Document Number: ICT-317669-METIS/D6.1

Project Name:
Mobile and wireless communications Enablers for the Twenty-twenty Information Society (METIS)

Deliverable D6.1

Simulation guidelines

Date of delivery:	31-10-2013	Version:	1
Start date of Project:	01-11-2012	Duration:	30 months

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Project Number:	ICT-317669
Project Name:	Mobile and wireless communications Enablers for the Twenty-twenty Information Society

Document Number:	ICT-317669-METIS/D6.1
Document Title:	Simulation guidelines
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Dissemination Level:	Public
Contractual Date of Delivery:	31/10/2013
Status:	Final
Version:	1
File Name:	METIS_D6.1_v1.docx

Revision History:

Revision	Date	Issued by	Description
01	30-Sept	T6.2	First version of D6.1 ready for review
02	31-Oct	T6.2	Final version after the internal/external revision

Abstract:

This deliverable describes the simulation guidelines that will be used across the METIS project to harmonize the evaluation and simulation work. This document also contains calibration material as well as general simulation considerations for the specific problem descriptions, which are referred to as test cases. The simulation guidelines, calibration and general simulation considerations are of clear importance to the METIS project as they contribute in the coordination and alignment of the work that responds to the societal challenges beyond 2020 by fulfilling the overall technical goals and providing a system concept for the new 5G generation system.

Keywords:

Simulation guideline, simulation calibration, simulation reference case

Executive summary

The overall goal of the METIS project is to lay the foundation for the mobile and wireless system beyond 2020, also referred to as 5G, by providing technical enablers that fulfill the foreseen requirements. The studied technologies should not only be investigated independently, but also be tied to an overall system perspective, e.g. considering the user experience.

Deliverable D6.1 provides simulation guidelines to align assumptions, methodology and simulation reference cases in order to allow for a direct comparison of different technology components. This is to address the need of guaranteeing valid simulation results for the evaluation of the METIS concept at the last phase of the project. In order to ensure consistency of results, a procedure for calibration, guidelines for simulation and a mechanism to support and control the validity for the simulations performed in the technical work within the project is needed. Therefore, this document has the following objectives:

- To establish and follow a rigorous calibration process to ensure that the starting point among partners is the same. The same calibration procedure is proposed for those who are interested in the validation of their simulation platforms.
- To set a first proposal of the simulation reference cases, i.e. simulation guidelines for the test cases given in [1], to be used within METIS.
- To state the simulation guidelines that will be used within the consortium in order to ensure the quality and validity of the simulation results.

The effort of calibration made within this deliverable addresses LTE (Release 8/9) with basic deployment, LTE-Advanced (Release 10/11) with basic deployment, and LTE-Advanced with ultra-dense deployment. Results provide some reference values for the efficiency of currently deployed more sophisticated technologies, that is, LTE. In an urban micro-cellular deployment scenario, cell spectral efficiency resulted to be 1.18 bps/Hz/cell, this number being increased up to 1.85 bps/Hz/cell when considering the more efficient technology defined so far, that is, LTE-Advanced. In LTE-Advanced with a realistic deployment, the cell spectral efficiency is 0.98 bps/Hz/cell. The lower spectral efficiency is due the realistic assumptions using non-optimized RRM algorithms, which results into e.g. sub-optimal selection of cells and frequencies. Hence, this figure is not showing the maximum performance of LTE-Advanced. These numbers represent the baseline scenario to benchmark the new technological components coming from the METIS consortium. More specifically, given that METIS aims at increasing cell spectral efficiency of current technologies, these numbers need to be taken into account. Note that the cell spectral efficiency is not the only performance indicator of interest within METIS. Rather, energy consumption, latency and cost will be also taken into account in the final assessment of candidate technology components [1].

Concerning simulation guidelines, all test cases have been properly characterized, although the simulation work started with test cases 1, 2, 3 and 4, which are now more mature as compared with the rest of test cases.

Contents

List of Abbreviations and Acronyms

2D	Two dimensional
3D	Three dimensional
3GPP	3rd Generation Partnership Project
4G	4th Generation
5G	5th Generation
AD	Application Driven traffic
AF	Amplify and Forward
AMR	Adaptive Multi-Rate
AoA	Angle of Arrival
AoD	Angle of Departure
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
bps	bits per second
BS	Base Station
BAD	Bursty Application-Driven traffic
BUD	Bursty User-Driven traffic
CDD	Cyclic Delay Diversity
CDF	Cumulative Distribution Function
CoMP	Coordinated Multi-Point
CQI	Channel Quality Indicator
CS	Circuit Switching
CSI	Channel State Information
D	Deliverable
D2D	Device to Device communication
DF	Decode and Forward
DL	DownLink
DR	Decode and Reencode
DRX	Discontinuous Reception
DTX	Discontinuous Transmission
eNB	evolved Node B
E2E	End-to-End
EPA	Extended Pedestrian A
ETSI	European Telecommunications Standards Institute
ESM	Effective SINR Mapping
ETU	Extended Typical Urban
EVA	Extended Vehicular A
EVM	Error Vector Magnitude
FDD	Frequency Division Duplexing
FEC	Forward Error Correction
FFT	Fast Fourier Transform
FTP	File Transfer Protocol
GF	Geometry Factor
HARQ	Hybrid Automatic ReQuest
HO	HandOver margins
HSPA	High Speed Packet Access
HST	High Speed Train
HT	Horizontal Topic
IEEE	Institute of Electrical and Electronics Engineers
IFFT	Inverse Fast Fourier Transform
IMT	International Mobile Telecommunication
InH	Indoor Hotspot model
IP	Internet Protocol
IRC	Interference Rejection Combining
ISD	Inter Site Distance
ITU	International Telecommunication Union
ITU-R	Radiocommunication sector of ITU
KPI	Key Performance Indicator
L2S	Link to System
LoS	Line of Sight
LTE	Long Term Evolution
MAC	Medium Access Control
MAP	Maximum A Posteriori
MCS	Modulation and Coding Scheme
METIS	Mobile and wireless communications Enablers for Twenty-twenty (2020) Information Society
MIESM	Mutual Information Effective SINR Metric
MIMO	Multiple-Input Multiple-Output
MMC	Massive Machine Communication
MMSE	Minimum Mean Squared Error
mmW	millimetre Wave
MN	Moving Network
NGMN	Next Generation Mobile Network
NLoS	Non LoS
NRT	Non RT
O2I	Outdoor to Indoor
O2O	Outdoor to Outdoor
OFDM	Orthogonal Frequency Division Multiplexing
OMD	OFDM Modulation/Demodulation
PDF	Probability Density Function
PDSCH	Physical Downlink Shared Channel
PL	Path Loss
PS	Propagation Scenario
PUSCH	Physical Uplink Shared Channel
QoE	Quality of Experience
QoS	Quality of Service
RAT	Radio Access Technology
RB	Resource Block
RLC	Radio Link Control
RSRP	Reference Signals Receive Power
RT	Real Time
RTT	Round Trip Time
Rx	Receiver
SFBC	Space-Frequency Block Coding
SIMO	Single-Input Multiple-Output
SINR	Signal to Interference plus Noise Ratio
SMS	Short Message Service
SNR	Signal to Noise Ratio
SU	Single-User
TC	Test Case
TCP	Transport Control Protocol
TDD	Time Division Duplexing
TS	Traffic to/from Sensors

TTI	Transmission Time Interval
Tx	Transmitter
UE	User Equipment
UL	UpLink
UMa	Urban Macro model
UMi	Urban Micro model
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
VoIP	Voice over IP
VRU	Vulnerable Road Users
VT	Video Traffic
WiFi	Wireless Fidelity
WINNER	Wireless world INitiative NEw Radio project
WP	Work Package
ZF	Zero Forcing

1 Introduction

METIS aims at defining a system concept beyond 2020 for the next generation 5G mobile network. This includes researching the necessary technology components by addressing and fulfilling the identified overall project goals. In this challenging task, 29 different partners are joining experience and efforts to research on the cornerstones for the foundations of 5G. Different approaches and points of view are going to be followed, ranging from basic modulation schemes to changes in spectrum regulation and frequency bands.

In the beginning of the project, we expect participants to pursue individual research based on the METIS scenarios, given in [1]. Each new contribution will be put forward for the project assessment and open discussion. In a later stage, partners should work more together, combining new ideas into more complex functional enablers that will build up the new METIS system concept.

There are some points to be addressed early in the project to guarantee the success of the process described above, namely, the common agreement on simulation reference cases, the methodology and the calibration of the simulations that allow for a direct comparison between the contributions coming from different partners. Only with the ability to validate results, the consortium will be able to identify the most promising proposals. This deliverable D6.1 document serves this purpose by presenting decisions and thoughts on simulation guidelines and alignment that will harmonize and coordinate the evaluation and simulation work within the METIS project.

1.1 Objective of the document

The objectives of D6.1 concerns the entire consortium, since all research activities shall follow the methodology and simulation guidelines established here. In short, the document aims to support and guide the simulation work within the METIS project. The same starting point among partners is ensured by calibration of the respective simulation platforms. Validations of future results within the consortium are prepared for by the introduction of reference case simulation guidelines proposal for each of the test cases within METIS. Further, a set of simulation guidelines that will be shared within the consortium ensure the quality and validity of the simulation results within the entire project.

1.2 Structure of the document

The remaining part of the document is organized as follows:

- Section 2 presents a detailed state of the art study that has been performed to check whether the approach of METIS is well-aligned with the research community. The state of the art comprises two parts, the former referring to the IMT-Advanced evaluation process, and the latter addressing the challenges of beyond 4G systems.
- Section 3 considers three identified calibration settings and the provided reference results for these. The calibration settings are LTE with basic deployment, LTE-Advanced with basic deployment, and LTE-Advanced with a realistic ultra-dense deployment.
- Section 4 provides a short description of simulation guidelines for each test case comprising environmental model, deployment considerations, propagation model, traffic model, mobility model, technology baseline, and key performance indicators.
- Section 5 describes a set of general simulation guidelines together with the proposed methodology for simulation. The aim of the simulation guidelines is to help all partners successfully assess their proposals in order to guarantee the comparability of the obtained results and enable the development of the overall METIS system concept.
- Section 6 summarizes the main conclusions of the document.

In addition to the main body, this deliverable has two annexes. The former describes with details some models that are transversal to several test cases. More specifically, propagation and traffic models are thoroughly described. The latter provides more details on some specific test cases that required special attention.

2 State of the art on simulation of IMT-Advanced and beyond technologies

In order to assess whether new radio technologies fulfill ITU-R's requirements of IMT-Advanced systems [2], system capabilities with respect to several key aspects, such as access to telecommunication services, data rates, Quality of Service (QoS) for a wide range of services and platforms, and user mobility, have to be evaluated. Key features of IMT-Advanced systems are [2]:

- a high degree of commonality of functionalities worldwide while retaining the flexibility to support a wide range of services and applications in a cost efficient manner;
- compatibility of services within IMT and with fixed networks;
- capability of interworking with other radio access systems;
- high-quality mobile services;
- user equipment suitable for worldwide use;
- user-friendly applications, services and equipment;
- worldwide roaming capability;
- enhanced peak data rates to support advanced services and applications (100 Mbps for high and 1 Gbps for low mobility were established as targets for research).

Major performance characteristics evaluated in this context include cell spectral efficiency, peak spectral efficiency, bandwidth scalability, cell edge user spectral efficiency, latency, mobility, handover, and VoIP capacity [2].

In [3], guidelines defined by ITU-R for evaluating candidate system performance from different perspectives, including users, manufacturers, application developers, network operators, and service and content providers are stated. Furthermore, [3] comprises system simulation procedures and methods for determining Key Performance Indicators (KPIs), such as cell spectral efficiency, as well as deployment, traffic, and channel models.

The basic evaluation characteristics and assessment methods for candidate radio interface technology and set of radios interface technologies can be categorized into three classes [4]-[6]:

- analytical (including peak spectral efficiency, control/user plane latency, intra-/inter-frequency handover interruption time),
- simulation (including characteristics such as cell/cell edge user spectral efficiency, VoIP capacity, mobility),
- inspection (including bandwidth and channel bandwidth scalability, deployment possibility in identified IMT bands, support for a wide range of services, inter-system handover).

2.1 Analytical approaches

Analytical methods for deriving specific KPIs are described in [7], where e.g. peak spectral efficiency is determined by extracting the overheads from the maximum total number of transmitted data bits per time unit. Control plane and user plane latency calculations for Frequency Division Duplex (FDD) and Time Division Duplex (TDD) modes of LTE-Advanced operation, which aims at assessing whether the latency complies with the requirements specified by International Telecommunication Union (ITU) for IMT-Advanced wireless communication systems are presented in [8]. In [9] approaches for analyzing handover interruption time in LTE-Advanced for FDD and TDD are shown and technology-specific delays are stated. Besides, an analytical model to calculate cell spectral efficiency of relay enhanced cell deployments in the context of the IMT-Advanced evaluation is presented in [10].

2.2 Simulation-based approaches

In system level evaluations simplified link models are usually used for reducing both complexity and simulation time. Of course, these models should be still accurate enough to allow for capturing the influence of link characteristics on system performance metrics. Mutual information based metrics are preferable and applicable to a large class of MIMO-OFDM transmission techniques, since they manage to represent link level performance with reduced complexity [6][11]. Examples for comprehensive system level simulation platforms that considered all relevant functionalities for evaluating IMT-Advanced candidate technologies are given in [12].

In general, system evaluation methodologies allow multiple evaluation groups to develop their own platforms, while the evaluation of IMT-Advanced system candidates should follow basic guidelines as defined in [3], including the evaluation process and steps of simulation calibration. The calibration steps of LTE-Advanced including system-level and link-level parts are detailed in [4].

Further, comprehensive reports [5][13] on system evaluation methodologies for IEEE 802.16m provide a systematic introduction to modeling relevant system aspects. Detailed information on constructing system and link level channel models, and an overview of several link-to-system models, such as effective SINR mapping (ESM), that allow predicting the instantaneous link performance are stated. In addition, methods for analyzing the influence of link adaptation, HARQ, and scheduling scheme are also presented.

Since multiple antenna techniques are important parts of new communication systems, [14][15] have developed mathematical models for evaluating MIMO performance on system level which allow to calculate system performance measures such as spectral efficiency.

Although system level simulation is an established method to evaluate the performance of complex systems, it faces challenges like excessive simulation run time, model imperfections, or possible implementation errors. Therefore, an analytical evaluation process has been brought up to verify simulation tools by calculating the SINR distribution and then mapping of SINR to data rate [16].

3GPP has also defined some system simulation scenarios in [17], where some baseline assumptions used for LTE-Advanced evaluations, such as system deployments, channel models, traffic models, scheduling schemes, and antenna patterns, are summarized.

2.3 Evaluation of beyond 4G technologies

Current channel models, such as ITU-R pedestrian and vehicular, are only reasonable approximations for conventional above rooftop antenna deployments, where UEs are far away from the transmitting antenna or base station. In particular, these models lack the incorporation of elevation aspects with respect to transmit and receive antennas. For evaluating beyond 4G technologies, where massive and ultra-dense antenna deployments are to be expected, more precise and realistic channel models that take the elevation dimension and the resulting changes in radio propagation into account are required.

Scenarios where it is important to incorporate three dimensional aspects for channel modeling are discussed in [18]. Base station, UE and building heights are considered for the extended channel models in a baseline environment, referred to as “Manhattan grid”, which models the location of streets and buildings. Furthermore, deployment assumptions with respect to the described scenarios for network nodes and UEs are also given.

In [19], issues for 3D channel modeling are stated. A concept for modeling signals propagating outdoor along two main propagation paths, around buildings and above rooftops, is established. The current ITU-R based channel models can be exploited to separately model these two main paths: the UMi model [17] for around building propagation and the UMa model [17] for above rooftop propagation. Then, the channel impulse response is obtained as the union of all “clusters”. It is also proposed to develop a reciprocal channel model that works for general BS, building and UE heights. Unlike current ITU-R based channel models where a stochastic model for determining LoS/NLoS conditions is used, [19] also proposes a new LoS/NLoS model that depends on transmitter/receiver and building heights and that is able to remove discontinuous jumps in path loss level over geographical locations due to switching of LoS/NLoS state. Moreover, the direction and location of streets need to be taken into account to accurately model path loss as well as angular characteristics.

In order to transfer current channel models to 3D channel models with minimal changes, [20] defines the elevation angle spread and median elevation angle at the eNB and UEs. Further, detailed information on creating a 3D channel model by using a 2D ITU-R channel model as a basis are stated. To show the influence of channel modeling in conducting system performance evaluation, [21] simulates UE specific elevation beam selection using three different models for elevation angular spread. It is demonstrated that very different results in terms of system performance gains are obtained by different models, therefore contributing to the conclusion that appropriate modeling of elevation angular spread is crucial in order to yield relevant results.

A critical resource of any wireless communication system is available spectrum. It is viewed as one of the main constraints for system capacity. Therefore, much effort has been put into studying means for increasing spectral efficiency. In last few years, the concept of low power nodes has attracted many research interests, since spectral efficiency can be dramatically increased by implementing this concept. In [22] and [23], the baseline evaluation methodologies for femto cell networks are provided, where link level simulation parameters, network deployment, and performance metrics for femto cells are stated.

In [24], the simulation assumptions and the results of the system simulator calibration activities regarding advanced relay concepts can be found. Common assumptions and guidelines for deployment scenarios, traffic models, and link parameters are provided for aligning system and link level simulations. Besides, reference signal received power (RSRP) and geometry factor (GF) are considered as key performance indicators for calibrating simulators.

In [25], a few classical settings, involving models for the fading and metrics which have served the research community for years are examined to determine whether they remain adequate in light of the rapid advances experienced by the wireless communication systems of today. Ergodic settings and Quasi-static settings are mentioned as the two most common classical settings used to model the fading dynamics. However, since wireless systems have evolved significantly compared with the time when these settings were defined, [25] addresses how these settings are impacted by features of current wireless systems, for instance, link adaptation, HARQ, wideband signaling and operating point. Therefore, it brings up new ideas for different way of modelling link level simulation tools. Also, to circumvent the main obstacle in evaluating the trade-off between bit rate and outage probability, some factors are considered as the convenient expressions for proxy metrics, e.g. diversity order (as indicator for the outage probability), the multiplexing gain (as indicator for the bit rate), and the trade-off between them.

A world with more base stations than cell phones can be foreseen in 10 to 20 years due to the deployment of heterogeneous networks [26]. Since small BSs will often be lightly loaded while others (the macro-cells) will be very heavily loaded, the congestion and load mostly determine the achieved rate. [27] recommends to stop measuring performance with BER or SINR distribution, or with spectral efficiency. Instead, use the rate distribution or area spectral efficiency as better metrics. Besides, since little information is yet available about picocell or femtocell deployments, it is proposed to exploit Poisson point process to demonstrate the best statistical model.

2.4 Positioning of METIS with respect to the SoA

After the state of the art analysis, it can be concluded that METIS is the first joint action to address the evaluation of beyond 2020 technologies in a holistic manner. The test-case-driven approach, with the associated evaluation methodology and evaluation criteria, is innovative and relevant. The usage of these test cases for the evaluation of beyond 2020 technologies is a true opportunity to bring new knowledge to the research community with respect to simulation.

Concerning channel modeling, from METIS point of view, ray-tracing approach is the preferred option whenever the computational burden is manageable. In large and complex deployment, new alternatives for 3D modeling should be studied keeping in mind the tradeoff between realism and implementation complexity. Annex in Section 8 proposes some propagation modeling alternatives that, being much simpler than ray tracing, still allow for a proper characterization in real environments.

3 Simulator calibrations

3.1 Link level calibration

No system level simulation can be built without an accurate characterization of the radio link by means of link level simulations. The implementation of the link level simulator is very arduous and difficult to draw out, since the whole transmission and reception chain of the system must be implemented. It entails, after all, designing a software prototype of the base station and the mobile terminal lower layers. To foster competition among mobile manufacturers, the receiver design is not specified. Therefore, it is quite important to define a reference receiver that allows replication of results.

This section describes in detail a step-wise approach to execute the calibration process for a LTE link level simulator. The methodology is based on breaking down the entire simulation chain of a link level simulator into its single building blocks.

Once the basic functional blocks have been derived, it is possible to identify subsets of functionalities, which will be defined as macro-blocks. These macro-blocks can be assessed both independently and on an End-to-End (E2E) basis. The first step of the calibration process is to verify the correctness of each single macro-block adding additional functionalities to the complete simulation chain in each step of the calibration.

Downlink and uplink are simulated separately. For each calibration step, a proper reference for cross-checking is proposed. Then, in a second phase of calibration, the entire simulation chain with all functionalities should be aligned to a valid reference for the considered system configuration. In particular, for this latter phase some references from the 3GPP LTE Release 9 specifications are proposed [28].

The next five subsections describe a set of five calibration steps defined for the downlink. Section 3.1.6 deals with the specific calibration of the uplink, and Section 3.1.7 explains the end-to-end calibration process of LTE performance aligned with the 3GPP. Figure 3.1 summarizes the overall calibration process.

