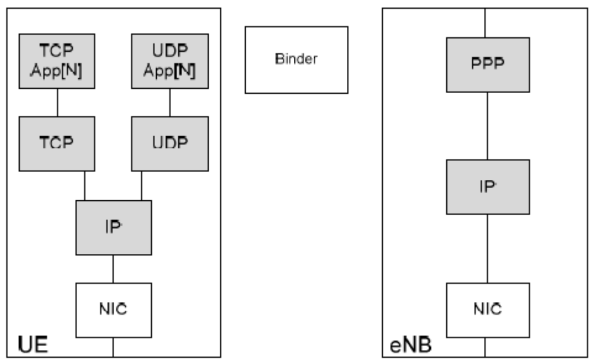


Figure 7-14 Module structure

7.3.2 LENA

LENA is a LTE/EPC network simulator based on NS-3. Target applications for LENA include the design and performance evaluation of:

- DL & UL LTE MAC Schedulers
- Radio Resource Management Algorithms
- Inter-cell interference coordination solutions
- Load Balancing and Mobility Management
- Heterogeneous Network (HetNets) solutions
- End-to-end QoE provisioning
- Multi-RAT network solutions
- Cognitive LTE systems

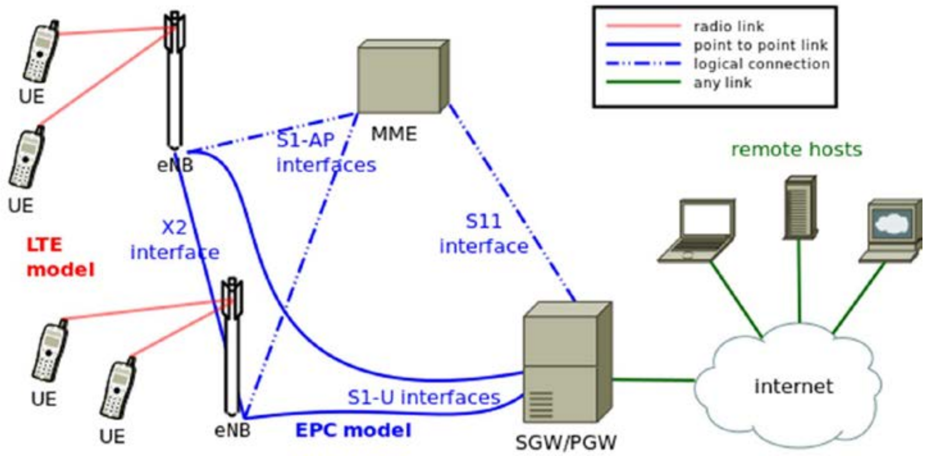


Figure 7-15 LTE Model

7.4 Channel Simulator

7.4.1 NYUSIM

The NYUSIM Channel Simulator provides a complete statistical channel model and simulation code with an easy-to-use interface for generating realistic spatial and temporal wideband channel impulse responses.

7.4.2 IMT-Advanced Channel Simulator

The C-based source code implements the channel model with the network deployment environment according to the ITU-R report M.2135 – the IMT-Advanced Channel Model. The program can be compiled and executed for any platform that supports ANSI C/C++ compilation. It has been tested on the MS Visual C++ environment as well. The program includes some random number generators from, but as it consistently operates according to the input seed, the results are the same regardless of the platforms or the time of execution. The codes are verified against an independent M.2135 implementation in a bit-exact fashion for the deterministic functions. These source codes can be used for the system-level simulation of IMT-Advanced system.

7.4.3 IMTAphy

IMTAphy is a freely available channel model implementation whose large-scale fading characteristics (i.e. path gains and wideband SINR distributions) as well as small-scale fading characteristics (delay and angular spread distributions) are calibrated with IMT-Advanced evaluation reference results. Its runtime performance is significantly better than that of other available implementations.

7.5 Open Source Policy

7.5.1 NS-3

NS-3 is free software, licensed under the GNU GPLv2 license, and is publicly available for research, development, and use.

7.5.2 Vienna Simulators

The simulators are released under the terms of an academic, non-commercial use license. They only provide one license per group with license agreements.

