Mobile and wireless communications Enablers for the Twenty-twenty Information Society-II

Deliverable D2.1
Performance evaluation framework

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Abstract

This deliverable contains a proposal for a performance evaluation framework that aims at ensuring that multiple projects within 5G-PPP wireless strand can quantitatively assess and compare the performance of different 5G RAN design concepts. The report collects the vision of several 5G-PPP projects and is conceived as a living document to be further elaborated along with the 5G-PPP framework workshops planned during 2016.

Revision History

Revision	Date	Description
1.0	2016-01-31	D2.1 release v1.0

Executive summary

The technologies studied in METIS-II should not only be investigated independently by the researchers in METIS-II, but also be tied to the activity in the wireless strand of the 5G-PPP. In order to allow for a direct comparison of different technology components it is very important, in particular in such a collective effort, to provide guidelines to align assumptions, methodologies and simulation scenarios at an early stage. On the other hand, the new use cases and system paradigms that are envisioned for the next generation of mobile communication systems impose the need to re-define such simulation procedures and models.

In this challenging environment, METIS-II is supporting the wireless strand of the 5G-PPP to obtain valid simulation results for the evaluation of the 5G concepts from the European point of view. In order to ensure consistency of results, METIS-II will, after reaching consensus with the other projects, provide to all partners in the 5G-PPP wireless strand a procedure for calibration, complete guidelines for simulation and a mechanism to support and control the validity for the simulations performed in the technical work.

This deliverable aims at providing an intermediate picture of these activities on the way towards final harmonization. Therefore, this document does not represent the definitive simulation framework, but rather fosters the discussion and permits other projects to study and comment on the METIS-II proposal. At the end of the process, 5G-PPP wireless strand will complete the guidelines for simulation that will be distributed within this group to ensure the quality and validity of the simulation results.

The content of this deliverable will be used as starting point for the work in the next months and culminate in the final simulation framework. This means that the conclusions and results summarized in this deliverable cannot be understood as definitive, but rather as a METIS-II proposal that will be presented in different standardization fora.

Contents

List of Abbreviations and Acronyms

2D	Two dimensional
3D	Three dimensional
3GPP	Third Generation Partnership Project
4G	4th Generation
5G	5th Generation
5G-PPP	5G Public-Private Partnership
BS	Base station
BW	Bandwidth
CAM	Cooperative Awareness Messages
CoMP	Coordinated multipoint
CP	Control plane
D2D	Device-to-device
DENM	Distributed Environment Notification Messages
DRX	Discontinuous reception
EESM	Exponential effective SINR mapping
EU	European Union
FBMC	Filter bank multicarrier
FDC	Flat distributed cloud
FFS	For future studies
FTP	File Transfer Protocol
GFDM	Generalized filtered multicarrier
HEW	High efficiency WLAN
HetNet	Heterogeneous network
ICT	Information and Communications Technology
IEEE	Institute of Electrical and Electronics Engineers
IMT-A	International Mobile Telecommunication-Advanced
InH	Indoor hotspot
ISD	Inter-site distance
ITS	Intelligent Transport System

ITU	International Telecommunication Union
IoT	Internet of Things
KPI	Key performance indicator
L2S	Link to system
LLS	Link level simulator
LOS	Line-of-sight
LTE	Long Term Evolution
LTE-A	LTE-Advanced
MAC	Medium access control
MBB	Mobile broadband
MIESM	Mutual information effective SINR mapping
MIMO	Multiple input multiple output
mMTC	Massive MTC
mmW	Millimetre wave
MTC	Machine-type communication
MU-MIMO	Multi user-MIMO
NGMN	Next Generation Mobile Networks
OAM	Operations and maintenance
OFDM	Orthogonal frequency division multiplexing
OSC	Outdoor small cell
OTT	One trip time
PER	Packet error rate
PRR	Packet reception ratio
QoE	Quality of experience
QoS	Quality of service
RACH	Random access channel
RAN	Radio access network
RAT	Radio access technology
RIT	Radio interface technology
RMa	Rural macro
RRC	Radio resource control
RRM	Radio resource management