3.1.1 OFDM modulation

The first step (step 1) of the calibration process consists in the validation of the OFDM Modulation/Demodulation (OMD) unit. In order to do so, it is necessary to focus only on the inputs and outputs of this macro-block (i.e. no coding/decoding functionalities will be considered in this case) and to make some assumptions on the system parameterization.

The following assumptions are suggested for the calibration of the OMD unit. The propagation channel is fixed and ideal channel estimation is assumed with a ZF receiver. Both an AWGN channel and a Rayleigh fading channel should be considered in the assessment of the OMD unit. The curves obtained by simulation in this first step should overlap the theoretical reference curves that can be found in literature (see, e.g., [29]).

3.1.2 Channel coding

In the next step (step 2) the coding functionalities of the LTE system must be included in the link level simulator. The turbo coding performance depends highly on the turbo block size. Hence, the actual PDSCH frame structure must be implemented and different RB allocations have to be tested in all calibration steps after OMD unit calibration.

Since the results obtained in this second step of calibration are LTE-specific, it makes sense to refer directly to the 3GPP documentation to perform the best-suited benchmark. In [30] turbo coding is evaluated assuming an AWGN channel, a ZF receiver and a maximum of only one HARQ transmission, for different coding rates and number of RBs allocated to the transmission. Once this step is assessed, the FEC macro-block based on turbo coding is included in all the rest of calibration steps.

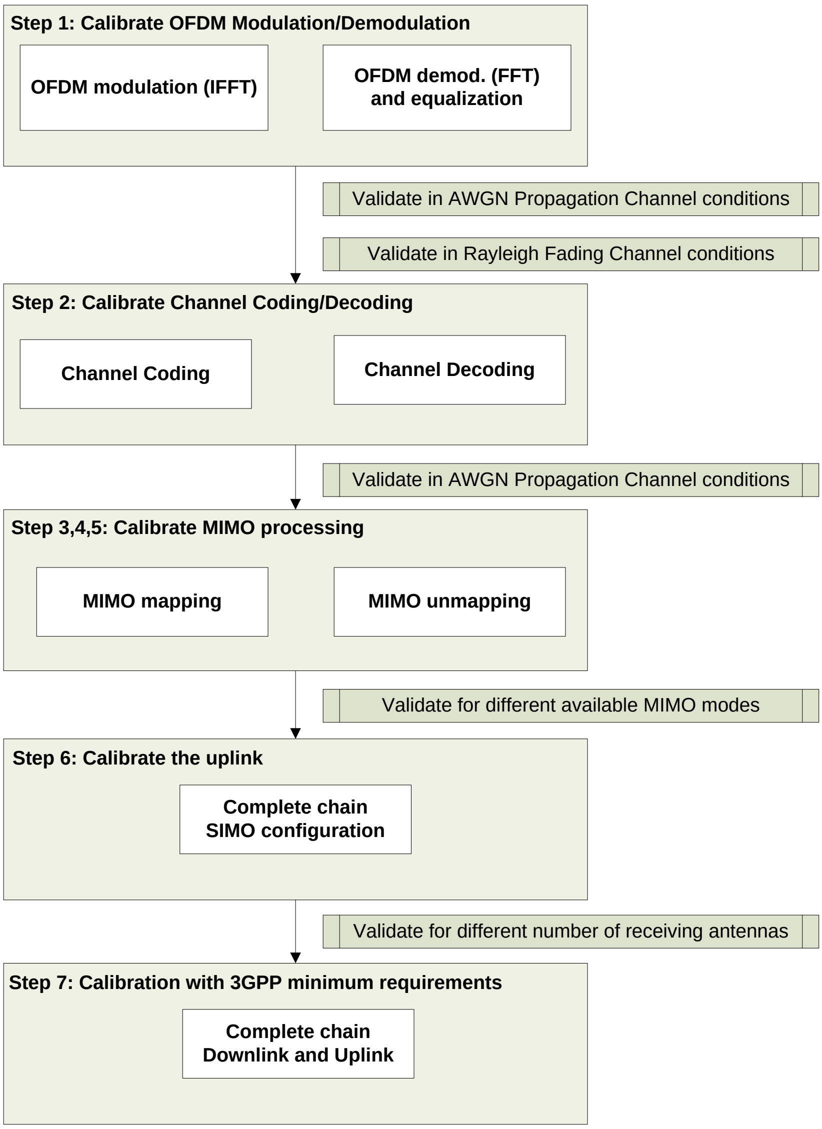

Figure 3.1: Link Level calibration process

3.1.3 SIMO configuration

In the next step (step 3) the entire transmission chain should be simulated with the channel model included. The following assumptions are suggested for this calibration step: a fixed bandwidth of 10 MHz –50 RBs– is simulated assuming the realistic channel estimation and different channels –EPA, EVA and ETU [31]– with a SIMO 1x2 configuration [32]. The scenario could be validated through a direct comparison with the minimum requirements specified by the 3GPP in [28]. This validation refers to a threshold value for the system throughput for a given SINR value. Other 3GPP internal references are recommended in this validation step. Specifically, in [33] an extensive collection of results from different manufacturers are shown and compared following the same recommendations made in this section.

3.1.4 MIMO configuration: Transmit diversity

Similarly, the fourth step (step 4) validates the system by a direct comparison with the 3GPP minimum requirements [28]. The simulation assumptions for the calibration of the transmit diversity scheme proposed in LTE includes a MIMO 2x2 configuration with space-frequency block coding (SFBC), maximum bandwidth of 10 MHz, realistic channel estimation and a ZF receiver. More details on these assumptions can be found in [34], whereas the 3GPP results used for calibration are summarized in [35].

3.1.5 MIMO configuration: Spatial multiplexing

In the fifth calibration step (step 5) spatial multiplexing simulations are assessed. These can be divided into open loop and closed loop scenarios. In case of open loop, Large-delay Cyclic Delay Diversity (CDD) precoding must be implemented following the 3GPP standard. Although minimum requirements for two antenna configurations –2x2 and 4x2– are provided in [28], a more detailed set of results can be found in [36] and [37], respectively. On the other hand, in case of the closed loop scenario, single layer and multiple layer spatial multiplexing configurations must be calibrated. Some specific results with 4x2 MIMO are summarized in [37].

3.1.6 Special characteristics of the uplink channel

With the previous five steps, the macro-blocks of the complete downlink chain have been fully validated. The next step (step 6) consists in assessing the system in the uplink using the PUSCH (Physical Uplink Shared Channel) channel. Obviously, the same five steps described for the downlink could also be valid for the reverse channel taking into account the particular characteristic of the DFT-precoded OFDM that exist in this direction. Provided the macro-blocks testing, the calibration process will continue with the complete uplink transmission chain. The simulation assumptions will include a SIMO 1x2 antenna configuration, realistic channel estimation based on MAP, MMSE receiver and complete channel modeling. This simulation scenario corresponds to the one proposed in [38]. The minimum requirements for PUSCH are provided in the specification [39]. For the validation purpose it is suggested to refer also to the 3GPP detailed results gathered in [40].

3.1.7 3GPP minimum requirements of the whole chain

Once the block-wise validation described above has been fulfilled, the entire simulation chain should be aligned to a valid reference for the particular system under consideration. This task can be based on the direct comparison of the end-to-end link level simulation results with other outcomes provided by the research community, using common simulation scenarios.

In particular, the 3GPP LTE Release 9 framework can be used as a reference for the E2E system performance comparison, by considering the minimum values provided in [28]. To get started, the simulator parameterization should be aligned with that of Common Test Parameters proposed in [28] and [39] and refer to the demodulation of PDSCH/PUSCH for the FDD case and/or for the TDD case (depending on the duplexing mode that has been implemented in the simulator), in the following configurations: (1) Single-antenna port, (2) Transmit diversity, (3) Open-loop spatial multiplexing and (4) Closed-loop spatial multiplexing.

If possible, one should refer to each of the above configurations. For each selected configuration, one should refer to at least one significant reference channel (defined in [28] and [39]) so to vary among the different tests: propagation conditions, modulation and coding schemes (MCS) and number of used antennas. All propagation conditions (EPA, EVA, ETU, HST) are defined in [28].

Once the simulations have been performed, the obtained results (expressed in terms of 70 % fraction of maximum throughput versus SNR) should be compared with the minimum performance values reported in [28] and [39], for the PDSCH and PUSCH respectively.

3.2 Multi-link level calibration

The METIS project will pay special attention to the assessment of multi-node and multi-hop transmission techniques. Multi-link level simulations are beneficial for that purpose, since they provide more details as compared to system simulators, and they are useful for providing models to be used in system level simulations. Therefore, it is important to perform multi-link level calibration activities. Note that the calibration of the basic system blocks in a multi-link scenario is identical to the method for the single-link case described previously. Therefore, one should refer to the previous sections for the calibration of the OFDM modulation, channel coding and SIMO/MIMO processing stages in a multi-hop setup.

This section focuses on the calibration of some of the most representative protocols for cooperative multi-hop transmission, which can be used as a starting point for further contributions on this topic.

A comprehensive comparison of multi-hop protocols was carried out in [41], [42] and [43], where the following protocols for two-hop relaying are considered:

- Amplify-and-forward (AF) transmission: The relay acts as an analog repeater and transmits a scaled version of its received noisy signal.
- Decode-and-forward (DF) transmission: The relay decodes the signal received from the source, re-encodes it and retransmits a regenerated copy of the same signal. We can further differentiate between fixed DF transmission, where the relay always forwards the processed version of the received signal, and adaptive DF transmission, where the relay can decide whether to forward the processed signal. The decision of adaptive protocols is usually made depending on the reliability of the signal received from the source by evaluating the fading coefficient of the source-relay channel.
- Decode-and-reencode (DR) transmission: In this case, the relay decodes the signal received from the source and constructs a new codeword different from the received one. This way, incremental redundancy is provided to the destination. Again, this protocol can work in either a fixed or an adaptive manner.

Analytical expressions to calibrate the outage probability of the different protocols can be found in [41][42]. Also, performance results for different end-to-end spectral efficiency values and relative positions of the relay are given. In addition, a calibration based on bit-error-rate performance can be done using the results in [43] as a reference.

3.3 System level calibration

3.3.1 Calibration case 1 - LTE with basic deployment

This is the minimum configuration of the system. The main assumptions are taken from 3GPP and ITU-R work [22][44], focusing on the Urban micro-cell case, as shown in the next table.

Table 3.1: Simulated cases for calibration case 1

Case	Carrier [GHz]	ISD [m]	Tilt [º]	Bandwidth [MHz]
Urban micro-cell scenario	2.5	200	12	FDD:10+10

Table 3.2 summarizes the characteristics of the system.

For calibration, the following performance metrics need to be considered:

- Cell-spectral efficiency
- Cell-edge user spectral efficiency
- Cumulative distribution function of the normalized user throughput
- Cumulative distribution function of the SINR. SINR will be collected after the MIMO decoder, thus resulting in a single SINR value per resource element allocated to the user. The final SINR per user is calculated as the linear average of all these values.

For calibration purposes, the following results are provided (see Figure 3.2 and Table 3.3). Note that, for the sake of clarity, Figure 3.2 plots the average of the obtained distributions.

Table 3.2: Other simulation assumptions for calibration case 1

Issue	Assumption	Additional Information
MIMO	1x2	Receiver diversity
Scheduling	Round Robin	
Cell selection	1 dB HO margin	
Traffic Model	Full Buffer	
Interference Model	Explicit	
CSI feedback	Realistic	5 ms period (5 RBs) Follow standard
SINR estimation	Perfect	
Feeder loss	2 dB	
Duplex	FDD	
Links	DL	
L2S Modelling	MIESM	
Control overhead	3 OFDM symbols	
Receiver Type	MMSE	

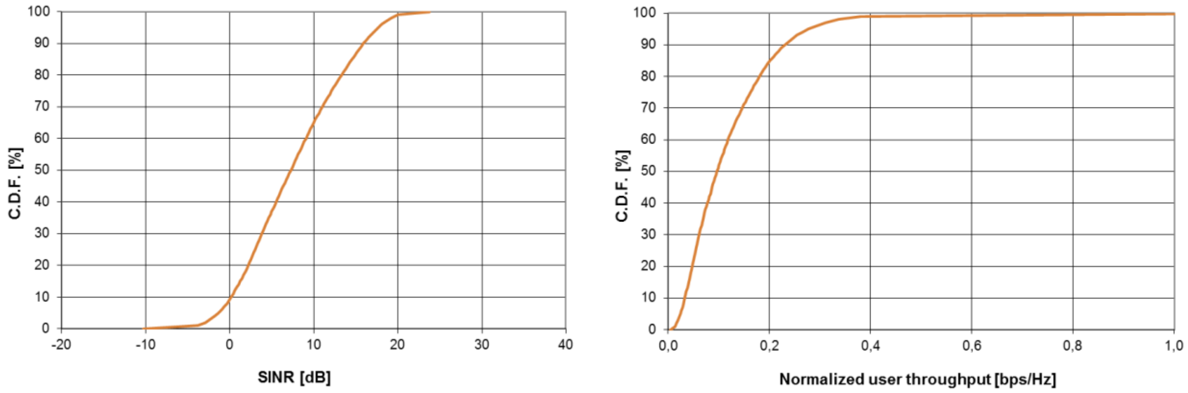

Figure 3.2: SINR and normalized user throughput distribution for calibration case 1

Table 3.3: Results obtained for the calibration case 1

Parameter	UPVLC	E///	NSN	ALUD	Nokia	Average
Cell spectral efficiency [bps/Hz/cell]	1.2077	1.1735	1.1744	1.1861	1.19525	1.187
Cell edge user spectral efficiency [bps/Hz]	0.0267	0.0231	0.0267	0.0232	0.0151	0.023

3.3.2 Calibration case 2 – LTE-Advanced with basic deployment

This calibration case has been defined for two reasons. First, given that in METIS the baseline system is based on 4G technologies, the reference scenario for METIS will be based on the assumptions made by 3GPP for the evaluation of IMT-Advanced [22]. Basic simulation assumptions for this calibration case can be found in [44]. Second, this scenario allows METIS partners to check the validity of the implementation of multi-rank MIMO schemes.

Table 3.4: Simulated cases for calibration case 2

Case	Carrier [GHz]	ISD [m]	Tilt [°]	Bandwidth [MHz]
Urban micro-cell scenario	2.5	200	12	FDD:10+10

In order to update this baseline system to the most updated version of 4G technologies, the assumptions summarized in Table 3.5 for the improvement of LTE-Advanced will be assumed.

For calibration, the following performance metrics need to be considered:

- Cell-spectral efficiency
- Cell-edge user spectral efficiency
- Cumulative distribution function of the normalized user throughput
- Cumulative distribution function of the SINR

For calibration purposes, Figure 3.3 and Table 3.6 show the calibration status within METIS project. The observed differences are due to the different implementation of the SU-MIMO mechanisms. However, results show a good alignment.

Table 3.5: Other simulation assumptions for calibration case 2

Issue	Assumption	Additional Information
MIMO	4x2	SU-MIMO scheme
Scheduling	Proportional Fair	5 users per subframe (at most) Priority to retransmissions Weight factor = 0.001
Cell selection	1 dB HO margin	
Traffic Model	Full Buffer	Other traffic models in a second round
Interference Model	Explicit	
CSI feedback	Realistic	5 ms period (5 RBs)
SINR estimation	Perfect with synthetic error	error → lognormal 1 dB std
Feeder loss	2 dB	
Duplex	FDD	
Links	DL	
L2S Modelling	MIESM	
Control overhead	3 OFDM symbols	
Receiver Type	MMSE	With intercell interference suppression capabilities

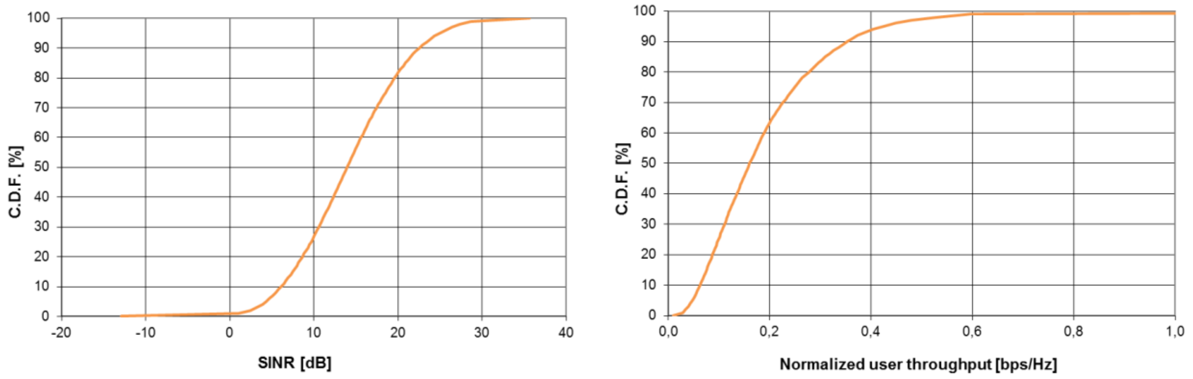

Figure 3.3: SINR and normalized user throughput distribution for calibration case 2

Table 3.6: Results obtained in the calibration process

Parameter	UPVLC	E///	Nokia	DCM	ALUD	Average
Cell spectral efficiency [bps/Hz/cell]	1.8458	1.8762	1.9469	1.9305	1.712	1.8623
Cell edge user spectral efficiency [bps/Hz]	0.0618	0.0446	0.0426	0.0424	0.0392	0.0461

3.3.3 Calibration case 3 – LTE-Advanced with ultra-dense deployment

A major objective of calibration case 3 is to provide calibrated models that serve as a good basis for modeling a range of test cases of D1.1 [1], in particular the Dense urban information society (TC2), Virtual reality office (TC1), Shopping mall (TC3) and Stadium (TC4) test cases of D1.1. This motivates a mix of macrocellular and microcellular outdoor deployments together with femtocellular indoor deployments.

For future dense deployments, it is foreseen that the distance between nodes is such that a 2D deployment model cannot capture the characteristics of the studied scenario. In the dense urban deployment considered in this calibration scenario, the height of high-rise buildings can be larger than the distance between the macro base station and the building. For this scenario, the 3D propagation model developed in METIS should be used.

For calibration purposes, we focus on a LTE-Advanced dense urban macro deployment. The network for this calibration case is close to the deployment scenarios defined in ITU and 3GPP and, therefore, is suitable to do the calibration in order to capture the new 3D deployment and propagation aspects. The LTE network is assumed to be configured as in calibration case 2 described in Section 3.3.2. The calibration scenario is a realistic baseline for METIS that represents what is possible with current technology. Calibrations done towards this calibration scenario are suitable for comparison with technologies developed within METIS.

In this scenario, the LTE-Advanced case in Table 3.5 in Section 3.3.2 above is extended with 3D modeling in a random city. The main difference in comparison with Table 3.5 is the use of single flow transmission. The model is a simplified version of TC2 in which the scenario is reduced to only four buildings, as illustrated in Figure 3.4. As compared with TC2 other simplifications are applied, being these simplifications summarized in Table 3.7. Concerning the radiation pattern of macro and microcells (femtocells are omnidirectional), vertical plane is represented as [45]

$$A_{E,V}(\theta) = -\min\left[12\left(\frac{\theta-90^{\circ}}{\theta_{3dB}}\right)^{2}, SLA_{V}\right], \theta_{3dB} = 65^{\circ}, SLA_{V} = 30,$$

whereas horizontal plane is calculated as

$$A_{E,H}(\theta) = -\min\left[12\left(\frac{\varphi}{\varphi_{3dB}}\right)^{2}, A_{m}\right], \theta_{3dB} = 65^{\circ}, A_{m} = 30.$$

The combination of both planes is $A_{E}(\theta,\varphi) = -\min\left\{-\left[A_{E,V}(\theta) + A_{E,H}(\varphi)\right], A_{m}\right\}$.