8. Simulator Requirements

8.1 Requirements of 5G Simulators

8.1.1 Characteristics of 5G Simulations

In 5G systems, a new type of simulation methodology may be required due to the emergence of new services and applications, new environments and requirements, new performance indicators, and increased need for end-to-end performance measurements of systems including wired and wireless sections. When compared with 4G simulations, 5G simulations have the following characteristics.

(a) Various application areas, performance indicators, and technologies

5G systems consider diverse applications and various technologies, and a different type of simulation methodology may be used depending on application fields, environments, performance indicators, and technologies.

(b) Increased complexity of simulation and simulator development

The simulation time and memory requirements for 5G simulations may be excessive due to massive MIMO, complicated channel models, and diverse techniques. Also, it takes a lot of time and effort for the development and verification of a simulator due to the high complexity.

(d) Integration or tight interoperation of link level, system level, and network level simulations

Integrated system level and link level simulation may be required to evaluate nonlinear operations such as NOMA in multi-cell multi-user environments. Integration or tight interoperation of system level and network level simulations also may be recommended to accurately evaluate the end-to-end performance considering both wired and wireless sections of a system, since the wireless section may not be the bottleneck in URLLC scenarios.

8.1.2 Requirements for 5G Simulators

Considering the characteristics of 5G simulations mentioned in the above section, 5G simulators may have the following requirements.

(a) Reusability, scalability, and flexibility

High reusability is required to prevent duplicated developments of simulators according to environment and feature changes. High scalability and flexibility is also needed to support various scenarios and technologies in a single simulator.

(b) Multiple levels of abstraction

Since 5G simulation takes a very long time to run, various tradeoffs between the simulation time and the accuracy of results need to be supported for the ease of development and verification. In the early stages of technology development, it is necessary to quickly verify the feasibility of the technology by confirming the performance using a simplified simulator over various environments. Later, the accuracy of results needs to be gradually improved by performing more complete and precise simulations.

(c) Parallel processing

In order to shorten the simulation time without sacrificing the simulation accuracy, parallel processing using multiple cores, hardware acceleration with graphic processing units, and distributed processing using cloud computing should be considered.

(d) Integrated simulator

Link level, system level, and network level simulators may need to be developed in consideration of integration since integration or tight interoperation of 5G simulators enables various types of simulations in accordance with user's requirements in a unified framework.

8.2 Open Source Simulator

8.2.1 Software Requirements

The system level simulator needs to have the following software characteristics:

- Open
- Modular
- Flexible
- Readable
- Extensible
- Easy to understand
- Easy to modify
- Multi-purpose
- Integration or interworking with other simulators
- Optimized

Note that complicated software techniques will not be used since one of the main requirements is to make the simulator easy to understand.

8.2.2 Open Source Development and Management

8.3 Simulator Features

8.3.1 Overview

The functional requirements of the simulator in the final form include the following:

- Basic scenarios and techniques for 4G
- Some of advanced scenarios and techniques for 4G
- Basic scenarios and techniques for 5G

The main purpose of the simulator is not to support all possible features relating to 4G or 5G and the extensibility to various scenarios and techniques is more important. Although we will examine many scenarios and techniques, only a few scenarios will be implemented and provided as examples.

8.3.2 Phase 1 Features

The following scenarios will be considered for phase 1 implementation of the simulator.

- Dense urban single layer
- Dense urban two layers

Table 8-1 Simulator Phase 1 Features

Parameter	Assumption	Comment
Layout	Hexagonal, 19 cells, 3 sectors, wraparound	
Layer	Single layer, two layers	
Band	< 6GHz, > 6GHz (mmwave)	
Channel model	5G channel model	
Mobility	Only channel is affected by mobility Handover is not considered	
Traffic model	Full buffer, non-full buffer	
Scheduling algorithm	Round robin, proportional fairness	
Effective SINR mapping	channel capacity	
CoMP	Not supported	
D2D	Not supported	
V2X	Not supported	
Relay	Not supported	
RRH	Not supported	
LAA	Not supported	

8.3.3 Phase 2 Features

The following scenarios might be considered but will be implemented later.

- High speed train macro only
- High speed train macro + relay
- Urban grid for eV2X macro only
- Urban grid for eV2X macro + RSU
- Highway for eV2X macro only
- Highway for eV2X macro + RSU
- Urban coverage for massive connection
- Extreme long range

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