RTT	Round trip time
SCM	Spatial channel model
SINR	Signal to interference and noise ratio
SLS	System level simulator
SOTA	State-of-the-art
TTI	Transmission time interval
UDN	Ultra-dense network
UE	User equipment
UF-OFDM	Universal filtered OFDM
UMa	Urban macro
UMa-H	UMa with a high rise buildings
UMi	Urban micro
uMTC	Ultra-reliable MTC
UP	User plane
V2X	Vehicle-to-anything
VoIP	Voice over Internet Protocol
WLAN	Wireless local access network
xMBB	Extreme MBB

1 Introduction

The 5th generation of cellular communication systems (5G) is expected to address the wireless connectivity needs for both humans and machine-type devices in 2020 and beyond. To ensure that 5G is introduced in time and in economically attractive form, several European research projects in phase 1 of the 5G-Public Private Partnership (5G-PPP) are investigating the most attractive improvement areas that could help addressing key 5G objectives. Among these projects, METIS-II, aims at:

- developing the overall 5G radio access network (RAN) through designing the technology for an efficient integration of legacy and novel RAN concepts into one holistic 5G system;
- providing the 5G collaboration within 5G-PPP for a common evaluation of 5G RAN concepts;
- preparing concerted actions towards regulatory and standardization bodies for an efficient standardization and development of 5G.

This deliverable concerns the second main objective of the METIS-II project and is seen as a key milestone into the collaboration for the common evaluation of the 5G within the 5G-PPP wireless strand.

1.1 Objective of the document

In comparison to 4th generation systems (4G), next generation of wireless communications will push the broadband connectivity to new extremes, by utilizing new solutions such as massive multiple-input multiple-output (MIMO), radio access using higher frequency ranges in millimetre waves (mmW) region or ultra-dense networks (UDN). Therefore, the 5G is expected to considerably improve the overall end user experience achievable in contemporary wireless communication systems, and significantly boost the cost-efficiency factor of running the network. At the same time, it is envisioned that the 5G will expand the application areas to new domains, such as Internet of Things (IoT) or road traffic safety and intelligent transport system (ITS), which require key performance indicators (KPIs) very different than the ones used for the assessment of broadband access performance in 4G.

Above-mentioned factors necessitate the creation of a new performance evaluation framework that will allow for a fair and comparable evaluation of various technology concepts proposed for 5G. The main objective of this deliverable is to provide such collaboration within 5G-PPP, which could be used for a common evaluation of 5G RAN concepts. Additionally, in the long term, such evaluation framework could be used to quantify the overall performance of designed 5G system similarly to International Mobile Telecommunication-Advanced (IMT-A) requirements presented in [ITUR08-M2134].

Having these objectives in mind, METIS-II deliverable D2.1 provides models, definitions and supplementary data necessary for the evaluation of all 5G use cases (UCs) proposed in [MET16-D11]. Results of this benchmarking will be published in METIS-II deliverable D2.3 'Performance evaluation results' in February 2017.

1.2 Structure of the document

The rest of the document is organized as follows:

- Section 2 provides a short overview of five METIS-II 5G UCs, KPI's definitions, basic simulation guidelines and evaluation methods (inspection, analysis and simulation).
- Section 3 describes synthetic and realistic deployment scenarios that are recommended for evaluation of technical concepts for 5G.
- Section 4 captures remaining models proposed for the 5G performance evaluation framework, such as channel, mobility, traffic models, etc.
- Section 5 summarizes the proposed evaluation framework.
- Appendix A provides remaining details of the deployment and channel models, including a description of mobility traces.
- Appendix B provides information on the supplementary material for METIS-II performance evaluation framework in form of preliminary calibration data.
- Appendix C recaps on IMT-A evaluation methodology, that was used as a baseline for the METIS-II approach.
- Appendix D summarizes state-of-the-art (SOTA) evaluation methods, UCs and technical requirements from projects and organizations that were identified as relevant from the 5G perspective.
- Appendix E details information needed for interfacing METIS-II visualization tool [MET16-D71].
- Finally, Appendix F highlights performance evaluation models, requirements and KPIs derived in other 5G-PPP projects.