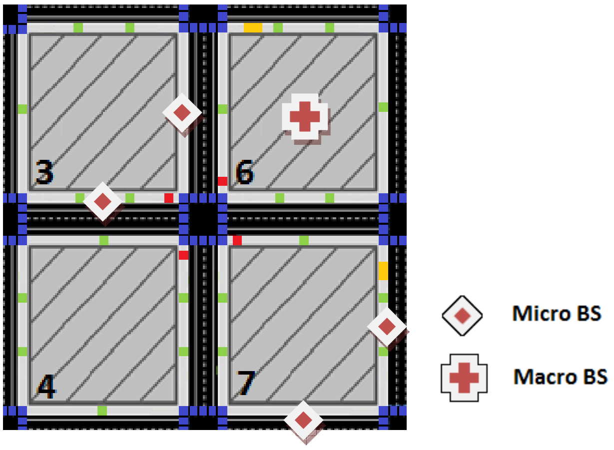

Figure 3.4: Calibration case 3, macrocellular (cross) and microcellular (diamond) deployment

Table 3.7: Calibration case 3, deployment details

Calibration parameters	
Deployment:	4 buildings 120 m x120 m each with 6 floors (3.5 m height) Sidewalks and parking lanes surrounding each building as in TC2 environment. Two lanes, one per direction, between buildings. Sidewalks and lanes are 3 m wide.
Macro BS	Height: 5 m above the top of building 6 Carrier: 800 MHz Bandwidth: 20 + 20 MHz Antenna gain: 17 dBi 3 sectors, 0º, 120º and 240º with respect to the north Tilt: electrical 12º, mechanical 0º. Antenna configuration: 4 transmit/receive antennas. Transmit diversity, single flow. Calculation of user direction for antenna pattern: direct.
Micro BS	Height: 10 m above the ground close to middle point of south and east walls of buildings 3 and 7. Carrier: 2.6 GHz Bandwidth: 80 + 80 MHz Antenna gain: 17 dBi 2 Sectors, pointing to the main street with an angle of 20º with respect to the closest wall Tilt: electrical 0º, mechanical 0º. Antenna configuration: 2 transmit/receive antennas. Transmit diversity, single flow. Calculation of user direction for antenna pattern: for users in perpendicular streets, user direction is calculated from the base station to the cross with the main street in which the base station is located.
Femto BS	Height: 3 m above the level of the floor. Carrier: 2.6 GHz Bandwidth: 20 + 20 MHz. There is coexistence (and mutual interferences) with Micro BS. Antenna gain: 0 dBi (omnidirectional) Noise figure: 5 dB Feeder loss: 0 dB Transmitted power: 20 dBm Antenna configuration: 2 transmit/receive antennas. Transmit diversity, single flow.
Indoor deployment	10 femtocells per floor uniformly distributed (see Figure 3.5)
Outdoor users	60 randomly deployed (50 % pedestrian 50 % vehicular)
Indoor users	240 (10 indoor users per floor randomly distributed)
Mobility	Static
Traffic	Full buffer
Cell Selection	Based on received power. There is a positive offset of 10 dB for femtocells, and 5 dB for microcells simulating cell range expansion.

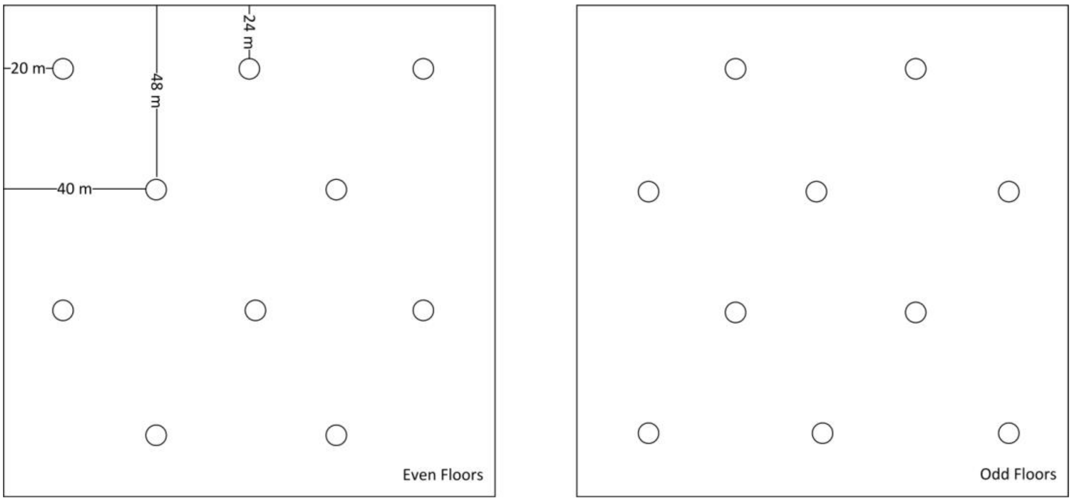

Figure 3.5: Calibration case 3, femtocellular deployment

Propagation models are those of TC2. The rest of parameters are the same as for calibration case 2.

For calibration, the following performance metrics need to be considered:

- Cell-spectral efficiency
- Cell-edge user spectral efficiency
- Cumulative distribution function of the Normalized user throughput
- Cumulative distribution function of the SINR

For calibration purposes, Figure 3.6 shows the calibration status within METIS project. Cell spectral efficiency is 0.9823 bps/Hz/cell, being so low due to the level of detail of the scenario. Finally, cell-edge user spectral efficiency is 0 bps/Hz, motivated by the huge amount of users and the interference levels. Note that SINR distribution is only for those users that indeed transmit in the system and does not collect the reality of the SINR map in the system. For instance, in 10 % of the situation SINR is below -8 dB and this is why 10 % of users cannot transmit.

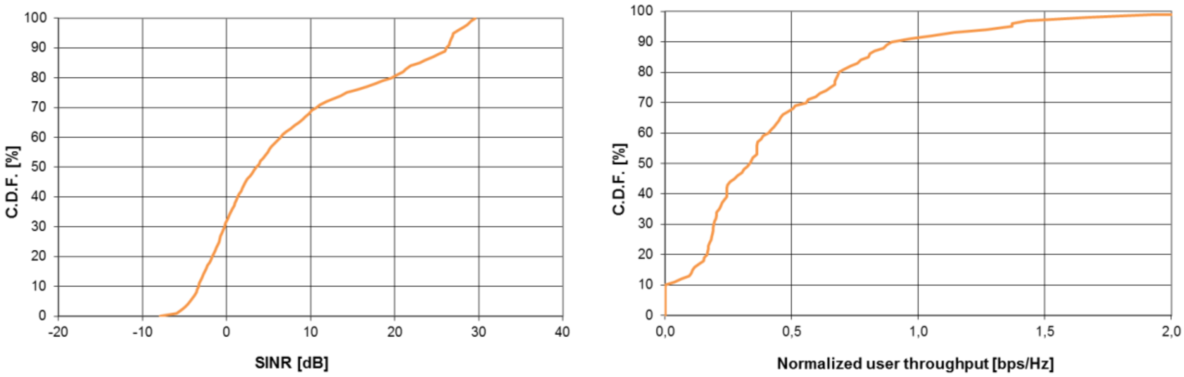

Figure 3.6: SINR and normalized user throughput distribution for calibration case 3

Finally, Figure 3.7 plots a representation of the deployment for the calibration case 3, together with a graph that represents the cell selection process. It can be seen how microcells and macrocell have coverage indoor, thus reducing the effectiveness of femtocellular indoor deployment. In particular, right part of Figure 3.7 shows that there are indoor users connected to the macro –blue– and different micros –green, black, red and cyan–. Of course, other users (mostly indoor but also outdoor) are connected to femtocells –purple–.

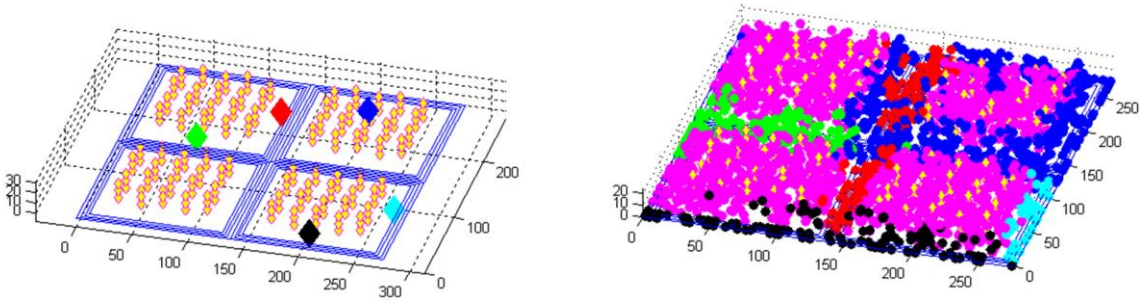

Figure 3.7: Calibration case 3, deployment (left) and distribution of users per cell (right)

4 Simulation reference cases

The simulation reference cases aim to provide a basic setup of simulation assumptions, which could be used for evaluation of solutions provided within the METIS project for different challenges defined in the test case description of D1.1, [1]. Those modeling assumptions should reflect potential setup and status of a real 2020 network up to the best knowledge and predictions available at the time of creation of this document. Following previous terminology used e.g. in the WINNER II project, the reference system design should go in sum far beyond the capabilities of individual simulators and should represent the target to which the simulators need to be developed [46]. In order to provide a framework for a fair comparison of different solutions, but not limit the individual research, various inputs have been collected from the consortium to align the current status of the ongoing technical work. The simulation reference cases, of each specified test case in [1], are presented below, in Section 4.1 to Section 4.12.

Despite of providing information for the complete set of test cases, test cases 1, 2, 3 and 4 were defined first. This is why Section 9 offers a detailed analysis of only these test cases.

Finally, it is worth noting that several resources, including software tools and valid mobility and path loss traces, are publicly available in the METIS webpage[1].

4.1 TC1: Virtual reality office

The Virtual reality office, TC1, is a future indoor setting where improved wireless technologies will provide really high data rates while fulfilling challenging capacity requirements at a reasonable cost.

4.1.1 Environmental model

A realistic office environmental model for this test case is attained by explicitly considering walls, screens, desks, chairs and people. To maintain reasonable cost, there will be only one single backhaul fiber connection. Hence, if applying multiple access points these will have to use in-band wireless backhaul.

The TC1 environmental model reference case within METIS is given in Figure 4.1. In the Annex Section 9.1 this model is described in more detail.

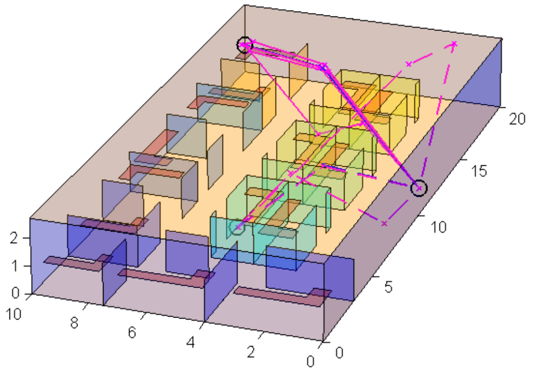

Figure 4.1: A 3D visualization of the Virtual reality office environmental model reference case

Another environmental model that could be considered is an 802.11ad conference room model, see e.g. [47]. This case is not explicitly described here, but could be derived in a similar way as the TC1 reference case.

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[1] https://www.metis2020.com/documents/simulations/

4.1.2 Deployment considerations

The deployment baseline is one main base station ceiling-mounted with fiber backhaul with UEs, as desktop computers, tablets and smartphones, in either a sitting or standing position. A coverage base station working at frequencies below 6 GHz will be located in the center of the office whereas other access points could be deployed to give further capacity to the system.

This scenario is assumed to be isolated from outside interferences.

4.1.3 Propagation model

An indoor propagation model to be used below 6 GHz is the WINNER II A1 model [48], a more detailed description of this model is given in Annex Section 8.1.5.

To attain propagation models at higher frequency regions such as millimeter Waves (mmW), i.e. 30-300 GHz, ray-tracing could be used. In order to perform the ray-tracing, a maximum number of reflections, as well as distance dependencies of free-space loss and material constants for penetration and reflection losses needs to be specified. In Annex Section 9.1 such information is provided for the TC1 propagation model reference case.

4.1.4 Traffic model

The FTP-traffic model in Annex Section 8.2.1 considers file downloads and uploads and is to be used as the TC1 traffic model reference case. For any fixed number of users, e.g. five users, the traffic volume 0.1 Gbps/m^2 translates to a corresponding reading time given the achieved data rates of the users. Hence the reading time should be varied so that the performance at the wanted data volume can be approximated. For the reference case the wanted total data rate is thus:

$$\text{Total rate: } 0.1 \text{ Gbps/m}^2 * 20 \text{ m} * 10 \text{ m} = 20 \text{ Gbps.}$$

Further simulations can be conducted with the video traffic described in Annex Section 8.2.2, either pure or mixed with the above FTP-traffic.

4.1.5 Mobility model

Given the short transfer times of each packet, the users are stationary for the duration of the simulation, e.g. either standing or sitting. The placement of the users is in the reference case defined as a distribution on the possible user positions.

4.1.6 Technology baseline

The technology baseline consists of a LTE-Advanced femtocell and several access points based on WiFi 802.11ad technology using one single channel at 60 GHz shared between downlink and uplink.

4.1.7 Key performance indicators

The key performance indicators are data-rate, delay and data-volume. More detailed KPI description for TC1 is given in [1]. The provided data-rate is to be more than 1 Gbps for 95 % of the office locations and more than 5 Gbps for 20 % of the office locations. The round trip time delay should be less than 10 [ms]. The provided data-volume is to be 0.1 Gbps/m^2 in both downlink and uplink. It is assumed that the UEs, i.e. desktop computers, tablets and smartphones, consume the same data-volume per device.

4.2 TC2: Dense urban information society

The Dense urban information society, TC2, is a future urban setting where the need to handle high traffic volumes and high experienced data rates are necessary in order to fulfil the foreseen requirements at a reasonable cost in these urban regions. The simulation reference case of TC2 is presented below. Note that a much more detailed description is given in the Annex Section 9.2.

4.2.1 Environmental model

The urban environmental model of this test case is made realistic by e.g. considering the different environments of buildings (with entrances), roads, park, bus stops, metro entrances, sidewalks and crossing lanes. These different aspects are captured within, what is referred to as, the Madrid grid environmental model. This model has been developed within the METIS consortium and is based on observations regarding the city structure of Madrid. It is an example of typical European city environment capturing way more aspects then Manhattan grid. The TC2 environmental model, the Madrid grid, is given in Figure 4.2, and is described in more detail in the Annex Section 9.2.1.

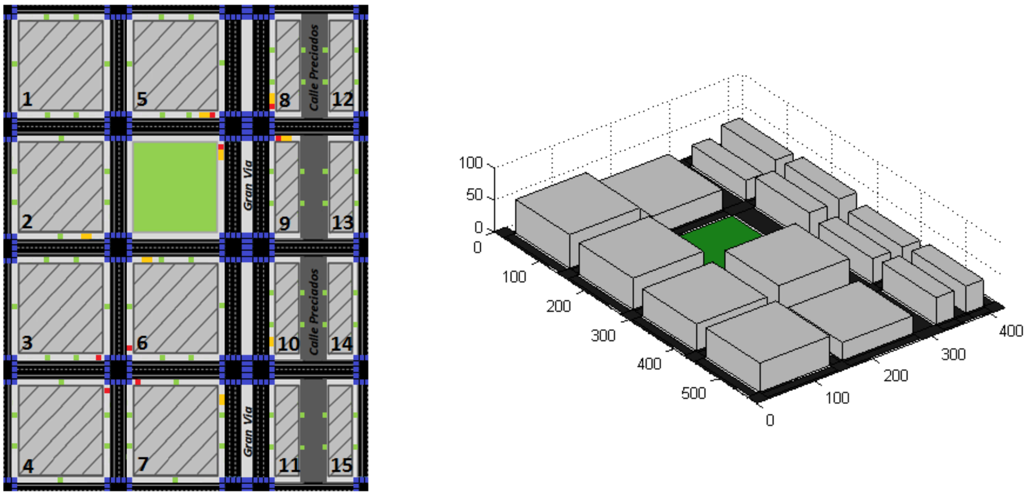

Figure 4.2: A 2D visualization (left) and a 3D visualization (right) of the Madrid grid

4.2.2 Deployment considerations

The deployment baseline is a network infrastructure with a three-sector macro station that is complemented with twelve pico stations, and it is given in the following figure.

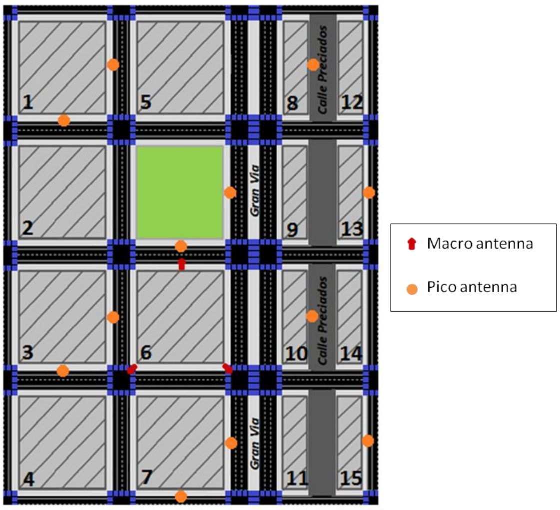

Figure 4.3: The deployment baseline of TC2

The deployment parameter details are given in the Annex Section 9.2.4 where the modelling of interferences is given.

4.2.3 Propagation model

The links where propagation models are needed for this test case are both between a base station and a mobile station as well as between different devices (i.e. D2D). The propagation models do also need to consider whether the communication takes place in an outdoor to outdoor (O2O), outdoor to indoor (O2I), or in a fully indoor environment. The TC2 propagation model details are given in the Annex for each of the relevant propagation scenarios (PS) of TC2 divided into corresponding subsections of Annex Section 8.1.

4.2.4 Traffic model

There are different forms of foreseen traffic within the dense urban information society. The traffic model needs to address these various forms, which are bursty user-driven traffic, video traffic, bursty but more or less permanent application driven traffic, real time video application-driven traffic, and traffic generated by sensors. In addition, the model needs to handle the user location as 75 % are supposed to be indoor users while the remaining 25 % are to be outdoor users on the move. Further, the traffic split, the activity levels, as well as more detailed traffic model specifications, are given in the Annex Section 9.2.2.

4.2.5 Mobility model

The TC2 mobility model needs to consider both indoor mobility and various outdoor mobility situations. In the outdoor, there is pedestrian mobility and vehicular mobility, as well as the possibility to consider the behaviour of the traffic lights. Details, e.g. regarding speeds of the moving objects as well as turning probabilities in the crossings, are specified in the Annex Section 9.2.3.

4.2.6 Technology baseline

The technology baseline is the same as for the system level calibration case number three, which is described in Section 3.3.3.

4.2.7 Key performance indicators

The main KPIs of the Dense urban information society is the end user data rate, the system capacity, various latencies, and the D2D discovery time. The more explicit description of the KPIs and its metrics are given in the Annex Section 9.2.5.

4.3 TC3: Shopping mall

The Shopping mall, TC3, is a setting with a high density of customers and staff that enjoys the benefit of a high quality future radio network that both involves traditional types of communication as well as wireless sensor networks. The test case both captures the need for high traffic volumes, high experienced user data rates, and good availability.

4.3.1 Environmental model

The Shopping mall environmental model is attained by explicitly modeling shops and passage ways. The TC3 environmental model reference case within METIS is given in Figure 4.4. In the Annex Section 9.3 this model is described in more detail.

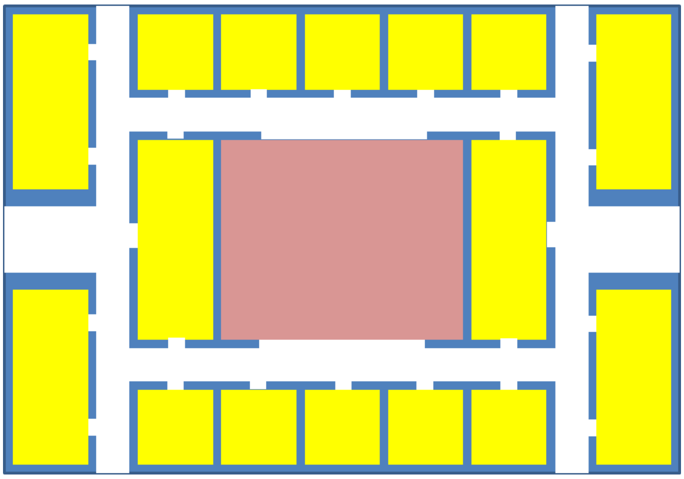

Figure 4.4: A 2D visualization of a 3D Shopping mall environmental model

4.3.2 Deployment considerations

An extra set of pico and femto stations can be assumed to be placed regularly along the passage way within the shopping mall where much of the traffic occurs. In addition, if considering mmW, a relay could be deployed at every store.

This scenario is assumed to be isolated from outside interferences.

4.3.3 Propagation model

The propagation model of the Shopping mall is similar to the Virtual reality office test case, TC1. The indoor propagation below 6 GHz is the WINNER II A1 model, [48], with additional details given in Annex Section 8.1.5. For higher frequency region propagation models, such as mmW, ray-tracing could be used, see Annex Section 9.1 where such information is provided for TC1.

4.3.4 Traffic model

The Shopping mall traffic model considers a file download (or upload) FTP-traffic model, see Annex Section 8.2.1, with a 20 Mbyte packet size for the regular users and 8 kbyte for sensors. It is worth noting that sensors are modeled as packets arriving by a Poisson process to a new random location in the area.

4.3.5 Mobility model

The mobility model is similar to the one used in TC2, and models the mobility of the users in the passage ways. In the shop areas, i.e. the yellow areas in Figure 4.4, users are performing a piece-wise linear random walk. In the food-court area, i.e. the pink area in Figure 4.4, users are performing a piece-wise linear random walk ending up at a random table where a user sits for a certain amount of time, for details see Annex Section 9.3.

4.3.6 Technology baseline

The shopping mall technology baseline is a LTE indoor femto deployment using 20 MHz carrier at 2.6 GHz located at 3 m height above the ground of the passage way.