2 5G performance evaluation framework – process, use cases and KPIs

2.1 Overview of the evaluation process

One of the main objectives of the METIS-II project is to provide the 5G collaboration within the 5G-PPP group of funded projects for a common evaluation of 5G RAN technologies. This includes the proposal of a joint evaluation framework that simplifies the alignment of the 5G-PPP projects within the wireless strand into a similar process that offers outside Europe a single view and positioning of the European industry. With this ambitious target, METIS-II organized a first 5G-PPP workshop in September 2015, while issuing 5G-PPP internal report R2.2 followed by this deliverable, that includes a first proposal for the evaluation process. In parallel METIS-II is releasing a refined set of scenarios and requirements, consolidated UCs, and qualitative techno-economic feasibility assessment [MET16-D11].

The final aim of this process is to be ready for the future IMT-2020 (5G) evaluation process, anticipating and aligning the positioning of the European industry to lead the process in a proactive manner. The report ITU-R M.2320 [ITU14-M2320] provides information on the technology trends of terrestrial IMT systems considering the time-frame 2015-2020 and beyond. Technologies described in this report are collections of possible technology enablers which may be applied in the future 5G air interface variants (AIVs). The report [ITU14-M2320] also specifies the objectives of the future development of the IMT-2020 family: among them is to reach 1000 times higher data volume support as compared with the cellular systems abilities in 2010. From this set of technology enablers and others, different 5G-PPP projects will develop 5G concepts, for which METIS-II is striving to obtain maximum consensus.

The different candidates proposed by 5G-PPP projects will be verified through the self-evaluation made by the proponents and the activity performed by the evaluation group in the METIS-II, which will count on a set of experts from the partners participating in this activity.

Coordination between METIS-II and concept proponents is strongly recommended to facilitate comparison and consistency of results and to simplify the understanding of differences in achieved evaluation results. The divergence in the results obtained in the evaluation of the same system is a common problem encountered in all forums, where researchers coming from different bodies try to provide their contributions to the progress of science and technology. A possibility to overcome this situation is the comparison of different approaches using the same evaluation framework. With this aim, and in order to simplify the internal 5G-PPP assessment, METIS-II has prepared this deliverable that contains a proposal for general simulation assumptions and the evaluation methodologies of this process. This document represents a significant reference that intends to ensure the proper harmonisation of the tools used by the 5G-PPP wireless strand group for performance evaluation of potential IMT-2020 technologies and is intended also to influence the future discussions in the WP 5D group. Final output of the performance evaluation made in METIS-II will be available in the deliverable D2.3 'Performance evaluation results', which will be issued in February 2017.

The rest of this section contains general structure of proposed evaluation framework and a short summary of the five METIS-II UCs belonging to the three UC families defined in [MET14-D63] and further elaborated in [MET16-D11]: extreme mobile broadband (xMBB), massive machine type communication (mMTC) and ultra-reliable machine type communication (uMTC). As depicted in Figure 2-1, proposed UCs cover completely the set of 5G requirements specified in [MET16-D11]. They are in line with generic services defined in [ITUR15-M2083]. This section provides also definitions and evaluation methods for KPIs that could be used to quantify performance of 5G solutions in proposed UCs, and finally, general simulation guidelines.