4.3.7 Key performance indicators

The identified key performance indicators of the shopping mall test case are traffic volume, experienced user data rate, availability. More detailed information regarding KPIs is specified in D1.1 [1].

4.4 TC4: Stadium

Test case Stadium belongs to the METIS *Great service in a crowd* scenario. It represents one of the most challenging use cases for network operators – a mass event with a very high probability of correlated demand for data transfer as a reaction of the stadium audience for the events on the playground. User experience during such events is a true benchmark and performance tests for the stadium’s network infrastructure, not only for the 2020 information society but also for the contemporary service providers.

4.4.1 Environmental model

The environment of TC4 is limited to the stadium area. Proposed approach is modeling a large 3D object occupying a space of roughly 50 000 m^2 (including 100 m x 70 m playground) that is capable of hosting up to 50 000 viewers. Platforms for spectators are roofed and tilted in order to provide a good visibility to the audience, hence appropriate modeling of Stadium requires 3D dimensioning. A 2D visualization is depicted in Figure 4.5 and the details of the environment are provided in Annex Section 9.4.1.

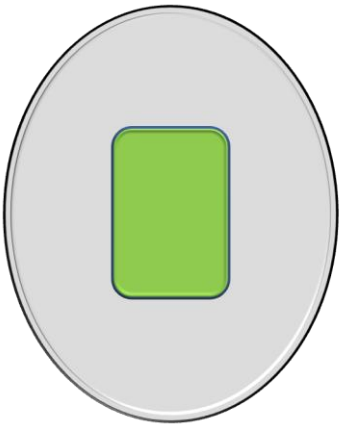

Figure 4.5. Simplified 2D visualization of Stadium environment

4.4.2 Deployment considerations

Network infrastructure is given as a dense network of small cells antennas deployed at the rooftop of the stadium and directed toward the audience. Small cells antennas are connected with optical fiber to a common baseband hotel. To limit intercell interferences small cells antennas are highly directive. Both sub 6 GHz and mmW deployments are allowed for Stadium. For details, see Section 9.4.4.

This scenario is assumed to be isolated from outside interferences unless macro-cellular coexistence was important for the research purposes. Section 9.4.4 gives more details about this interference modeling.

4.4.3 Propagation model

The propagation model for Stadium needs to characterize LOS transmission from the small cell antennas deployed at the deck of the stadium and targeted at the audience. For this purpose an outdoor UMi LOS model will be used as defined in [3]. Additionally, for D2D traffic PS#9 should be used as defined in Section 8.1.6. For further details see Section 9.4.2.

4.4.4 Traffic model

Two most network challenging situations are foreseen for TC4. First situation assume that users want to upload and share the video of recorded event (e.g. goal or some spectacular play). The second case assumes mixture of Video traffic and Bursty User-Driven (BUD) traffic during breaks in the stadium event.

4.4.5 Mobility model

No mobility is assumed for users.

4.4.6 Technology baseline

The technology baseline is the default LTE-Advanced system.

4.4.7 Key performance indicators

Key performance indicator is experienced end user throughput (median, average and cell edge) and also traffic volume density from the simulation evaluation area. The requirement is that users experience instantaneous packet throughput at the speed of 30 Mbps at the availability of 95 % of space and time.

4.5 TC5: Teleprotection in smart grid network

This test case shows main challenges in the low latency and high reliability of the message transfer. The substations, i.e. elements of the smart grid network such as voltage transformers or entities performing other functions related with the generation, transmission or distribution of power, being equipped with communication devices, typically report data periodically with small net payloads of 200 to 1521 bytes. The latency requirements are very tight, in the range of 8 ms over distances of up to 10 km, and the messages need to be conveyed with 99.999 % reliability [1].

System simulations may be conducted with 3GPP or TC2 models, assuming stationary outdoor deployment of the substations. The substations are randomly placed and the substation density is up to hundreds, 15 and 1 substation per km^2 in dense urban, urban and rural environments, respectively [1]. When modeling dense urban environments, we assume a density of 200 substations per km^2. As the TC2 Madrid grid model occupies a surface of about 0.21 km^2 (387 m x 552 m), this results in a number of 42 substations for the Madrid grid, where the substation shall be positioned at random along the building edges.

The major KPIs to be assessed by system simulations are the latency and reliability.

4.6 TC6: Traffic jam

The high occurrence and severity of traffic jams has increased the penetration ratio of in-car digital terrestrial TV receivers in markets. However, the capacity required by this kind of service during traffic jams can easily swamp the capabilities of existing networks. Therefore, this test case captures the challenge of providing good quality network experience for in-vehicle users that utilize bandwidth-demanding services during future traffic jam situations.

4.6.1 Environmental model

In urban scenarios, the Madrid grid model defined in TC2 can be used here, although other Manhattan grid models could apply. In motorway scenarios, a single road of a certain length can be assumed. Since a special scenario of traffic jam is under focus here, a 6-lane highway of length 1 km suffering a traffic jam should be considered in both the motorway and the urban scenarios. An average vehicle length of 5 m and a separation between vehicles of 1 m are used to deploy vehicles. Therefore, a vehicle density of 1000 vehicles per squared kilometer can be derived with a maximum of four active users per vehicle.

4.6.2 Deployment considerations

In urban scenarios, besides a typical deployment defined in TC2, an extra set of base stations can be assumed to be placed regularly along the road where traffic jam occurs. In the motorway scenario, the usual deployment corresponds to the case of 2 sectors per site covering both directions of the motorway and an ISD of 25 km. The vehicular antenna is assumed to be deployed on car rooftop.

4.6.3 Propagation model

As starting point, the 3D propagation model defined in TC2 can be reused here (see PS#9 description in the Annex Section 8.1.6). More specific D2D or V2V propagation models will be developed within METIS.

4.6.4 Traffic model

A data rate of at least 100 Mbps in the downlink and 20 Mbps in the uplink is used to derive traffic model for in-vehicle users. Therefore, the total traffic volume is 480 Gbps/km^2 including downlink and uplink. Traffic model defined for TC2 for in-vehicle users can be used here with special focus on video streaming services.

4.6.5 Mobility model

The mobility model defined in TC2 can be reused here to model the mobility of background users. Regarding in-vehicle users, a user speed less than 3 to 10 km/h is exploited for modeling aspect.

4.6.6 Technology baseline

The technology baseline is the same as TC2.

4.6.7 Key performance indicators

The key performance indicators are data-rate and data-volume. The provided data-rate is to be more than 100 Mbps/user in the downlink and 20 Mbps/user in the uplink with an availability of 95 %. A reliability of 95 % is necessary in order to satisfy the QoE requirements of public cloud services (seamless experience without perceived errors).

4.7 TC7: Blind spots

This test case inspects on ubiquitous capacity demands of future users in blind spots, such as rural areas with sparse network infrastructure or in deeply shadowed urban areas. Since user density is normally correlated with density of vehicles, a very important aspect to be considered in this test case is the high correlation between the distribution of vehicles and users satisfaction. In other words, the higher the data traffic demands, the higher the number of vehicles in the proximities. This property can be exploited to cope with the presence of blind spots in the service area in a flexible and cost efficient manner.

4.7.1 Environmental model

Urban or rural scenario should be separated based on different node density, grid size and radio propagation models. In rural area, 100 vehicles per km^2 and 100 users per km^2 are distributed. These two values are 10 times more in an urban area. A fraction (e.g., 50 %) of the users is randomly distributed near the vehicles. Alternatively, those users can be placed within a radius of 50 m from a vehicle. Vehicles are randomly distributed along the streets or parking areas.

4.7.2 Deployment considerations

Vehicles are equipped with relays, which can be integrated into the infrastructure of the operators. The vehicles are randomly moving or parked on the street of the Madrid grid, and can be configured by the base station for activation and deactivation.

4.7.3 Propagation model

As starting point, the 3D propagation model defined in TC2 can be reused here (see PS#9 description in the Annex Section 8.1.6). More specific D2D or V2V propagation models will be developed within METIS.

4.7.4 Traffic model

The traffic model defined in TC2 for pedestrians can be reused here to model users' behavior in blind spots area. In particular, each user should experience a data rate of at least 100 Mbps in the downlink and 20 Mbps in the uplink. Mostly, video streaming and file downloads are required, corresponding to a very high data rate per user.

4.7.5 Mobility model

Vehicles in movement have a low mobility profile, with a constant speed of 50 km/h, and pedestrian users have low mobility, equal to 3 km/h. Parked vehicles are stationary.

4.7.6 Technology baseline

The technology baseline is the same as TC2.

4.7.7 Key performance indicators

High data rate coverage is expected at every location of the service area, even in remote rural areas. The provided data-rate is to be more than 100 Mbps/user in the downlink and 20 Mbps/user in the uplink with an availability of 95 %. Therefore, it results in a total traffic volume of 12 Gbps/km^2 in a rural scenario and 120 Gbps/km^2 in an urban scenario. Reliability is not in the focus of this test case. Nevertheless, a reliability value of 95 % is assumed to guarantee the QoE of some services, e.g. video service. Regarding energy efficiency, 30 % and 50 % reduction should be achieved as compared with the legacy network.

4.8 TC8: Real-time remote computing for mobile terminals

TC8 focuses on providing real-time access to remote computing and cloud facilities for highly mobile terminals. The main challenge involves providing high data rates and low latency, even in the presence of high mobility. This test case concerns a detailed aspect of TC2, the dense urban information society, since the focus is only on terminals with mobility. As a result, the environment, propagation, traffic, mobility and deployment models assumed for TC2 can all be reused for TC8.

For a detailed list of the KPIs for this test case, please see [1].

4.9 TC9: Open air festival

The Open air festival is a test case that is considered to be situated in a small rural area that only during a few days has lots of visitors. The legacy network infrastructure is thereby highly under-dimensioned. Therefore, the network needs to be complemented in a cost efficient way for this time period. Further details are given in [1].

4.9.1 Environment model

The environment assumed for this test case is an open space in a rural area, which is surrounded by virtually no high buildings. For simulation purposes, a square field, with an area of 1 km by 1 km could be used. A total of ten stages for the festival with equal dimensions should be placed in the field, with the following constraints:

- Each stage has dimensions of 3 m x 5 m x 20 m (height, width, length).
- A minimum distance of 300 m between any two stages.

On average, up to 10 000 people can be assumed per stage with a density of up to four people per square meter.

4.9.2 Deployment considerations

Some temporary infrastructure, in the form of mobile base stations, each with a height of 10 m, is assumed to be deployed around the open field. Several deployment options are possible

- A total of five base stations deployed, with one at the center of the field and the remaining four at each corner of the field.
- A total of nine base stations deployed, with one in the center of the field and the remaining eight distributed around the four sides of the field, with a spacing of 500 m between them.
- A total of twenty five base stations deployed in a grid with a spacing of 250 m.

In addition, up to 10 000 machines and sensor devices are assumed to be randomly distributed in the festival area. The heights for these devices range from 1 to 5 m.

This scenario is assumed to be isolated from outside interferences.

4.9.3 Propagation model

Two kinds of propagation should be modeled:

- Propagation between the base stations and the users (or machines). In case of below 6GHz carrier frequencies, this could be modeled with rural macro cellular scenario of WINNERII (100 MHz bandwidth), WINNER+ or ITU IMT-Advanced channel models (recommended) [44].
- Direct propagation between users or between users and sensors or between sensors should be modeled according to the description in the Annex Section 8.1.6.

4.9.4 Traffic model

Three types of traffic are envisaged in this test case

- Real time traffic – considerations in TC2 can be applied.
- Delay-tolerant traffic – considerations in TC2 can be applied.
- Device communications – uplink data transmissions from devices (vending machines, some specific sensor, etc.), with a payload of 100 kbytes transmitted every ten minutes from each sensor/machine.

In addition, some degree of correlation is expected between the data traffic of users. The ratio of uplink to downlink traffic as well as the mix between real-time and delay tolerant traffic, as well as, global and local traffic can be in line with the specifications for TC2.

4.9.5 Mobility model

Users are assumed to be static for simplicity. For more detailed mobility modeling, a two state mobility model can be used, where users transition between a pause state and a move state. Users are initialized with a given probability to be in one of the two states. The probability can be adjusted to reflect different scenarios at the festival, e.g., during a highlight performance, the probability of pause is expected to be much higher. The pause times are chosen from a heavy tailed distribution with long pause times being more likely. When a user is in a move state, the destination is chosen from a heavy tailed distribution where it is more likely to make short trips than long trips. A fixed speed of 1 km/h is assumed when users move. When the destination is reached, the user again enters into a pause state with a pause time chosen from the pre-defined distribution.

4.9.6 Technology baseline

The technology baseline is the default LTE-Advanced system.

4.9.7 Key performance indicators

The detailed list of KPIs for this test case is specified in METIS deliverable D1.1 [1].

4.10 TC10: Emergency communications

This test case targets the communication expectations after a natural disaster in dense urban environment. The main challenges of this test case are on power consumption and ultra-reliable communications setup.

4.10.1 Environment model

The environment to model is the same as in TC2 but after a natural disaster. The model can be simplified in the sense that 3D buildings will not exist anymore after an earthquake. Building footprints are replaced by 2D rubbles.

4.10.2 Deployment considerations

It is assumed that a natural disaster will destroy up to 90 % of the infrastructures. Consequently, the inter site distance (ISD) in dense urban environments between remaining macro cells increases up to 5 km.

Temporary emergency base stations are expected to be used in this type of situation. Amount of such equipment shall be adapted with their expected capacity.

4.10.3 Propagation model

Three kinds of propagation should be modeled:

- Communications between users below rubbles or communications from first responders using emergency temporary base stations to survivors below rubbles. Specific propagation model might be needed to characterize rubbles properties. An alternative can be to apply a strong penetration loss to Outdoor to Indoor, O2I, propagation model to reflect rubbles loss.
- Communications between first responders who are located outdoor in a devastated dense urban environment.

- Communications between emergency temporary base stations and working Base Stations from commercial networks.

4.10.4 Traffic model

Two type of traffic should be modeled:

- Voice traffic (CS or VoIP) between users below rubbles or communications from first responders using emergency temporary base stations to survivors below rubbles. User density is defined as 10 UE/m^2. This test case targets 10 voice calls and 10 SMS per survivor during a week. Considerations in TC2 can be applied.
- Voice traffic between first responders. Part of this traffic is broadcasted to every people belonging to the rescue team.
- Terminals acting as routers or special emergency nodes should enable a backhaul link with a minimum constant guaranteed bit rate of 1 Mbps for at least one week.

4.10.5 Mobility model

Survivors below rubbles are of course static. First responders have low mobility and can be modeled as pedestrians. This test case does not challenge QoS at high speed.

4.10.6 Technology baseline

The technology baseline is the same as TC2.

4.10.7 Key performance indicators

The detailed list of KPIs for this test case is specified in METIS deliverable D1.1 [1].

4.11 TC11: Massive deployment of sensors and actuators

This test case shows main challenges in the large number of connected devices. The devices typically need only transmit data occasionally with small net payloads, and the latency requirements are moderate, in the range of a few seconds.

System simulations may be conducted with 3GPP or TC2 models, assuming outdoor deployment of the machine devices, where up to 300 000 randomly placed devices per cell shall be supported, and the devices may be stationary or moving e.g. being mounted on a vehicle [1].

For modeling, we assume the maximum number of 300 000 devices being deployed per macro cell area with the 3GPP model, and per (387 m x 552 m) Madrid grid area with the TC2 model.

The traffic model for MMC is described in detail in the Annex Section 8.2.4. We assume a payload of 125 bytes being transmitted with an average period of 5 minutes. With 300 000 devices per macro cell, this results in an average of one payload being transmitted per 1 ms subframe when assuming LTE numerology, and potentially large numbers of transmitted payloads per subframe.

The major KPIs to be assessed by system simulations are the number of devices supported, energy efficiency and coverage. The required coverage is 99.99 %. Precise definitions of the above KPIs can be found in METIS deliverable D1.1 [1].

4.12 TC12: Traffic efficiency and safety

This test case shows main challenges in the required reliability, availability, and latency of automotive safety services.

4.12.1 Environment model

This test case should work in any road environment, whether this is urban, rural, or highway. Therefore, three environment models are suggested in this test case.

- In urban environments, the vehicular devices density can be up to 1000 users per km^2 with vulnerable road user devices density up to 5000 relevant users per km^2. The required communication range is up to 300 m.
- In rural environment, the vehicular devices density can be up to 100 users per km^2 with vulnerable road user devices density up to 150 relevant users per km^2. The required communication range is up to 500 m.
- In highway environment the vehicular devices density can be up to 100 users per km^2 with vulnerable road user devices density up to 150 relevant users per km^2. The required communication range is up to 1 km.

4.12.2 Deployment considerations

All vehicles and vulnerable road users (VRU) devices will eventually be equipped with the METIS system. Cars will have a relative small number of antennas (due to cost reasons), while commercial vehicles (trucks, buses, construction equipment) might have more antennas. The antennas are mounted on the top of the vehicles, which are between approximately 1.5 to 4 meters high, depending on the vehicle type. Some road infrastructure (e.g., road signs, traffic lights) will be equipped with communication modules. For the case of VRU, the number and type of antennas will be those of regular UE (e.g., smartphones).

4.12.3 Propagation model

Vehicle-to-vehicle (V2V) and also the vehicle-to-vulnerable road user (V2VRU) channel are examples of D2D channels that can be modelled according to the description in Section 8.1. The vehicle-to-infrastructure (V2I) channel can be modelled using more traditional cellular channel, since the road infrastructure is not mobile and has antennas that are usually placed at some height.

4.12.4 Traffic model

Traffic model specific for traffic safety issue includes both periodic and event-driven broadcast traffic defined as:

- Periodic broadcast traffic consisting of at least a payload of 1600 bytes (for transmission of information related to 10 detected objects resulting from local environment perception and the information related to the actual vehicle) with repetition rate of at least 5 to 10 Hz. For communication between vehicles and VRU, a payload of 500 bytes may be sufficient (for transmission of the information from the actual consumer electronics device, such as current position and additional data from the device sensors). The traffic generated by each vehicle has to be delivered to all the neighbouring vehicles and VRU devices within the specified range.
- Event-driven broadcast traffic consisting of at least a payload of 1600 bytes with repetition rate of at least 5 to 10 Hz (for transmission of information related to 10 detected objects resulting from local environment perception and the information related to the actual vehicle). For communication between vehicles and VRU, a payload of 500 bytes may be sufficient (for transmission of the information from the actual consumer electronics device, such as current position and additional data from the device sensors). The event-driven messages have to be delivered to all the vehicles and VRU devices in the service area.
- Both traffic types (periodic and event-driven) can exist at the same time. Note that the repetition rate of both traffic types is determined by the need of tracking changes in the environment.

4.12.5 Mobility model

Three different mobility environments need to be distinguished: Urban, rural, and highway.

- Urban: maximum absolute velocity of 60 km/h and 120 km/h relative velocity between vehicles.
- Rural: maximum absolute velocity of 120 km/h and 240 km/h relative velocity between vehicles.
- Highway: maximum absolute velocity of 250 km/h and 500 km/h relative velocity between vehicles.

VRU velocities range from 3 km/h (pedestrian) up to 30 km/h (bicycle).

4.12.6 Technology baseline

The technology baseline LTE-Advanced for rural and highway and the same as TC2 for the urban scenario.

4.12.7 Key performance indicators

A maximum network end-to-end delay (including device detection, connection setup and radio transmission) of 5 ms with transmission reliability of 99.999 % should be guaranteed to deliver the drive safety service. Besides, 100 % availability is required such that the services are present at every point on the road.

5 Simulation guidelines

METIS will investigate future technology components for different scenarios and test cases. The technology components should be assessed in such a way that the project KPIs can be evaluated to quantify the capabilities of the METIS system concept. To be able to compare the simulation evaluations, an agreement on how to conduct and document simulations is needed. This agreement and the procedure for the inclusion of a certain technology component into the METIS system are described in this section. Only technology components evaluated according to these guidelines are considered quality assured and thus for consideration for inclusion into the METIS system concept.

The role of simulation evaluation guidelines for the METIS project is to coordinate the activities in the individual work packages and the horizontal topics using the methodology and guidelines described in this section. These guidelines, which focus on how technology components should be evaluated in terms of simulations, must be combined with D1.1 [1], which describes key assumptions regarding requirements and KPIs in each scenario and test case. Additionally, the guidelines should secure that simulation results are properly documented, which will further facilitate synchronization, comparison between results and the cross-check. Each technical solution proposed by METIS partners will have assumptions on deployment, available spectrum and usage of technology components, and these should be appropriately documented to allow the results to be evaluated, reproduced and used within the METIS concept. This description of the guidelines for simulation is based on currently available information and is likely to be extended, improved, and documented in future METIS deliverables.

Ideally, if different technology components can be used to solve the same technology challenge or be used in the same test case, then the used scenario and methodology should be as identical as possible. To ensure this, the test cases have in Section 4 been defined in some detail as reference cases. A partner should only deviate from these reference cases if there is a strong need. Then the need for this should be discussed with the technical coordinators and be clearly documented.

In Section 5.1 and Section 5.2, a general methodology to be used and some evaluation criteria are introduced. Moreover, these are mapped to the various simulation settings. Section 5.3 and Section 5.4 contains the way of working for choosing simulation methodology and level of documentation for the investigation and evaluation of the technology components. This also relate to the work made in D1.1 [1] where each test case is specified in terms of simulation scenario and KPIs.

5.1 Evaluation methodology

Methodology guidelines are given in order to evaluate performance in a consistent manner between partners. These guidelines serve also as a framework to ensure that results from link-level simulations can be used in system level evaluations. To facilitate the inclusion of new technology components in the METIS concept a consistent choice of models and documentation is necessary.

Furthermore, performance comparison should be limited to results from the same type of simulator and the same choice of simulation settings. To exemplify, link simulations are not meant to be compared to system simulations, but can be used as a possible input to system simulations.

5.1.1 Channel and propagation models

The choice of channel and propagations models for simulation evaluations should be made according to the developed and recommended models within METIS. Initial recommendation for channel models in the test cases can be found in Section 4 and these propagation models are described in more detail in Annex Section 8.1.

5.1.2 Link level simulations

Link level simulations are simplified evaluations in the sense that the upper layer protocols are removed and only layer 1 functionality is included. Furthermore, a link level simulation study should include detailed models for the radio link and give precise and accurate results for the radio link. Link simulators are calibrated according to the methodology described in Section 3.1.

Link level simulations should be used whenever any new radio link technology is evaluated. If the link level simulator is capable of running the baseline radio link technology this can be used to produce calibration results, e.g. LTE-Advanced. For some of the test cases the baseline technology is defined in Section 4.

5.1.3 System level simulations

The system level simulators are calibrated according to the common calibration scenarios. For LTE capable simulators, the simulation scenarios in Section 3.3 should be used whenever suitable for calibrating simulators between partners. Moreover, a system level simulator should include detailed models for the deployment and user distribution. In addition, macro propagation and inter-cell interference (inter-user interference) should be accurately modelled.

5.1.4 Multi-hop evaluations

In multi-hop evaluations, the simulation setting can be either of link level or system simulation type. The additional requirement for multi-hop is that for a technology component containing 5G protocol solutions the protocol and time dynamics for the multi-hop procedure should be modelled accurately, i.e. the simulation should be casual for the packet delivery over a multi-hop link.

5.1.5 D2D evaluations

In D2D evaluations, the simulation setting can be either of link level or system simulation type. The additional requirement for D2D is that for any technology component containing new protocol solutions the protocol and time dynamics for the D2D procedure should be modelled accurately, i.e. the simulation should implement an application abstraction representative of the studied D2D simulation setting.

5.2 Evaluation criteria

For all simulation campaigns in METIS, a specific criterion should be defined to evaluate the simulation outcomes. The different technology components try to solve different technology challenges and therefore may need a different evaluation criterion. The same is applicable to different test cases.

Many evaluations will span some set of parameter settings, for example, system load in a system simulator or SNR in a link level simulator. For these cases and when the graphical representations of simulation outcomes show a number of different evaluation criteria, all the graphical representations should show the same span of the parameters. This is to make sure that different results can be compared, e.g., if a study shows separate CDFs for 90th percentile latency and 10th percentile user throughput at different system loads, you should be able to distinguish both values for a given system load.

5.2.1 User throughput

The definition of the throughput criterion is the total amount of received information bits at the receiver divided by the total session time. The session time is defined as sum of the transmit time of all packets transmitted during the session. The transmit time for a packet is counted from when the user's data is available at the transmitter until either all information is successfully received at the receiver or the end of the simulation duration for the user. Observe that any time when data from multiple packets is available at the transmitter is only counted once.

Two relevant traffic examples are full-buffer traffic and equal buffer traffic. The difference between full-buffer traffic and equal buffer traffic is that for full-buffer traffic the maximum session time is fixed, e.g. 100 s, whereas for equal-buffer traffic the amount of information bits is fixed, e.g. 1 000 000 bits.

Observe that all overhead bits related to the transmissions of signalling or retransmissions and overhead in retransmission protocols, e.g. RLC, are not included into the information bits used for the user throughput. However, information bits could contain bits related to higher layer protocols, e.g. TCP headers.

5.2.2 Data rates

Data rates is in METIS defined as the rate from the application layer of the user, i.e. data bits related to TCP and both higher layer and lower layer protocol overhead should be excluded from the measures when measuring data rates. This definition is used to facilitate comparison between technology components that could implement changes at any layer in the protocol stack. Observe that the data rate could be studied between any layers of the protocol stack, but that the METIS comparison in the concept development will use this definition.

5.2.3 Cell throughput

In the context of METIS, the definition of a cell is a single point of data aggregation containing a single MAC element for the RAT for which the cell throughput is measured, i.e. a WiFi access point or a traditional 3GPP cell. The cell throughput is then the aggregation of the user throughput of all the users. The cell throughput is defined as the total amount of received information bits divided by the time when at least one user is transmitting a packet. Observe that time when more than one user is transmitting is only counted once. Consider for example a CoMP LTE scenario, then the MAC is situated at the serving cell of the UE and hence the aggregation is over all UEs connected to the same serving cell, even though reception/transmission can occur at different locations.

5.2.4 Spectral efficiency

Spectral efficiency is defined as the aggregated user throughput divided by the aggregated spectrum used per measurement unit. The aggregated spectrum used should include the spectrum used for control signalling, broadcast signalling etc. The measurement unit is defined according to the test case under investigation. For example, for complementary or evolved technologies in LTE a measurement could be a LTE cell. Another suitable measurement unit is area.

This implies that the spectral efficiency can have the following units: [bps/Hz/cell] or [bps/Hz/km^2].

5.2.5 Traffic volume

Traffic volume is defined as the aggregated served traffic to all users, either in total for the simulation setting or per area unit, i.e. per km^2. For some test cases a fixed limit is set on some other metric, e.g. above 300 Mbps data rate in DL for the 5th percentile user in TC2. For the cases with a fixed metric, traffic volume gives a measure on how much capacity the system has given the fixed requirement on some other measure. Traffic volume thus has the unit: [Gbit/km^2].

5.2.6 Error rate

For the error rate evaluation criterion there is a number of possible cases to measure. The following list should be amended when additional error cases are identified.

- Bit error rate: A link level simulator measurement on the raw demodulation performance of the investigated technology.
- Frame error rate: A link and system level error rate of the transmitted information blocks, e.g. for link level, the information block can be a codeword and for system level this can be a transport block at the MAC layer.

5.2.7 Delay

For METIS KPIs the delay in terms of time, e.g. in ms, of a technology component is important. The investigated technology component can influence the end to end delay experienced by the end user in different ways. The delay of interest for a given simulation campaign can be of different type depending on the technology investigated and simulator used for the study. The main types of delay are:

- End to end delay: Total delay from the application layer at source to the application layer at destination.
- Air delay: The delay of the radio interface, which is the time between data arriving at the MAC element (or RLC if used) at transmitter to leaving at the MAC (or RLC) on the receiver side. Hence, this delay includes the scheduling delay, encoding and decoding delay, any delay introduce by HARQ retransmissions, etc.
- Packet delay: The time elapsed between a packet arriving in the queue at transmitter side and the complete packet arriving at the receiver side.

5.2.8 Energy efficiency and cost

It is not foreseen that each simulation results in energy consumption and cost calculations as this depends on the use case. However, to evaluate the validity of a solution, the KPIs of energy efficiency and cost are very important. Therefore, related KPIs are mandatory for enabling these calculations:

- Transmit power CDF.
- Number and types of states, i.e. off, DTX/DRX, transmitting etc.
- Transition time between states.
- Activity rate per node type and state.

5.3 Technology components

In METIS, different technology components will be investigated and must be documented. This documentation should describe the simulation scenario and evaluation methodology in a sufficiently detailed manner. Level of detail and methodology is determined by the mapping to the solutions where the technology component is used. This mapping determines who is the receiver/evaluator of the study results and hence should be used to coordinate the choice of methodology and documentation details of the simulation study. It is important in this work to capture how the evaluation of different technology components can be compared and how the results can be used in the METIS concept.

5.4 Documentation for the simulation studies

The test cases to be considered within the scope of METIS have been defined in D1.1 [1] and the initial simulation assumptions have been described in more detail in Section 4. In the documentation of a simulation study both the technology components and their mapping to the appropriate test cases should be included. Further, the used models together with the assumptions on the legacy network and the end-user KPI(s) improvements should be documented. Thereafter, the mapping to the simulator study and the relevant aspects considered within the study should be motivated. In this description of the simulations study it is important that the researcher identifies and document which assumptions are excluded, added or modified compared to D1.1 and Section 4. Any deviations should be motivated together with an estimate of the impact. Examples of deviations can be that, a link level simulator does not include all the macro properties of the test case and that a system simulation does not correspondingly contain all the link level details.

The recommended way of documenting evaluation results in METIS is to use a combination of a graphical and tabled representation of the simulation results. For each scenario the choice is dependent upon the investigated technology challenge and test case.

For simulation campaigns, it is recommended to document in a table:

- 10th, 50th and 90th percentile performance, and
- mean performance of the evaluation criterion.

This should be accompanied with a graphical plot showing the CDF or PDF of the investigated evaluation criterion. Together with the table, the definition of the sampling should be included and the mean is thus related to the defined sampling. For example, for downlink SINR on PDSCH, the sampling could be wide-band average SINR for either each user, average SINR for each cell and TTI or the momentary average SINR for the individual PDSCH transmissions.

6 Summary

Deliverable 6.1 describes the simulation guidelines that enable alignment and validations of the simulation work within the consortium in order to quality assure simulation results and the fulfillment of the overall goal of the METIS project.

A methodology for simulator calibration has been defined in order to ensure comparability of the obtained results provided by the different simulators. Due to the complexity of the system under investigation several different simulators and of different types are available, such as link, multi-link and system level simulators. The attained consensus in the consortium is that the simulation tools is of vital importance for the continuation of the simulation work within the project, so that striving for new solutions can be in focus.

A short simulation guideline description for each test case that concerns environmental model, propagation model, traffic model, mobility model, together with deployment considerations, technology baseline and key performance indicators is given in order to coordinate the definition of system-simulation reference cases that allow for technology components comparisons within the project. The work with these simulation reference cases provides both new simulation models for the challenging problems to be solved within METIS and also a foundation on how to approach and simulate the test cases that serve as a basis for the design and evolution of the technical solutions within the project. The specific test cases thereby address the much wider class of problems that are relevant for the fundamental challenges of the beyond 2020 information society.

Overall consensus on how to perform simulations is documented in the simulation guideline section. This material enables tight collaboration and alignment within the consortium for the remaining work that is to be conducted within METIS. The simulation guidelines also bring common understanding of what is needed in order to assure that the overall goal of the METIS project will be attained.

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Annex

8 Annex: General simulation models

8.1 Propagation models

In this section, some of the propagation scenarios (PS) identified in METIS are described. It is also worth noting that the propagation scenarios will be further defined and described in more detailed in deliverable D1.4 where the complete list of PS is to be given.

Considering carriers below 6 GHz, there are 8 propagation scenarios relevant for the test cases described in D1.1 [1]. This section provides more details on the models to be used in these Propagation Scenarios (PSs).

Table 8.1: Subset of propagation scenarios of relevance for simulation of test cases

BS-MS	Urban Micro O2O	PS#1
	Urban Micro O2I	PS#2
	Urban Macro O2O	PS#3
	Urban Macro O2I	PS#4
	Indoor Office	PS#7
D2D	Urban O2O (also V2V)	PS#9
	Urban O2I	PS#10
	Indoor Office	PS#13

Regarding general assumptions, it is quite important to highlight two points. The first one is the need for a realistic (no synthetic) scenario. Past experience with other study works performed in 3GPP have shown the need for a proper characterization of realistic effects. Some conclusions reached with synthetic simulations have turned out to be incorrect once the proposed techniques were applied to the field. In this sense, and provided that the definition of the METIS concept is driven by the test cases fulfillment, we recommend the usage of realistic scenarios that allow a proper evaluation of the potential of the new technological concepts. In the same direction, the second important assumption is the use of 3D models for propagation. The 3D characterization motivates the extension of current small scale models, activity that is being carried out by the 3GPP too, and the use of ray-tracing-based models for large scale effect.

Small scale parameters

Stochastic and geometric models use two different sets of channel parameters. The first one is related to the large scale parameters, such as shadow fading and path loss. The second one concerns small scale parameters, including Angle of Arrival (AoA) and Departure (AoD) or delay of the rays.

In order to generate channel samples between one transmitter and one receiver, mobility and exact location of both ends must be known. Based on this information all large scale parameters are generated, followed by the small scale parameters.

Concerning small scale parameters characterization, as a first approach we will use ITU-R M.2135 models [3] with the mapping summarized in Table 8.2. There are three issues to be solved concerning these models. The first one is the extension to 3D that will be addressed in a later stage in D1.4. This extension is required for the proper characterization of massive MIMO, although for conventional MIMO structures the 2D approach is valid enough. The second one is the validity of such models for dynamic simulations in which the position of users change over time. In this sense, we will assume that the conditions for rays and cluster generation remain static along a certain correlation length depending on the PS. After this distance, new cluster and rays must be generated according to the new geometry. Finally, in [3] these models are particularized for LoS or NLoS conditions. For synthetic simulations these conditions are randomly selected. However, for realistic test cases sight condition will be re-evaluated for each correlation length based on the actual position of transmitter and receiver.

Table 8.2: Small scale models for the different propagation scenarios

PS	Model	Correlation length
#1	ITU-R UMi	10
#2	ITU-R UMi O2I	10
#3	ITU-R UMa	50
#4	ITU-R UMa	50
#7	ITU-R InH	10
#9	ITU-R UMi *	10
#10	ITU-R UMi O2I *	10
#13	ITU-R InH *	10

*Updated according to the height of the device

Finally, it is important to note that, due to computational restrictions, the use of small scale parameters is optional for the METIS evaluations under complex scenarios, like TC2. A wideband characterization of the channel that only includes large scale effects is also valid. The next subsections describe this large scale modeling for the different propagation scenarios given in Table 8.1.

8.1.1 PS#1

PS#1 refers to propagation conditions in which the transmitter is situated much below the mean building height, in the sense that it lacks dominant visibility of the users and main propagation occurs by reflection between buildings.

For this PS a detailed modeling of buildings is needed. The proposed model is based on the ITU-R UMi path loss model for Manhattan grid layout [3].

In general, this model distinguishes the main street, where the transmission point is located, perpendicular streets, and parallel streets. Figure 8.1 shows the geometry used.

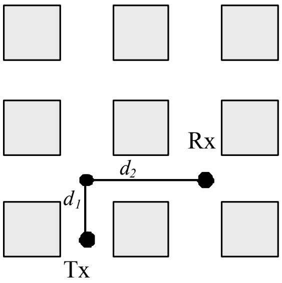

Figure 8.1: Upright projection of the geometry in PS#1

If the receiver is in the main street, LoS path loss in decibels is calculated according to

$$PL_{LOS}\left(d_1\right)=40\log_{10}\left(d_1\right)+7.8-18\log_{10}\left(h'_{Tx}\right)-18\log_{10}\left(h'_{Rx}\right)+2\log_{10}\left(f_c\right),$$

where d_1 is the distance in meters between transmitter and receiver, f_c is the frequency in GHz and h'_{Tx} and h'_{Rx} are the effective antenna heights in meters of transmitter and receiver, respectively. The effective antenna heights h'_{Tx} and h'_{Rx} are computed as follows

$$h'_{Tx} = h_{Tx} - 1 ,\ h'_{Rx} = h_{Rx} - 1$$

where h_{Tx} and h_{Rx} are the actual antenna heights, and the effective environment height in urban environments is assumed to be equal to 1 m. Note that the 3D extension of the model depends only on varying h_{Rx} as desired. If the receiver is in a perpendicular street, then

$$PL = \min\left(PL(d_1, d_2), PL(d_2, d_1)\right),$$

where:

$$PL(d_k, d_l) = PL_{LOS}(d_k) + 17.9 - 12.5 n_j + 10 n_j \log_{10}(d_l) + 3\log_{10}(f_c)$$

and

$$n_j = \max(2.8 - 0.0024 d_k, 1.84).$$

For the sake of simplicity, the height used in the LoS formula will be the one of the receiver in Rx. It is worth noting that in case of being in a perpendicular street with distance less than 10 m between transmitter and receiver, then LoS conditions apply. Finally, for parallel streets, the path loss is assumed as infinite. Moreover, minimum coupling losses are set to 53 dB.

8.1.2 PS#2

In a real scenario, signal from outdoor transmission points reach also indoor users. This scenario is about outdoor-to-indoor propagation. As a baseline, we have chosen WINNER+ B4 [49]. According to this model, path loss in dB is calculated as

$$PL = PL_{out} + PL_{th} + PL_{in},$$

where $PL_{out} = PL(d_{out} + d_{in})$ use the models of PS#1 considering the sight conditions of the wall closest to the receiver and its actual height, and

$$PL_{th} = 9.82 + 5.98\log_{10}(f_c) + 15(1 - \sin(\theta))^2$$

$$PL_{in} = 0.5 d_{in},$$

being f_c in GHz.

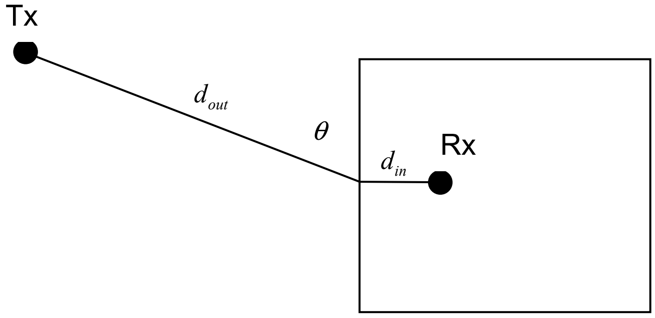

Figure 8.2: Upright projection of the geometry in PS#2

8.1.3 PS#3

This scenario refers to the situation in which the base station is situated over a building rooftop and has dominant visibility of users. For the urban macrocell scenario, most part of the signal reaches users via diffraction. PS#3 is similar to the scenario assumed by ETSI in [50] and the same models apply. The total transmission loss in decibels is expressed as the sum of free space loss, the diffraction loss from rooftop to the street, and the reduction due to multiple screen diffraction past rows of buildings, that is,

$$L(R) = \begin{cases} L_{fs} + L_{rts} + L_{msd} & if \quad L_{rts} + L_{msd} > 0 \\ L_{fs} & if \quad L_{rts} + L_{msd} \le 0 \end{cases}$$

Given a mobile-to-base separation R, the free space loss between them is given by:

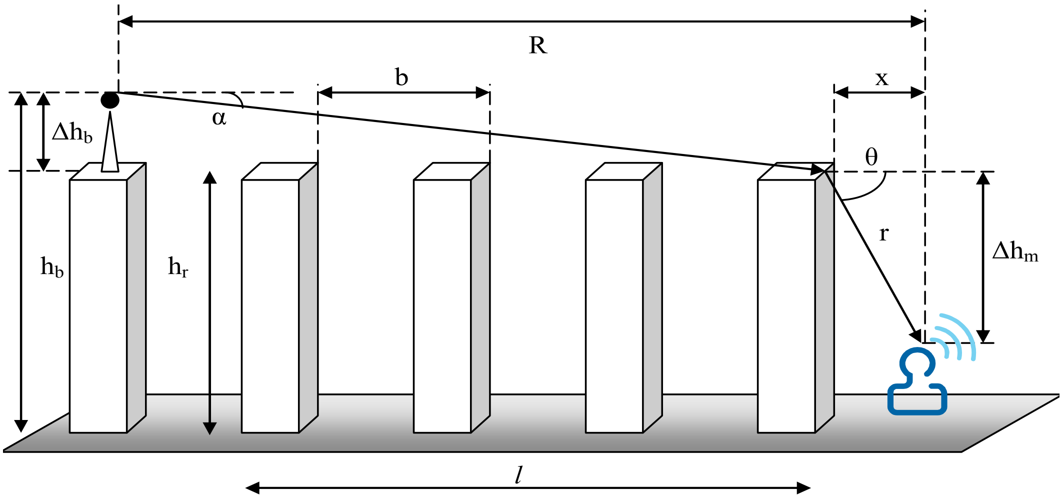

Figure 8.3: Geometry in PS#3

The free space loss is given by

$$L_{fs} = -10 \cdot \log_{10}\left(\frac{\lambda}{4\pi R}\right)^2 .$$

The diffraction from the rooftop down to the street level gives the excess loss to the mobile station [51]

$$L_{rts} = -20 \cdot \log_{10}\left[\frac{1}{2} - \frac{1}{\pi}\arctan\left(\operatorname{sign}(\theta)\sqrt{\frac{\pi^3}{4\lambda} r(1-\cos\theta)}\right)\right],$$

where, according to Figure 8.3,

$$\theta = \tan^{-1}\left(\frac{|\Delta h_m|}{x}\right)$$

$$r = \sqrt{(\Delta h_m)^2 + x^2} ,$$

being Δh_m the difference between the last building height and the mobile antenna height and x the horizontal distance between the mobile and the diffracting edges.