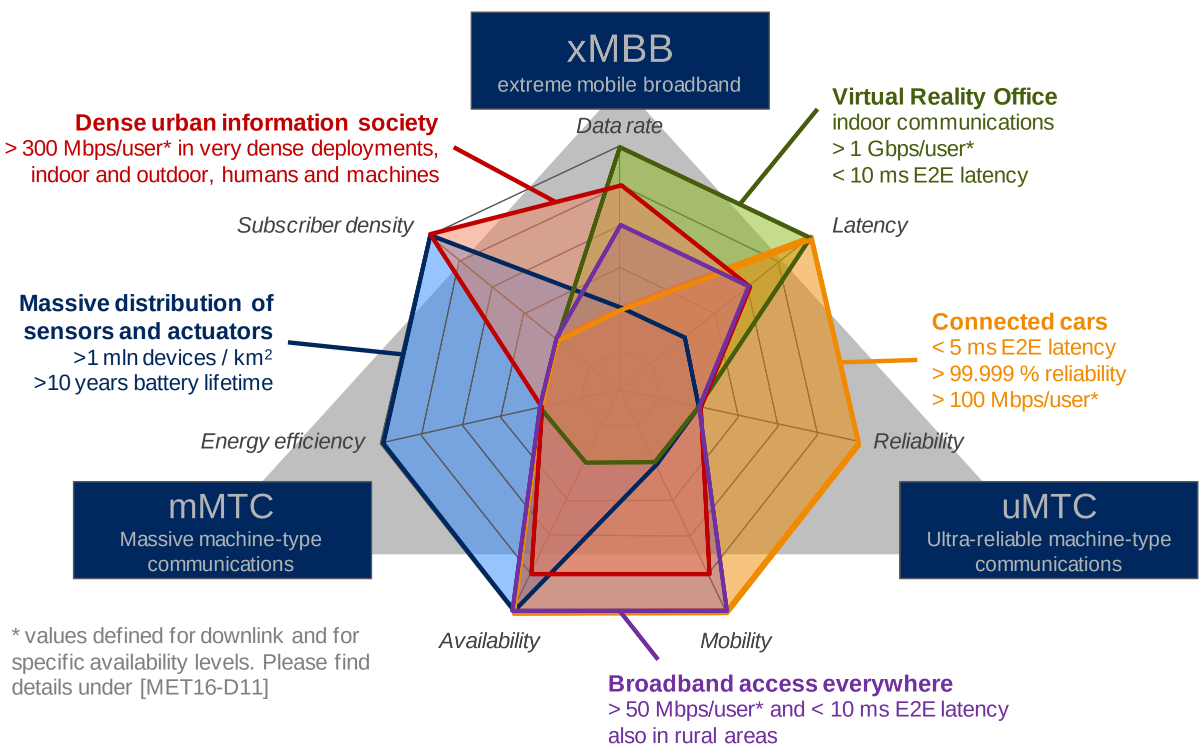


Figure 2-1: METIS-II UC families and their requirements.

2.2 Structure of the METIS-II 5G performance evaluation framework

Figure 2-2 depicts the METIS-II evaluation framework that can be grouped into four basic building blocks:

- 5G UCs reflecting predicted applications and their requirements. In order to show the full potential of the next generation of wireless cellular communication systems, these UCs need to be defined in a demanding network operation conditions e.g., in a rush hour. UCs should also span over all potential 5G utilization scenarios e.g., cover all UC families, low and high mobility of users, dense and sparse infrastructure, etc.;
- KPIs and their evaluation methods (comprising inspection, analysis and simulation) as well as procedures that would guarantee a fair assessment of different technical solutions proposed for 5G in a given UC.
- deployment scenarios that would represent expected real infrastructure deployment options envisioned for 5G networks, typical for proposed UCs;
- models and their parameters that will be used for performance assessment of 5G technical solutions or different network configurations. Proposed models are simple but, on the other hand, they also reflect key properties of 5G deployments and predicted 5G user behaviour, whenever it is possible.