The multiple screen diffraction loss from the base antennas due to propagation past rows of buildings depends on the base antennas height relative to the building heights and on the incidence angle [52]. A criterion for grazing incidence is the “settled field distance”, d_s:

$$d_s = \frac{\lambda R^2}{\Delta h_b^2} ,$$

where Δh_b is the base station antenna height, h_b, relative to average rooftop h_r. Then for the calculation of L_{msd}, d_s is compared to the length of the path covered by buildings l.

If $l > d_s$

$$L_{mds} = L_{bsh} + k_a + k_d \log_{10}\left(R/1000\right) + k_f \log_{10}\left(f\right) - 9\log_{10}\left(b\right),$$

where

$$L_{bsh} = \begin{cases} -18\log_{10}\left(1+\Delta h_b\right) & for\ h_b > h_r \\ 0 & for\ h_b \le h_r \end{cases}$$

is a loss term that depends on the base station height,

$$k_a = \begin{cases} 54 & for\ h_b > h_r \\ 54 - 0.8\Delta h_b & for\ h_b \le h_r\ and\ R \ge 500 \\ 54 - 1.6\Delta h_b\, R/1000 & for\ h_b \le h_r\ and\ R < 500 \end{cases},$$

$$k_d = \begin{cases} 18 & for\ h_b > h_r \\ 18 - 15\dfrac{\Delta h_b}{h_r} & for\ h_b \le h_r \end{cases}$$ and

$k_f = 0.7\left(f/925-1\right)$ for medium sized cities and suburban centers with medium tree density whereas $k_f = 15\left(f/925-1\right)$ for metropolitan centers. Note that frequency is expressed in MHz in these equations.

On the other hand if $l \le d_s$ a further distinction has to be made according to the relative heights of the base station and the rooftops.

$$L_{msd} = -10 \cdot \log_{10}(Q_M{}^2),$$

where:

$$Q_M = \begin{cases} 2.35\left(\dfrac{\Delta h_b}{R}\sqrt{\dfrac{b}{\lambda}}\right)^{0.9} & for\ h_b > h_r \\ \dfrac{b}{R} & for\ h_b \approx h_r \\ \dfrac{b}{2\pi R}\sqrt{\dfrac{\lambda}{\rho}}\left(\dfrac{1}{\vartheta} - \dfrac{1}{2\pi + \vartheta}\right) & for\ h_b < h_r \end{cases},$$

$$\vartheta = \tan^{-1}\left(\frac{\Delta h_b}{b}\right)$$

and

$$\rho = \sqrt{\Delta h_b{}^2 + b^2}.$$

In this scenario, minimum coupling loss is set to 70 dB.

8.1.4 PS#4

Similarly as in PS#2, we choose WINNER+ C4 model [49] as starting point. According to this model, path loss in dB is calculated as

$$PL = PL_{out} + PL_{th} + PL_{in},$$

where PL_{out} uses the path loss model of PS#3 assuming that the building within which the user is disappears but Δh_m equals the actual height above terrain of the user, and

$$PL_{th} = 9.82 + 5.98\log_{10}\left(f_c\right) + 15\left(1-\sin\left(\theta\right)\right)^2$$

$$PL_{in} = 0.5 d_{in} ,$$

where d_{in} is the distance from the wall that is closest to the transmitter to the receiver, θ is the angle between the outdoor path and the normal of the wall and f_c is the frequency in GHz. Note that the wall is chosen according to the sight to the transmitter.

8.1.5 PS#7

For the simulation of indoor propagation, two options are possible. The former is more realistic and requires a real layout of the walls and materials used within the building. The second option consists in using ITU-R InH model [3], which is a statistical approach.

For the realistic model, the WINNER II A1 model is suggested [48]. According to this model, propagation loss in decibels between transmitter and receiver given a certain distance in meters, d, is expressed as

$$PL(d) = A\log_{10}(d) + B + C\log_{10}(f_c/5) + X ,$$

being f_c in GHz. The set of constant depends on the sight conditions. In LoS

$$A = 18.7 \quad B = 46.8 \quad C = 20$$

whereas in NLoS

$$A = 36.8 \quad B = 43.8 \quad C = 20 \quad X = 5(n_w - 1) ,$$

being n_w the number of walls between transmitter and receiver.

For the propagation between floors, we need to add the floor losses if the transmitter and receiver are in different floors as

$$FL = 17 + 4(n_f - 1) .$$

being n_f the number of floors between transmitter and receiver.

Concerning the statistical approach, the same model for propagation between floors is applied. Besides, LoS/NLoS allocation will be the same as proposed in [48].

On the other hand, small indoor cells in the ground floor propagate outdoor. For this modeling, we will assume the same models as for indoor propagation plus an additional attenuation factor of 17 dB representing the isolation of the building.

In this scenario, minimum coupling loss is set to 50 dB.

8.1.6 PS#9

As a default model for D2D, we propose the same model as PS#1 but using $h_{Tx} = h_{Rx} = 1.5$ m. However, given that transmitters will suffer from additional obstacles in the propagation due to the lower height of the transmitter, non line-of-sights conditions should be taken into account. In this sense, an additional loss of 10 dB will be added to the propagation loss whenever devices have others in between.

We also consider as an alternative for D2D modeling in the outdoor the model proposed by ITU-R in [53], since this is the only measurement-based study actually based on O2O measurements where both ends of the link are low.

In case of vehicles, the default model can be still applicable (PS#1 with lower transmitter height plus 10 additional dB of attenuation in case of having other cars in the middle of the communication channel) but other options more specific are contemplated. In particular, Karendal's models for small and large scale characterization are suggested for vehicular to vehicular communications [54][55]. According to this model path loss is calculated as

$$PL(d) = PL_0 + 10 \cdot \log_{10}(d/d_0) + X_\sigma + \zeta \cdot PL_c$$

$$\zeta = \begin{cases} 1 & \text{for reverse pathloss} \\ -1 & \text{for forward pathloss} \\ 0 & \text{for convoy pathloss} \end{cases}$$

Table 8.3: Parameters of V2V path loss [55]

Scenario	n	PL_0	σ	PL_c	d_0
Highway	1.77	63.3	3.1	3.3	10
Suburban	1.59	64.6	2.1	N.A.	10
Urban	1.68	62.0	1.7	1.5	10

8.1.7 PS#10

The same model as PS#2 but using $h_{Tx} = h_{Rx} = 1.5$ m.

8.1.8 PS#13

The same model as PS#7 applies here.

8.2 Traffic models

8.2.1 3GPP FTP Model 2

Bursty User-Driven (BUD) traffic, Non Real-Time Video traffic and Bursty Application-Driven (BAD) traffic are modelled thanks to 3GPP File Transfer Protocol, FTP, Model 2 [22].

3GPP Model 2 defines bursty traffic according to three parameters:

- File size S (Mbytes)
- Reading Time D (s) with an exponential distribution
- Number of users K

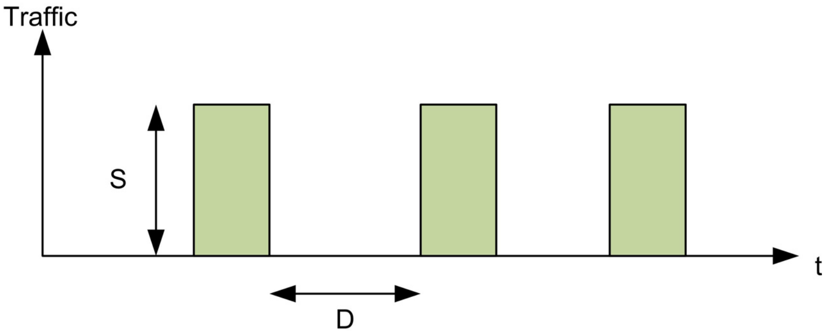

Figure 8.4: Traffic generation of 3GPP FTP Model 2

Bursty User-Driven (BUD) traffic is defined with 20 Mbytes file size (defined as METIS webpage size [1]). Video traffic is defined thanks to the target video coding rate, which is equal to 50 Mbps. File size and reading time parameters will be directly derived from this target coding rate. Bursty Application-Driven (BAD) traffic is defined with 2 Mbytes file size.

8.2.2 Real time streaming model

Real-Time Video application driven traffic model is defined with the following IP packet distribution:

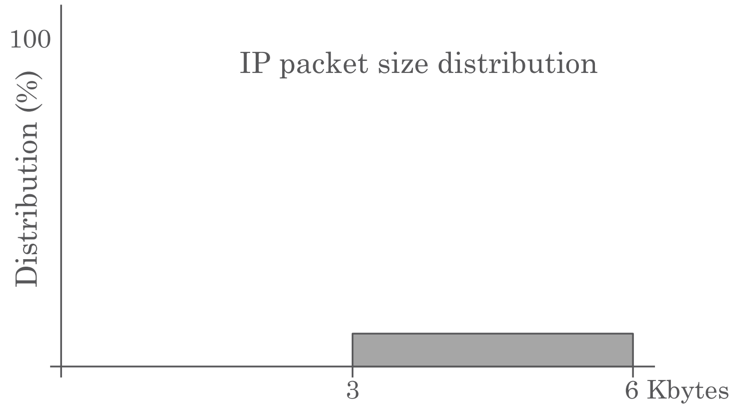

Figure 8.5: Distribution of packet size for real time streaming

The inter packet delay is 36 ms with a burst size following a uniform law from 3 kbytes to 6 kbytes. A user is considered as satisfied if its achieved data rate equals the transmitted data rate at IP level.

8.2.3 Traffic for Moving Networks (MN)

Vehicle to Infrastructure (V2I) traffic is mapped with Bursty User-Driven (BUD) traffic, which is modelled with 3GPP FTP Model 2. Model parameters (burst size and Reading time) from general TC2 scenario will be reused.

Vehicle to Vehicle (V2V) traffic is defined with messages of 1.6 kbytes sent every 100 ms with a delay constraint of 10 ms. Initial number of moving users performing V2V traffic is equal to the initial number of users in cars performing Real Time streaming in general TC2 scenario.

Table 8.4: Traffic model parameters for MN

Location	Num users	Traffic type	Initial number of users	Burst size	Reading time / Inter packet delay	Traffic volume [Mbytes/s] V=K*S/R
Moving Users	TC-specific TC2: 5240	V2I traffic	3873	20 Mbytes	167 s reading time	464.8
		V2V traffic 10 ms delay constraint	1367	1.6 kbytes	100 ms inter packet delay	0.085

8.2.4 Traffic for Massive Machine Communication (MMC)

Traffic is defined with Real Time and Non Real Time Application-Driven traffic.

Table 8.5: Traffic model parameters for MMC

Num users	Traffic type	Initial number of users	Burst size [Mbytes]	Reading time [s]	Traffic volume [Mbytes/s] V=K*S/R
TC-specific TC2: 723	BAD RT streaming 1 Mbps	465	0.125	1	58.1
	BAD NRT	258	2	9	58.1
TC11 : 300 000	TC11 NRT	300 000	125 E-6	300	125 E-6

8.2.5 Traffic for Direct Device-to-Device communication (D2D)

In [22] 3GPP defines FTP Model 2 and VoIP for D2D communications assessment. Bursty-User Driven traffic (BUD) is specified thanks to 3GPP Model 2 so consequently BUD traffic parameters are reused.

VoIP is defined as an enhancement of 3GPP VoIP traffic model where AMR 12.2 kbps CODEC was assessed. To cope with METIS requirements of 2020 information society, enhanced codec is assumed for modelling VoIP traffic. Wideband AMR codec at 23.85 kbps is used instead of AMR 12.2 kbps codec defined in [61]. Other assumptions are kept: messages sent every 20 ms, 50 % voice activity factor and compressed IP header. The resulting payload size is 69 bytes. A VoIP user is satisfied if more than 98 % of its speech frames are delivered successfully within 50 ms (air interface delay).

Table 8.6: Traffic model parameters for D2D

Num users	Traffic type	Initial number of users	Burst size	Reading time / Inter packet delay	Traffic volume [Mbytes/s] V=K*S/R
TC-specific TC2: 2536	Bursty User-Driven traffic (BUD)	1853	20 Mbytes	265 s reading time	139.5
	VoIP WB AMR	684	69 bytes	20 ms inter packet delay	1.2

9 Annex: Detailed test case simulation models

9.1 TC1: Virtual reality office

9.1.1 Environmental model details

The environmental model geometry, see Figure 4.1, is given by the dimensions of the rooms, cubicle offices and tables. The width and depth of these objects are illustrated in the following two-dimensional figure.

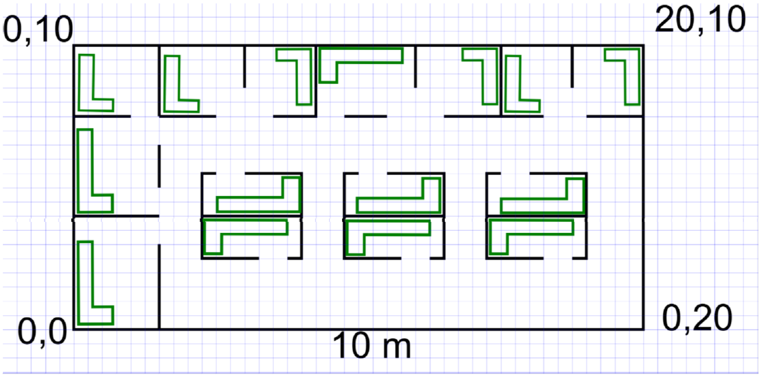

Figure 9.1: A 2D visualization of the Virtual reality office environmental model reference case

The respective heights and materials of these objects are given in the following table.

Table 9.1: List of heights and materials in the office

Object	Height [m]	Material
Room	2.9	Concrete
Cubicle	1.5	Wood
Table	0.7	Wood

9.1.2 Propagation model details

For the materials used in the TC1 reference case, some parameters are given in the following table.

Table 9.2: Propagation characteristics of the materials used in TC1

Material	Conductivity, *n*	Permittivity, *k*	Penetration loss
Concrete	6.14	0.3	71.5
Wood	1.64	0.11	8.6

Given the conductivity, *n*, and the permittivity, *k*, the complex relative permittivity of the material, *e*, is given by *e*=(*n*-*ik*). Let θ denote the angle of incidence of the array to the reflective surface. Then the perpendicular coefficient, $Rperp$, is given by

$$Rperp = \left(\frac{\cos\theta - \sqrt{e - (\sin\theta)^2}}{\cos\theta + \sqrt{e - (\sin\theta)^2}} \right),$$

and the parallel coefficient, $Rpar$, is given by

$$Rpar = \left(\frac{e\cos\theta - \sqrt{e - (\sin\theta)^2}}{e\cos\theta + \sqrt{e - (\sin\theta)^2}} \right).$$

These complex values are then used to compute the complex amplitude of the signal after the reflection.

9.2 TC2: Dense urban information society

9.2.1 Environmental model

Madrid grid, an environment model for TC2, is a compromise between the need to reflect a realistic characterization of a dense urban architecture and existing popular models like Manhattan grid. More realistic and non-homogenous building layout in proposed model is necessary to capture e.g. real life behavior of users in motion, diversity of SINR distribution or heterogeneity of cellular network deployment. Such approach allows for a fair and realistic evaluation of different solutions and network enhancements envisioned in METIS project.

The complexity of TC2 scenario motivates the research on large-scale effects, and therefore, small-scale characterization is not mandatory. A 3D visualization of Madrid grid is depicted in Figure 9.2.

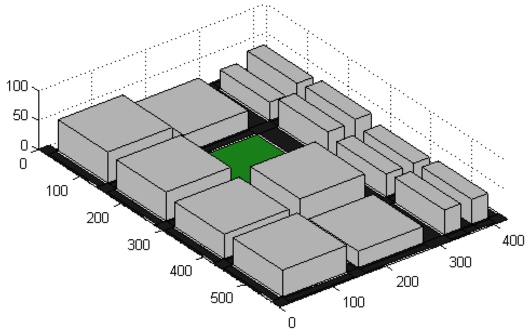

Figure 9.2: 3D visualization of the Madrid grid

The environmental model for outdoor is depicted in Figure 9.3. Model consists of several elements with unique properties or dimensions: square buildings, rectangle buildings, building entrances, metro entrances, bus stops, park, sidewalks, crossing lanes, roads and parking lanes. The description and dimensions of each element is as follows:

- Square shaped buildings. Both length (east-west orientation) and width (south-north orientation) is equal to 120 m and the height of the building varies. Buildings are the source of the indoor traffic.
- Rectangle shaped buildings. Length is equal to 120 m, width is 30 m and the height of the building varies. Similarly to square shaped buildings they are the source for the indoor traffic.
- Building entrances. Adjacent to square and rectangle buildings with dimensions of 3 m x 3 m. Square shaped buildings have always 6 symmetrical entrances with two possible configurations:
    - Horizontal. Each building wall with east-west orientation has two entrances with the center positioned 40.5 m from the closest building corner (see green rectangles in Figure 9.3). Building walls with south-north orientation have only one entrance with the center in the middle of the wall.
    - Vertical. Each building wall with south-north orientation has two entrances with the center positioned 40.5 m from the closest building corner. Building walls with east-west orientation have only one entrance with the center in the middle of the wall.

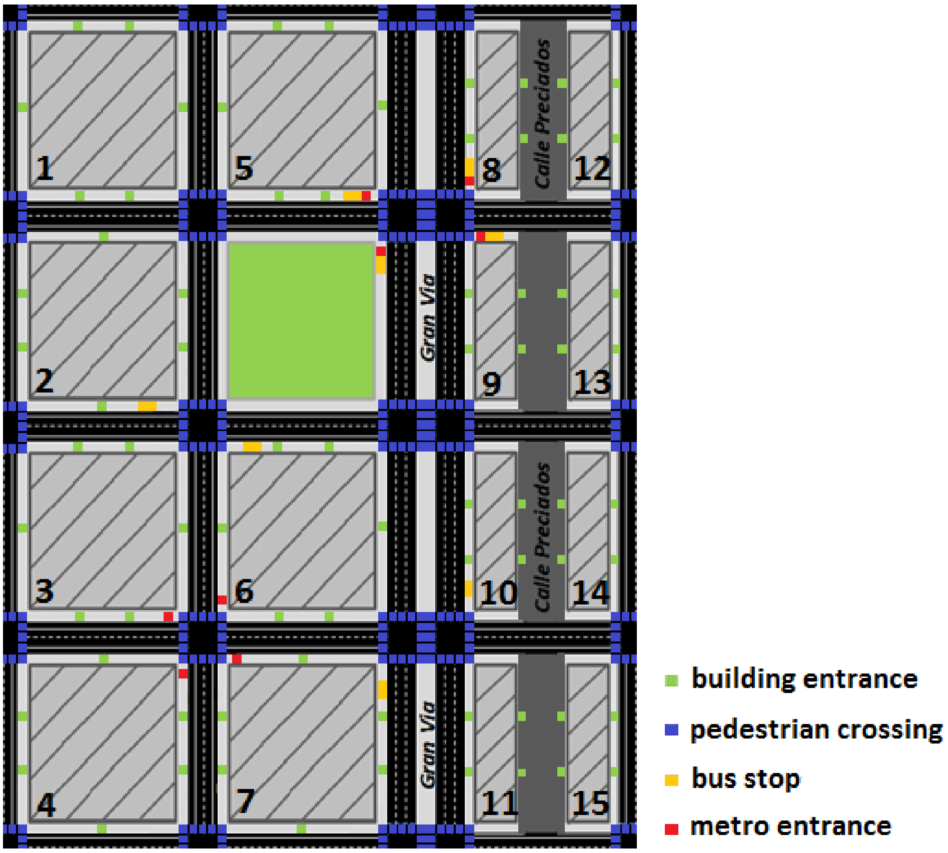

Figure 9.3: Madrid Grid outdoor layout

Rectangle shaped buildings have exactly 4 entrances, two at each south-north oriented walls with the centre positioned 40.5 m from the closest building corner. Every building entrance is adjacent to the building and overlays the sidewalk. Every pedestrian user is either moving from the building entrance to the bus stop/metro entrance or moving from the bus stop/metro entrance towards the building entrance.

- Metro entrance. There are 8 metro stations in total in Madrid grid. Dimension of metro entrance is 3 m x 3 m and they are adjacent to the buildings, overlaying the sidewalk. The center of each one is positioned 4.5 m away from the closest building corner. The position of each metro entrance is given in Figure 9.3.
- Bus stops. There are 8 bus stops in total in Madrid Grid. Dimensions of the bus stops are 3 m x 18 m and they are adjacent to the buildings and overlaying the sidewalk. The center of each one is positioned 15 m from closest building corner. The position of each bus stop is represented in Figure 9.3 as a yellow rectangle.
- Park. Both length and width is 120 m.
- Sidewalks. They surround every building and are 3 m wide. Pedestrians are allowed to move on sidewalks and overlaying elements like bus stops, building entrances, and metro entrances. Special types of sidewalks are:
  - Gran Via sidewalk. Double (6 m wide) sidewalk between Gran Via road lanes.
  - Calle Preciados. South-north oriented sidewalk of 21 m between rectangle shaped buildings.