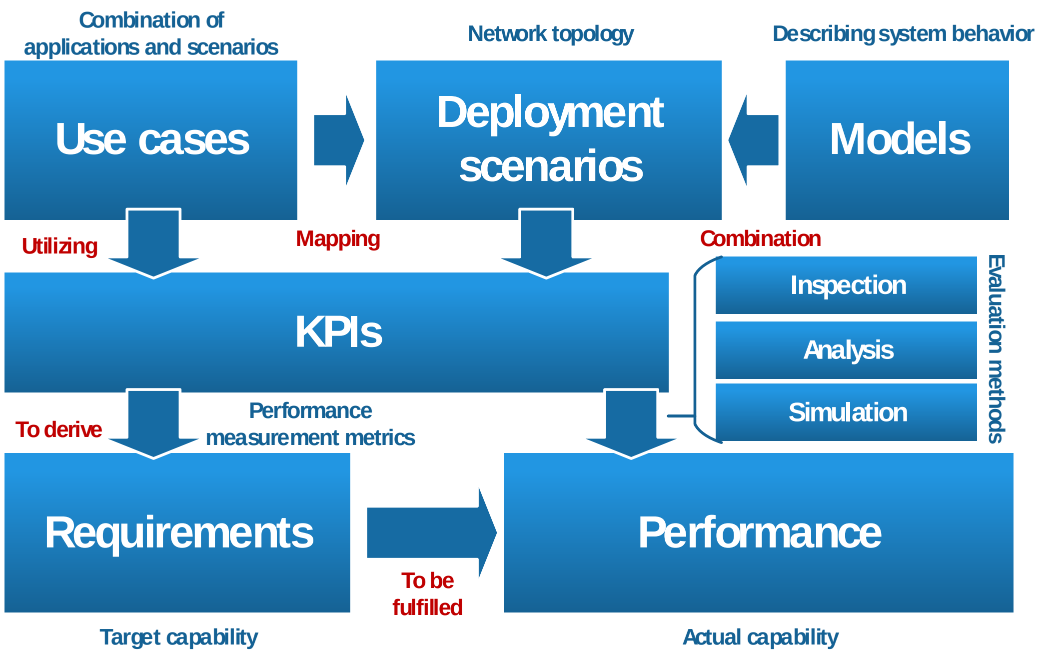


Figure 2-2: METIS-II evaluation framework.

It should be underlined that selection of above mentioned aspects for METIS-II performance evaluation framework was done based on a reasonable compromise between the complexity of evaluation process and accuracy of prediction of 5G users' quality of experience (QoE) or 5G system performance in a given UC.

2.3 METIS-II 5G use cases

2.3.1 UC1: Dense urban information society

The Dense urban information society UC, UC1, caters for providing 5G xMBB connectivity for city dwellers at any place and time. From a service point of view, adopters of 5G in this UC may particularly want to experience immersive multi-media provided by 5G services, including 4K/8K ultra high definition video, virtual reality or real time mobile gaming. These 5G experiences should come with a palpable improvement from the QoE of users compared to the legacy 4G services.

This UC spans over the typical dense urban area where humans access data-hungry services. Such environments are challenging for network operators due to the demand for providing a high capacity network that is able to handle a varying (in both space and time) mobile traffic exchange. These short/midterm traffic variations can originate from the dynamic crowd formation caused by traffic lights, gatherings at bus stops, etc. In modern cellular deployments, such above-mentioned aspects are tackled by using heterogeneous networks (HetNets), which are capable of providing local capacity through utilization of small cells resources over a limited area. However, HetNet deployments comprising macro and small cell layers lead to additional challenges. Major drawbacks are caused by increased complexity and cost (to a large degree influenced by consumption of electricity). Additionally, optimal mapping of users/services to appropriate network layer is not straightforward and requires utilization of knowledge on surrounding environment, especially if mobility is taken into account.

As in year 2014 54% of global population lived in urban areas (and this trend is increasing [UN14]), it is of the uttermost importance to evaluate potential 5G solutions in the setup envisioned by this UC.