- Crossing lanes. Traffic lights areas where pedestrians can wait for the street light to change (if overlaying the sidewalk) or cross the street (if overlaying the road). Crossing lights are 3 m wide and there are no traffic lights in Calle Preciados.
- Roads. Used for a vehicular movement. They are 3 m wide and are always one lane for one direction accompanied by parking lanes. Special type of road is Gran Via where there is no parking lanes on both sides and there are three road lanes in each direction.

Total dimensions for Madrid grid is 387 m (east-west) and 552 m (south north) assuming only one sidewalk, parking lane and road lane between edge buildings and the layout border. The building height is uniformly distributed between 8 and 15 floors with 3.5 m per floor. Summary of building properties is given in a table below.

Indoor space is modelled as follows:

- Square buildings: uniform net of closed rooms with 10 m x 10 m dimensions.
- Rectangle building: dual stripe of rooms with 10 m x 10 m dimensions separated from each other by a 10 m x 120 m long corridor. Rooms have no separation wall toward the corridor.

Table 9.3: Building types in TC2 environment

Building index	Building type	Building entrances	Number of floors
1	Square	2 entrances on horizontally oriented sides 1 entrance on vertically oriented sides	15
2	Square	2 entrances on vertically oriented sides 1 entrance on horizontally oriented sides	14
3	Square	2 entrances on horizontally oriented sides 1 entrance on vertically oriented sides	12
4	Square	2 entrances on vertically oriented sides 1 entrance on horizontally oriented sides	13
5	Square	2 entrances on horizontally oriented sides 1 entrance on vertically oriented sides	9
6	Square	2 entrances on horizontally oriented sides 1 entrance on vertically oriented sides	15
7	Square	2 entrances on vertically oriented sides 1 entrance on horizontally oriented sides	8
8	Rectangle	2 entrances on vertically oriented sides	9
9	Rectangle	2 entrances on vertically oriented sides	13
10	Rectangle	2 entrances on vertically oriented sides	11
11	Rectangle	2 entrances on vertically oriented sides	12
12	Rectangle	2 entrances on vertically oriented sides	13
13	Rectangle	2 entrances on vertically oriented sides	14
14	Rectangle	2 entrances on vertically oriented sides	11
15	Rectangle	2 entrances on vertically oriented sides	12

9.2.2 Traffic model

According to [1], the overall KPIs for TC2 have been defined as such:

- A user "bucket" of 500 Gbyte/month/subscriber (overall bucket, covering uplink and downlink communication from/to the cloud as well as directly among devices or with sensors)
- A user density of 200 000 users/km^2
- A traffic volume density in the range of 700 Gbps/km^2
- A desired experience on the MAC of up to 300 Mbps / 60 Mbps, at availability (over space and time) of 95 % for public cloud services.
- For device-centric services, the experienced data rate between UEs or sensors is required to be 10 Mbps or more.

The following different forms of traffic in TC2 are considered:

- **Bursty, user-driven traffic** (e.g. related to web browsing, file download etc.) – with rather lenient latency requirements (average web page to be downloaded in less than 0.5 s), with minimum required throughput of 300 Mbps DL/ 60 Mbps UL.
- **Video traffic**, non real-time with rather lenient latency requirements (video start in less than 0.5 s). Video coding rate is designed for high quality (1080p) and is equal to 50 Mbps.
- **Bursty, but more or less permanent application driven traffic** (e.g. related to permanent cloud connectivity, etc.). Minimum target throughput is 10 Mbps.
- **Real time video application-driven traffic** (e.g. related to real time streaming applications, augmented reality, Google glasses, etc.). This has very high latency requirements due to real time constraint (2 to 5 ms RTT). Video coding rate is designed for high quality video on smartphones and is equal to 1 Mbps.
- **Traffic generated by sensors** in the proximity of users.

The following **bucket split** between the traffic forms is considered:

Table 9.4: Traffic split for TC2

	UL	DL	Direct	**Total**
Bursty, user-driven traffic (BUD)	6 %	34 %	Not considered in TC2	**40 %**
Video traffic (VT)	6 %	34 %	Not considered in TC2	**40 %**
Bursty, but rather permanent application-driven traffic (BAD)	1.25 %	6.25 %	Not applicable	**7.5 %**
Real Time application-driven traffic (RT AD)	1.25 %	6.25 %	Not applicable	**7.5 %**
Traffic from/to sensors (TS)	Split to be investigated			**5 %**

Users location probabilities on the minimal simulated layout are the following:

- **Indoor**: 75 %
- **On the move**: 25 %
    - Walking on the road / shopping outdoors: 4.25 %
    - Standing at traffic light: 1 %
    - Standing at e.g. bus stop: 2 %
    - In a vehicle: 12.5 %

- In the park: 6.25 %

Further, activity levels in certain places are defined as follows:

Table 9.5: Activity levels

	Indoor (office)	Outdoor (sidewalk)	Outdoor (traffic light)	Outdoor (bus stop)	In vehicle	Park
Bursty, user-driven traffic	80 %	10 %	30 %	50 %	50 %	30 %
Video traffic	80 %	-	10 %	30 %	50 %	30 %
Bursty and real time permanent application-driven traffic	Always 100 %					
Traffic from/to sensors	Always 100 %					

From a simulation perspective, one user is allocated one single traffic type, being these traffic types described in Section 8.2.

The number of simulated users for each traffic type and location must be defined according to METIS traffic density requirements and environment model specifications. Moreover, the reading time parameter of the FTP Model 2 (see Section 8.2 for more details on this model) must be derived per service and per UE location depending on mobility and environment model specifications to allow moving users to change their traffic patterns.

To account for those users that on the move will change their traffic pattern depending on their location (more traffic at bus stop than on the sidewalks…), the reading time parameter of the FTP Model 2 should be dynamically changed based on user location. The reading time parameter *D* should adapt with the activity factor defined above. For example, mobility model defines that pedestrian users will start at building entrance on the sidewalk and move to bus stop. While on the sidewalk, the activity level for BUD traffic is 10 %. The reading time parameter will be updated once the pedestrian has reached the bus stop. It will be then be updated to 50 %. The reading time parameter should be dynamically adapted accordingly.

From TC2 definition, environment model and traffic assumptions, total number of UEs to simulate and total traffic volume to serve can be derived:

- The environment model defines a minimal layout of 0.25 km^2. Considering global user density of 200 000 users/km^2, the total number of UEs to simulate on such minimal layout is **50 000 users**.
- Considering of global traffic volume density of 700 Gbps/km^2, **175 Gbps** have to be served on this minimal layout.

According to those traffic assumptions (traffic volume, number of users, activity period, traffic type distribution and location), the following traffic model parameters are derived:

The methodology used to derive those parameters is the following:

- 1. Derive number of users with video traffic in each environment type (real time and non-real time) based on the video coding rate, target volume, traffic distribution and activity levels.
- 2. Derive number of users for other traffic types (BUD and BAD) with total number of users, number of video users and traffic type distribution.
- 3. Derive reading time parameters for BUD and BAD traffic based on target volume, traffic distribution, activity levels, burst sizes.

Table 9.6: Traffic models parameters

Location	**Num users**	**Traffic type**	**Initial number of users**	**Burst size [Mbytes]**	**Reading time [s]**	**Traffic vol. [Mbytes/s] V=K*S/R**
Indoor	37500	BUD	23805	20	107	4462.5
		VT NRT 1 Mbps	1115.625	5	1	5578.1
		BAD RT streaming 1 Mbps	8203	0.125	1	1025.4
		BAD NRT	4376	2	8.5	1025.4
Cars	6250	BUD	3873	20	167	464.8
		VT NRT 1 Mbps	298	3.125	1	929.7
		BAD RT streaming 1 Mbps	1367	0.125	1	170.9
		BAD NRT	712	2	8.3	170.9
Buses[2]			0	20	91	0.0
Parks	3125	BUD	1853	20	266	139.5
		VT NRT 1 Mbps	248	1.88	1	464.8
		BAD RT streaming 1 Mbps	684	0.125	1	85.4
		BAD NRT	341	2	8.0	85.4
Pedestrians Sidewalks	2125	BUD	1402	20	887	31.6
		VT NRT 1 Mbps	0	0	1	0.0
		BAD RT streaming 1 Mbps	465	0.125	1	58.1
		BAD NRT	258	2	9	58.1
Pedestrians Traffic light	500	BUD	119	20	106	22.3
		VT NRT 1 Mbps	250	0.6	1	156.3
		BAD RT streaming 1 Mbps	109	0.125	1	13.7
		BAD NRT	22	2	3.2	13.7
Pedestria Bus stop	1000	BUD	238	20	64	74.4
		VT NRT 1 Mbps	500	1.9	1	937.5
		BAD RT streaming 1 Mbps	219	0.125	1	27.3
		BAD NRT	44	2	3.2	27.3
		Num users	50 500		Vol. TC[3]	16023 Mbytes
		Target users	50 000		Target volume	17609 Mbytes

---

[2] Mobility model defines that buses are created empty and are filled up at bus stops by pedestrian waiting. So there is no need to define an initial number of simulated users in buses.

[3] Note that initial number of simulated users meets the target defined for the environment. But too many hypotheses on traffic (fixed total number of users, fixed traffic types distribution, fixed activity levels…) prevent to meet exactly the expected traffic volume. This will result in an average traffic volume on the simulated area 15 % lower than the METIS target.

9.2.3 Mobility model

Three different mobility considerations must be taken into account in TC2 namely indoor mobility, outdoor pedestrian mobility and vehicular mobility. The simplified and detailed mobility models to be used for TC2 system simulations are described below.

Indoor mobility

In the simplified case, indoor mobility is ignored during system simulations. Detailed indoor mobility modelling will follow the model described in, the Appendix B.1.6.4.1 of, [50].

Pedestrian mobility

The simplified outdoor pedestrian mobility model is based on the urban (Manhattan) mobility model considered in 3GPP [50]. The modified model is described below.

A fixed number of pedestrians are initialized at random building exits with a speed uniformly chosen from the interval [0,3] km/h. If the speed is greater than zero, they are also assigned a direction of movement (left or right with equal probability). Pedestrians move in the middle of the sidewalk in the given direction with the assigned speed until they reach a junction. Each intersection has four junctions. At each junction, a pedestrian may go straight, turn left or turn right according to the probabilities shown in Figure 9.. The turning probability, *TurnProb* is fixed to 0.5.

Collisions between pedestrians are ignored. At boundaries of the simulation environment, pedestrians bounce back with the same speed.

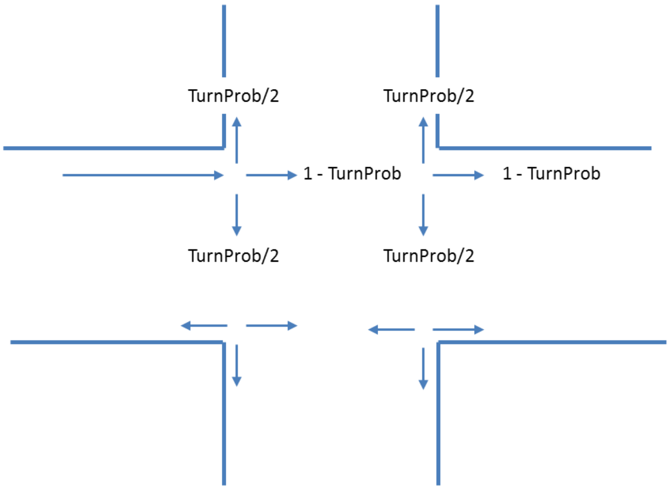

Figure 9.4: Pedestrian mobility at cross streets. The turning probability, TurnProb, is 0.5

In the detailed mobility model, a fixed number of pedestrians are initialized at randomly chosen building exits with a fixed speed uniformly chosen from the interval [0,3] km/h. If the speed is greater than zero, the pedestrian is also assigned a destination that could be either the closest metro stop or the nearest bus stop with equal probability. Pedestrians move in the middle of the sidewalk and use the shortest distance to reach the assigned destination (taking traffic light status into account) and only stop at traffic lights or at the destination. Collisions between pedestrians are not modelled.

Pedestrians temporarily disappear when they reach the metro entrance and reappear after a random time interval within the remaining simulation run-time at the entrance of a randomly chosen metro station. Users are then re-initialized with a speed chosen from the interval [0,3] km/h and a destination chosen with equal probability as the nearest bus stop, nearest metro station or nearest building entrance, if the speed is greater than zero. When users reach a building entrance as a destination, they become indoor users and are assigned, with equal probability, to one floor in the building and follow the detailed indoor mobility model described previously.

At bus stops, users enter buses on a first-come-first-served basis until the capacity of a bus is reached. Buses disappear upon reaching the boundaries of the simulation environment and each user in the bus reappears after a random time interval at a randomly chosen bus stop. The users are then re-initialized with a given speed and a destination as done for the case of pedestrians appearing at metro exits.

Allowing some pedestrians to have zero speeds provides the opportunity to create organically hotspots in the simulation environment over time.

Outdoor vehicular mobility

A fixed number of cars (2 m x 2 m) are distributed in the scenario with a fixed velocity of 50 km/h and a fixed number of users chosen uniformly from the interval [1,5]. Cars may turn at cross streets following the probabilities in Figure 9.5. It is assumed that cars are able to switch lanes automatically to make the required turn and collisions with potential vehicles in the lane are ignored. Cars stop at red traffic lights and also when there is another vehicle less than 4 m in front.

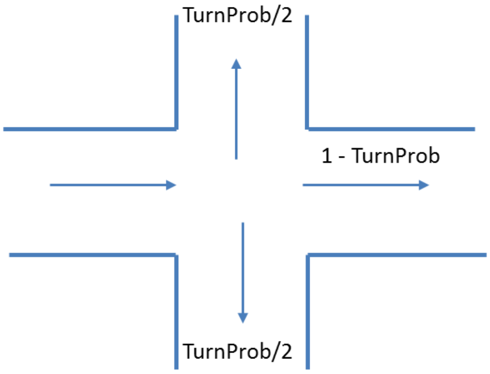

Figure 9.5: Car mobility in the simplified model. The TurnProb is 0.5

Buses (20 m x 2 m) arrive through a Poisson process with an inter-arrival time of two minutes on each street with a fixed velocity of 50 km/h and a fixed number of users chosen uniformly from the interval [1,50]. Buses move in straight lines and only stop at red traffic lights or when there is another vehicle less than 4 m in front. Both cars and buses bounce back at boundaries of the simulation environment.

Concerning the detailed model, the initialization and the mobility of cars remain unchanged. However, the initialization and the mobility of buses change significantly in the detailed model.

Buses arrive through a Poisson process with an inter-arrival time of two minutes on each street. Each bus is assigned a fixed velocity of 50 km/h and is initialized with only one user (the bus driver). Buses move with the fixed velocity in the rightmost lane in straight lines and stop under three conditions: at red traffic lights, when there is another vehicle less than 4 m in front and at a bus stop for 20 s when the number of passengers in the bus is less than the capacity of the bus, defined as 50. At each stop at a bus stop, the bus picks up waiting pedestrians until either there are no pedestrians left or until its capacity is reached and then moves again at the fixed velocity.

At boundaries of the simulation, buses disappear. All passengers in the bus disappear from the scenario and fill a pool of "in the metro" users. After a predefined time of 5 minutes all those users appear again in one metro station (one after the other, that is, the metro station periodicity is 10 minutes).

Traffic light model

All traffic lights in the grid possess only two states, namely red and green, and switch simultaneously with a pattern which repeats every 90 seconds. The switching pattern is described as follows

- 0-30 seconds: horizontal lights green, vertical lights red
- 30-45 seconds: both horizontal and vertical lights red
- 45-75 seconds: horizontal lights red, vertical lights green
- 75-90 seconds: both horizontal and vertical lights red

9.2.4 Deployment considerations

Default network infrastructure for basic layout is depicted in the Figure 9.6.

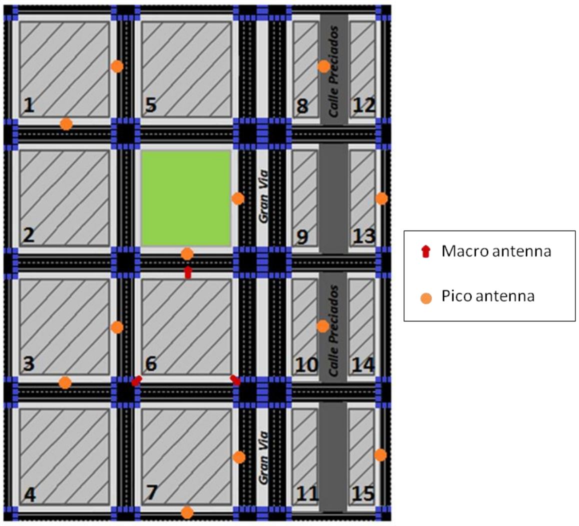

Figure 9.6: Deployment model for TC2

In order to limit the boarder effect the environment model may be extended by placing considered simulation area in the broader area as depicted in Figure 9.7. The broader area consists of nine identical representations of simulated area. The evaluation of simulation result is allowed only based on the data derived from the central one (or the selected subarea of the central one). Surrounding copies are used to create the realistic (i.e. not isolated) simulation environment for instance interference profile.

Network consists of a single macro station operating in 3 sectors. Antenna elements of macro station are positioned on top of the building 15 at the height of 52.5 m on the edge of the building top. Their azimuth (with respect to the north direction) and vertical orientation (clockwise) is as follows:

- Antenna 1: azimuth 0^0, electrical tilt 15^0, mechanical tilt 7^0
- Antenna 2: azimuth 120^0, electrical tilt 15^0, mechanical tilt 18^0
- Antenna 3: azimuth 240^0, electrical tilt 15^0, mechanical tilt 18^0

The macro cells are complemented with 12 micro/pico cells. Antennas of micro/pico station are positioned on the lamppost, 10 m above the ground, 3 m away from the nearest building and on the symmetry axis of the nearest building as depicted in Figure 9.6. Two cells per micro-station point toward the main street with the same antenna pattern as macrocells. The network can be also enhanced by the dense network of small cells. Outdoor small cells are positioned on the facades of the building 5 m above the ground level. Indoor small cells are positioned at the ceiling of the rooms at the height of 3 m relatively to the floor ground. Small cell antennas are perfectly isotropic.

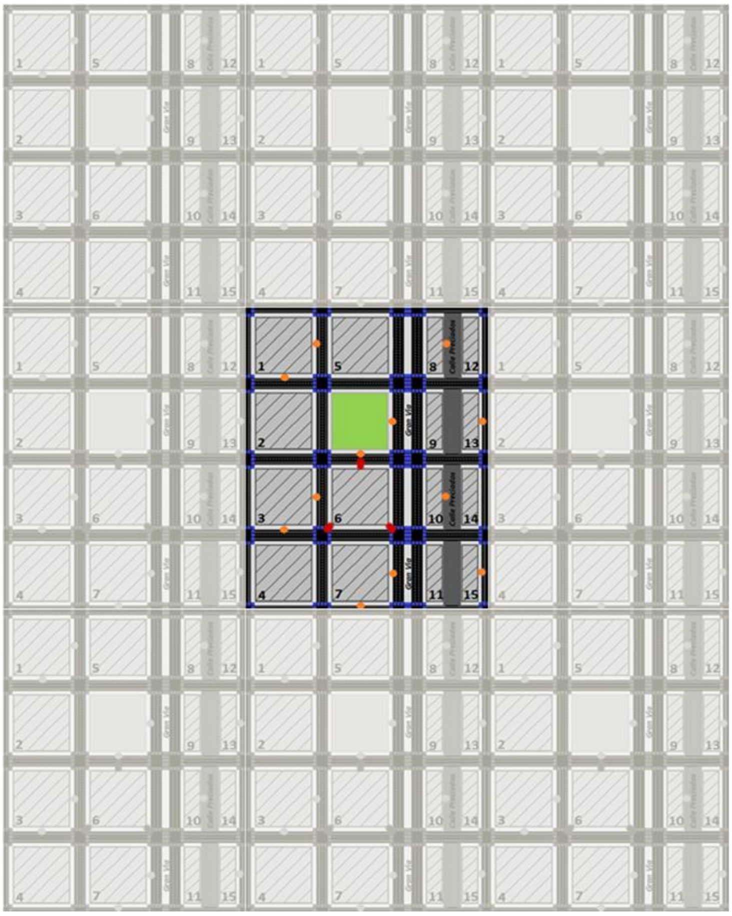

Figure 9.7: Simplified Wrap around approach for TC2. Shadowed area used to avoid boarder effects

Other deployment and parameters are summarized in next table.

Table 9.7: Default deployment parameters

	Macro	Micro/Pico	Small cells
Carrier frequency [MHz]	800	2600	2600
Bandwidth [MHz]	20	80	20
Maximum Tx power (per 10 MHz) [dBm]	43	30	20
Antenna height [m]	52.5	10	*outdoor*: 5 *indoor*: 3 relative to the floor level
Antenna configuration	4 TX/RX MIMO	2 TX/RX MIMO	2 TX/RX MIMO
Receiver noise figure [dB]	5	5	7
EVM [%] (SINR limited to 30 dB)	2	5	5

Other default simulation parameters are the following: UE height is 1.5 m and UE receiver is IRC with 2 TX/RX antennas.

Concerning users' deployment, their distribution is not specified. It could be made random or specific. Therefore, crowds/local users concentration is allowed.

9.2.5 Key performance indicators

The objective of this section is to define the KPIs of TC2 in the form of explicit metrics to evaluate in simulations. The evaluation metrics needed for evaluating the overall METIS goals as defined in D1.1 [1], is first described with the corresponding KPIs. Then some additional KPIs are described that are need when the performance of a solution is investigated for some particular sub-scenario within TC2. A particular TC2 sub-scenario can be defined using Section 9.2.1 to Section 9.2.4. For example, when investigating a technology applicable to D2D communication only the subset of the models applicable to this use-case is of interest. Then a KPI for this TC2 sub-scenario should be defined and compared to the corresponding KPI for the technology baseline as defined in Section 4.2.6.

KPIs and metrics for TC2

We first list the KPI, for the definitions of the KPIs see D1.1 [1] and for each KPI we define the relevant metric for some relevant simulation studies as sub-sections to each KPI section.

End user data rate

The requirement is that 95 % of locations and time have an experienced data rate of 300 Mbps and 60 Mbps in downlink and uplink, respectively.

System simulations

In a system simulation the evaluations metrics can facilitate both direct and indirect evaluation of the KPI. The requirement implies that the sampling here is per user and unit of time **U** when the user has data in the transmit buffer. The users need to be distributed according to the user arrival; mobility and traffic models as described in Section 9.2.2 and Section 9.2.3. The unit of time **U** for FTP-traffic should be defined according to the packed size **S** [bits] and the investigated 5th-percentile-rate **P** [bps] of the investigated system so that each sample contains at least one packet per user within the 95 % of the users and times that are meeting the requirements. The time unit is hence defined as:

$$\mathbf{U} = \mathbf{S} / \mathbf{P} \text{ [s]}.$$

For 160 Mbps user data, and the 300 Mbps downlink FTP data-rate the unit of time should be 160/300 s.

The relevant metrics for direct evaluation of the requirement is here CDF and 5th percentile data-rate and average SINR for the samples, each sample is as described above one user and one unit of time **U** as defined above. SINR is defined as the average wideband SINR for the used spectrum.

Further for the indirect evaluations the same metrics must be listed for 5th 50th 95th percentile and average together with a corresponding CDF for all samples and also separately for each of TC2 sub-scenarios. One type of important TC2 sub-scenarios are each of the different channel models as defined in Section 8.1. If a sample contains multiple channel models the particular sample should be discarded from the statistics for the individual channel models but be included in the statistics for all samples. For other TC2 sub-scenarios mixed samples should in a similar way be discarded.

Link simulations

For link simulations the evaluation metrics should be possible to map according to the above system simulations data. Hence for all the channel models as defined for the system simulations above a SINR to data-rate CDF should be evaluated and documented, the CDF samples should be per unit of time where the unit of time can be technology specific but typically the unit of time is one TTI (in LTE 1 ms).

Traffic volume

The system capacity requirement is a pure system simulation measure while fulfilling the end user data rates. The traffic volume target is 700 Gbps/km^2. The metric is the aggregated data transmitted by all users during the simulation time divided by the system area at the end user 5th percentile data rates 300 Mbps and 60 Mbps in downlink and uplink receptively. The traffic volume capacity will be strongly dependent upon the user distribution and which traffic models the different user categorizes use and can only be evaluated when implementing TC2 potentially with different propagation models if different spectrum is used for some technology component.

End-to-end delay

The delay requirements are specified for cloud applications (less than 2 to 5 ms) and D2D HARQ feedback (less than 1 ms) in D1.1 but are related to all simulations where the protocol specifics of the investigated technology are simulated. The metrics is in this case the same independent upon the used simulator. It is foreseen that specialized link simulators with a protocol focus could be used for the evaluation of these aspect, but also full system simulations.

HARQ delay

An HARQ protocol can either operate synchronized or asynchronized. For the both cases the relevant metric is the distribution over retransmission attempts, that is, which fraction of the transmissions are successful in the first transmission attempts, after the first retransmission (i.e. after two attempts) etc. Further for both, although more important for the asynchronize case; also a CDF over the total HARQ delay must be documented.

Setup (random access) delay

The metric here is the 5th, 50th, 95th and average time for setup (if the setup is always successful otherwise the percentage of successful setups) and also a CDF over the time for setup (random access). Further the distribution over setup attempts, that is, which fraction of the setup attempts are successful in the first attempt, after the second attempt etc.

D2D discovery time

For a D2D communication the two devices that will participate in a D2D communication will initiate a discovery procedure that is technology specific for establishing a connection with each other on the radio link. The initiation procedure is also strongly dependent upon the used environment and traffic model. The metrics for documentation are the 5th, 50th, 95th; the percentage of successful discoveries and a CDF over the discovered terminals as a function of time. The discovery process initiation is defined according to the traffic model for system simulations or in a dedicated way for the D2D cluster for link simulations.

TC2 sub-scenario KPIs

One of the main usages of the defined metrics is to be able to evaluate the performance of technology components when used in TC2. Further should also be possible to compare to the results for the baseline technology. In order to facilitate other evaluation criteria’s relevant to the METIS technology concepts and make it possible to evaluate for other end-user KPIs (other than the ones included in D1.1, [1]). For example, an animated office would support much higher data-rates than what is experienced by the 5th percentile users, as evaluated according to D1.1. But with the knowledge from link simulations of the proposed new technologies for the office environment and knowledge about the SINR for the relevant spectrum; channel model; traffic model and user distribution the experienced data-rates for a specific technology component can be roughly estimated. In later stages of the METIS project it is foreseen that the most promising technologies could be evaluated in more detail for a better estimate of their performance when used in a particular test case.

9.3 TC3: Shopping mall

9.3.1 Environmental model details

The size of the objects in Figure 4.4 is given in the following table.

Table 9.8: Environmental details of TC3

Object	**Width [m] (x-direction)**	**Depth [m] (y-direction)**	**Height [m] (z-direction)**
Total mall area	300	200	5
Corner stores	40	90	4
Outer stores	40	40	4
Inner stores	40	100	4
Food-court	120	100	5

Inner walls are geometrical represented by a surface with thickness zero and the penetration loss is according to the values corresponding to the used spectrum e.g. 2.6 GHz or mmW. The wide corridors are 20 m wide and the narrow corridors are 10 m wide. The openings to the food-court are both 80 m wide.

9.3.2 Mobility model details

There are a fixed number of users throughout the simulation. These users are at the start of the simulation uniformly distributed throughout the entire shopping mall. A user that is placed in a shop is given a random direction. A user in the passage way picks a random direction along the passage way. A user in the food-court walks to the closest table, and spends a random amount of time at this table (specified below).

Detailed mobility model in the passage way: The users in the passage way walk at the speed of 5 km/h.

Detailed mobility model in the shopping areas: Given that a user enters a shopping area, through a white opening/exit, it at random then uniformly chooses an angle. The user walks in this direction, given by the previously random chosen angle, at the speed 1 km/h until either reaching a wall or one of the exits of the shopping area. If the user reaches one of the other exits it leaves the shopping area. On the other hand, if the user enters a wall it randomly chooses one of the exits of the shop and then leaves the shop by performing a linear walk from its current position to the chosen exit of the shop. The user then once again enters the passage way of the shopping mall.

Detailed mobility model in the food-court area: Given that a user enters the food-court area, through one of the white opening/exits, it at random choses one of the predefined table positions. The user then walks to the table position at the speed of 1 km/h. Sits down and eat, i.e. wait for a random amount of time, before once again getting up and leaving through the closest exit.

Random amount of time at a table in the food-court area: Exponentially distributed with mean of ten minutes.

Probability to enter a shopping area: The probability to enter a shop from the passage way given that one passes an entry to the shop is five percent. This is the only way to enter a shop.

Probability to enter the food-court area: The probability to enter the food-court from the passage way given that one passes an entry to the food-court is five percent. The food-court has five entries per side, i.e. in total there are ten entries.

Probability to turn in the passage way: The direction in a crossing is uniformly picked in among all outgoing direction (i.e. all directions except for the incoming direction). Given the chosen passage way the user uniformly pick where to go in the passage way, i.e. for a ten meter outgoing passage one pick a real number uniformly between zero and ten. The user then follows the passage way in a straight line, i.e. with the distance to the walls of the passage way at the constant distance given by the random number.

Exit of shopping mall: If a user enters one of the exits of the shopping mall area, i.e. the outer boundaries of the map given in Figure 4.4, it will reappear in one of the other entrances (with equal probability for all the other entrances) of the shopping mall. Given the chosen entrance the user uniformly pick where to enter in the passage way.

An illustration of a user's path through the shopping mall is given in the next figure.

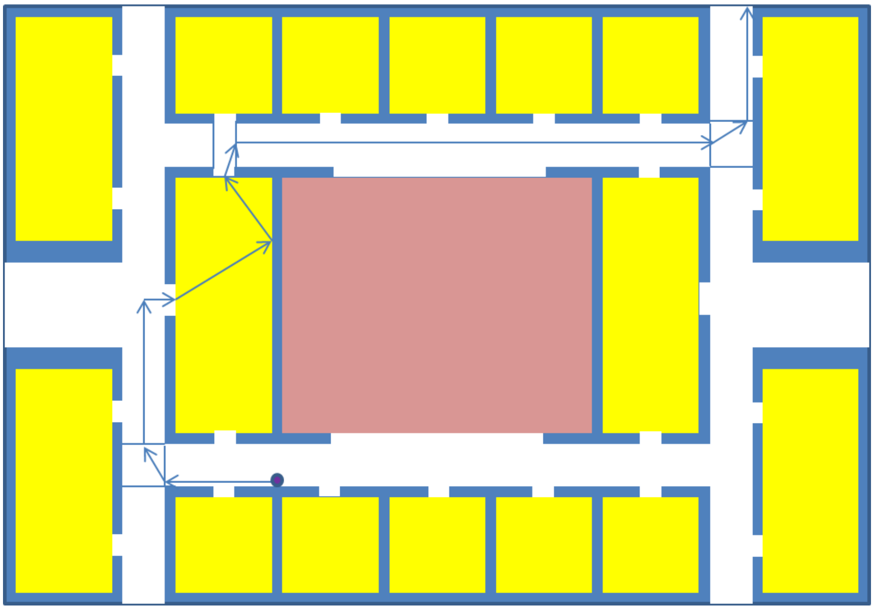

Figure 9.8: An illustration of a user's path through the shopping mall

9.4 TC4: Stadium

9.4.1 Environment model details

The stadium is placed on an ellipse with a minor radius of 105 m and the larger radius of 150 m. The center of this ellipse is occupied by a playground of 70 m x 100 m and the height of the stadium in its highest point is equal to 33 m. All area of stadium except the playground is covered with a deck at the height of 33 m. The angle of the tribunes is 30^0 with respect to the ground.

Out of entire stadium, selected area of 50 m x 100 m adjacent to the playground is selected for simulation purposes, out of which the range of 30 m x 40 m is used to evaluate the simulation results. The environment is depicted in Figure 9.9.

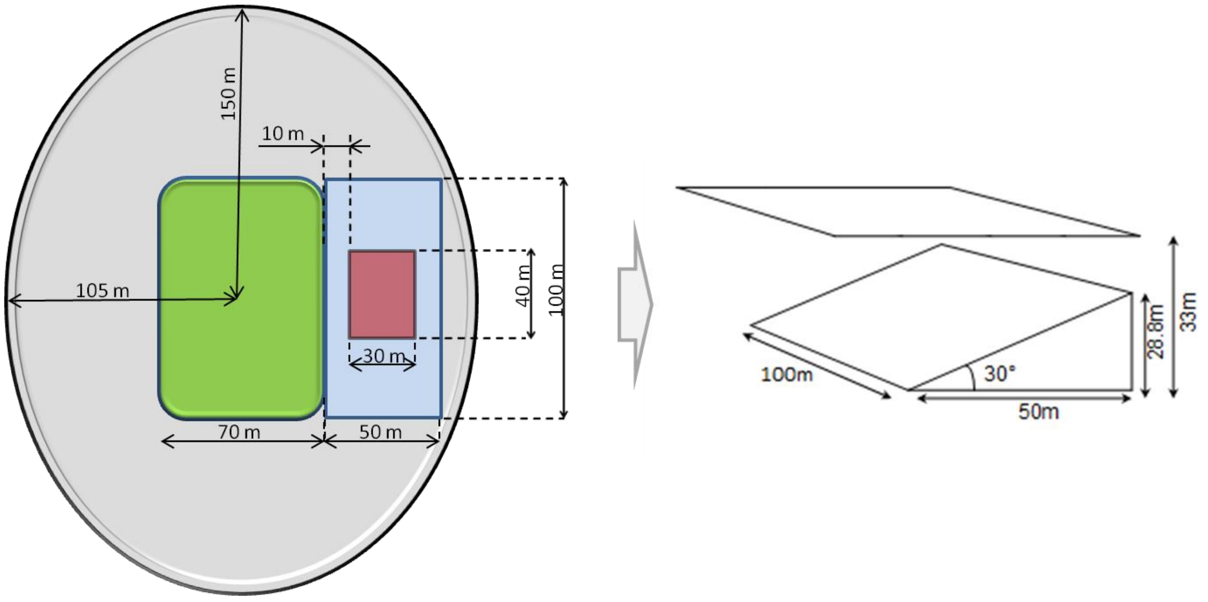

Figure 9.9: Detailed stadium environment model

9.4.2 Propagation model details

Models defined in Section 8.1 should be used with the necessary modification for 3D calculations:

- the user relative height is 1 m above tribune level,
- distance between UE and small cell antenna as well as between UE and UE in D2D communication mode is a 3D distance,
- for D2D transmission additional propagation losses of 3 dB/m are added to account for human body loss attenuation,
- although no mobility of users is assumed for Stadium, a velocity of 3 km/h should be used to account for small scale effects.

More detailed propagation models are allowed if standardized by 3GPP [45] with respect to small cell – UE propagation and for D2D communication if derived from 3GPP or METIS.

9.4.3 Traffic model

Two options of most challenging cases are proposed for TC4 accounting for busy hour:

- DL heavy traffic + UL + D2D traffic (optional). This traffic is expected during the breaks in the event. Users are downloading, uploading and exchanging 50 Mbytes files (in case of D2D transmission the file size is equal to 25 Mbytes) every 20 s. The DL:UL ratio is 7:1 (or in case of optional D2D the DL:UL:D2D ratio is 7:1:1).
- UL heavy traffic + DL + D2D traffic (optional). This traffic is expected after e.g. a team scores a goal and the audience is sharing compressed video files. Users are uploading, downloading and exchanging 75 Mbytes (in case of D2D transmission the file size is equal to 37.5 Mbytes) file every 30 s. The DL:UL traffic ratio is 1:7 (or in case of optional D2D the DL:UL:D2D ratio is 1:7:1).

All users are active. Aforementioned mean packet inter arrival time is a mean value and is modelled with a Poisson distributions.

Both options yield 9 Gbytes/h per user according to the test case description in [1].

For e.g., energy efficiency studies other traffic configurations are allowed giving that user traffic restrictions from Table 10.1 in [1] are met.

9.4.4 Deployment considerations

In the Stadium test case there are 9751 users distributed uniformly in the considered area. The distance between the users is 1 m along the major stadium axis and 0.5 m along minor stadium axis. There are 49 rows with 199 UEs each as depicted in Figure 9.10. Additionally, users separated along minor axis have different height, linear to slant of the stadium (30^0).

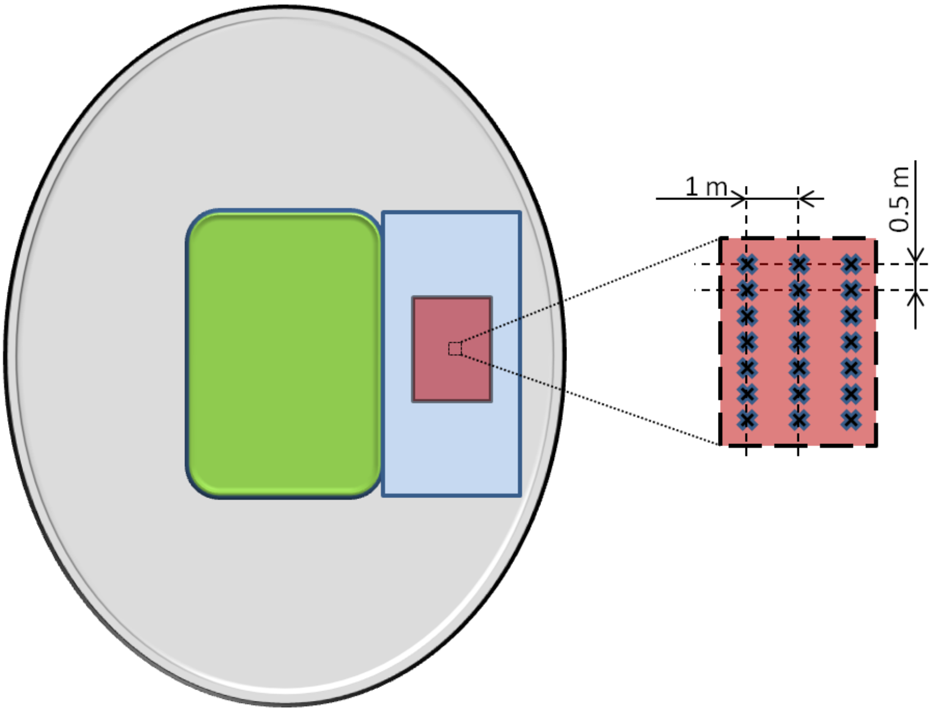

Figure 9.10: 2D user deployment in TC4

In the considered simulation area there are 27 small cells antennas deployed on the roof of the Stadium. Deployment of small cell antennas is depicted in Figure 9.11.

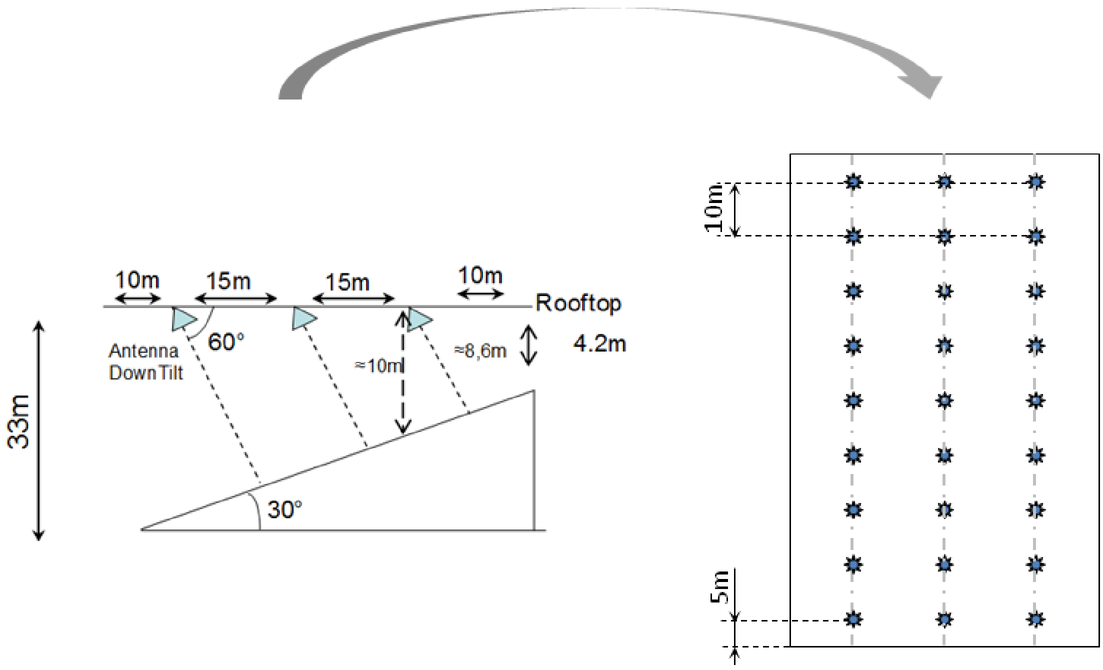

Figure 9.11: Details of small cell antennas deployment in the deck of the Stadium

Antennas of different cells are all deployed at the height of 33 m, with horizontal plane separation of 10 m along the major Stadium axis and 15 m along minor Stadium axis. To avoid intercell interferences the antennas are directive and all of them are 60^0 angled with respect to the roof plane orientation. The total output power for small cell is limited to 30 dBm.

By default small cells are deployed on out band frequency with respect to macro layer. For optional in band deployment a TC2 environment should be used for macro layer simulations or an extra noise raise of 10 dB should be added to account for co-channel macro-small cell interferences.