2.3.2 UC2: Virtual reality office

The Virtual reality office UC, UC2, is a future indoor setting where improved wireless technologies will provide extremely high experienced user throughputs while fulfilling challenging capacity requirements at a reasonable cost.

xMBB indoor scenarios are extremely demanding, as the end users expect QoE similar to the one achievable using wired solution. Additionally, traffic demand in indoor spaces very often shows a strong time correlation among different users e.g., during office hours in the business enterprises. This leads to a UC that shows highest requirements w.r.t. supported traffic volume densities and experienced user's throughputs. Due to the presence of a large number of xMBB consumers over limited area, network densification is inevitable leading to a inter-site distances (ISDs) unpreceded in legacy 4G network. Such deployments, also known as ultra-dense networks (UDNs), are expected to operate on higher frequency ranges to provide >1 Gbps throughputs, and in a time division duplexing (TDD) mode to better adapt available radio resources to instantaneous traffic variations (UL vs DL). In the same time, UDN deployments will require technical solutions that will mitigate the detrimental effects of dynamic interferences and provide high performance at low cost and power consumption.

It is expected that majority of the traffic in the nearest future will come from indoors [CIS15], therefore this UC plays a key role in the performance assessment of 5G solutions.

2.3.3 UC3: Broadband access everywhere

Last UC focusing explicitly on xMBB, UC3 Broadband access everywhere, emphasizes the need of providing decent broadband user experience practically everywhere, even in areas with sparse network infrastructure or at very high user speeds. The target value of 50 Mbps everywhere should be understood as the minimum experienced user throughput and not as a desired average data rate. Sparse deployments and high velocities assumptions are typically encountered in areas outside of urban agglomerations. Large ISDs pose the need for lower frequency ranges for radio access, and exploitation of high power base stations (BSs), usually mounted on high radio masts or transmission towers. Due to the low penetration of potential customers, both capital and operational expenditures of rolled out infrastructure should be economically justified.

This UC is an important enabler for an an overall economical development as '10% increase in broadband penetration brings up the gross domestic product (GDP) by 1-1.5%*'* [EC-Web].

2.3.4 UC4: Massive distribution of sensors and actuators

A progressive trend is observed in contemporary networks, where machine type devices use radio access to transmit data related to the variety of applications. This trend, also known as the IoT, with tens of billions of connected devices in the next decade, is expected to become one of the biggest revenue streams for the future 5G players through solutions belonging to mMTC UC family [MET16-D11]. As key challenges for mMTC are different than for xMBB or uMTC (e.g., a very large number of low cost devices requiring sporadic access for a low payload data exchange), a separate UC addressing these challenges is necessary.

Machine type devices usually operate in the lower frequency regimes. It may be also expected that, despite the number of versatile applications for IoT, a vast number of mMTC devices will be deployed in cities (smart grid, wearables, automotive sensors, tracking or eHealth devices). Additionally many of the measuring devices can suffer very high penetration losses (e.g., water meters located in the basement of a building) when deployed indoors. In order for 5G to be an economically justified system for these mMTC application, it needs to enable a low-cost (complexity) and a low-power operations (device energy efficiency), as well as solutions allowing coverage extension beyond the values achievable in previous cellular generations.

Since mMTC is expected to open new viable business opportunities for 5G operators, it is essential for 5G to address this domain as well.

2.3.5 UC5: Connected cars

The Connected cars UC completes the set of 5G UCs proposed by METIS-II, by covering the last corner of 5G UC families, i.e. uMTC. Contrary to previously defined UCs, UC5 focuses on providing ultra-reliable data exchange. Although there are several examples of applications for uMTC (e.g., industry automation, or power line transmission), connected cars focus on the exchange of safety related data between moving vehicles (or potential vulnerable road users). Such safety related communication required for ITS is challenging, as reliability of the transmission can be impacted by the availability of radio resources (possible concentration of vehicles in a single cell) and high velocity (frequent cell change and challenging transmission conditions caused by the high Doppler effect).

As vehicular safety and other mission-critical application can bring huge societal benefits by e.g., decreasing the overall number of traffic accidents [MET13-D11], 5G is expected to cater for such services as well.

2.4 5G KPIs definitions and evaluation methods

In order to quantify how certain technical solutions would affect a QoE of end users or what would be the 5G system performance in a desired UC, specific evaluation metrics are needed. This section gives definitions of 5G main characteristics and KPIs, similar to the ones defined in [ITUR15-M2083], and provides basic info on how to evaluate them through inspection, analysis or simulation methods:

- Evaluations through simulations contain both system level simulations and link level simulations although it is expected that majority of solutions proposed in METIS-II will be assessed using system level evaluation.
- In case of analytical procedure, the evaluation is to be based on calculations using the technical information provided by the technology component owner (methodology, algorithm, module or protocol that enables features of the 5G system is a technology component or enabler).
- In case of evaluation through inspection the evaluation is based on statements.

Definitions provided in this subsection will be further specified w.r.t. expected 5G performance values in METIS-II deliverable D2.3 ‘Performance evaluation results’.

2.4.1 Inspection method

Inspection methods are applied to 5G KPIs that are design-dependent and can be assessed by looking into general system design information. Despite the fact that these KPIs require only simple yes/no answer for assessment, it should be highlighted that all KPIs that are listed in this section will play a fundamental role in 5G and are basis for high performing wireless system.

Bandwidth and channel bandwidth scalability

Scalable bandwidth is the ability of the 5G system to operate with different bandwidth allocations. This bandwidth may be supported by single or multiple radio frequency carriers.

The 5G system shall support a scalable bandwidth of at least 1 GHz. Proponents are encouraged to consider extensions to support operation in wider bandwidths (e.g. up to 2 GHz).

Deployment in IMT bands

Deployment of the 5G system must be possible in at least one of the identified IMT bands. Proponents are encouraged to clarify the preferred bands for the proposed candidate/s.

Operation above 6 GHz

The candidate air interface shall be able to operate in centimetre wave and/or mmW bands with one or several AIVs especially suited to these bands.

Spectrum flexibility

The ability of the access technology to be adapted to suit different DL/UL traffic patterns and capacity needs for both paired and unpaired frequency bands [3GPP15-152129].

Inter-system handover

Inter-system handovers between the 5G system and at least one legacy radio access technology (2G/3G/4G) shall be supported.

Support for wide range of services

The ability of the access technology to meet the connectivity requirements of a range of existing and future (as yet unknown) services to be operable on a single continuous block of spectrum in an efficient manner [3GPP15-152129].

Note that hybrid services including xMBB, mMTC and uMTC may be supported in the same band.

2.4.2 Analysis method

Analysis methods are applied for 5G KPIs that can be assessed using elementary calculations. Although some input parameters for such KPIs depend on e.g., network load, and can be specified using simple simulations, in general their value is repetitive or static during regular network operations.

Control plane latency

The following steps should be detailed, included their need and, if appropriate, the time required for each one of the steps. Total latency must be provided together with the latencies of all intermediate steps, if any. Note that the full set of steps represents the idle to active state transition. However, the proponent must clarify intermediate states that could be included in the AIV, like a connected-inactive state, and the latencies associated with each intermediate state.

Table 2-1: Steps for the control plane (CP) latency analysis. Not all steps are required.

Step	Description	5G aspects for considerations
0	UE wakeup time	Wakeup time may significantly depend on the implementation (e.g., different for mMTC water meter sensor and for automotive uMTC device). Additionally, 5G may introduce intermediate states in addition to 4G LTE idle and connected, for the purpose of CP latency reduction and device energy consumption savings. The new introduced intermediate state might provide a widely configurable discontinuous reception (DRX) and thus contribute to different CP latency for different traffic patterns and battery requirement. Since UE can be configured by the network with different DRX in different situations, this delay component might be better reflected with simulation approach.
1	DL scanning and synchronization + broadcast channel acquisition	This step includes also beam finding / sweeping procedures in the terminal side, if needed. On the other hand, 5G may introduce different forms of multi-connectivity which may allow skipping this step e.g., broadcast information for the idle AIV could be delivered over other AIV where UE is able to receive it. With different configuration of multi-connectivity, broadcast information for the idle AIV might be delivered in different ways. In case of CP/user plane (UP) decoupling between two or more cells, detection of UP cells discovery signals needs to be taken into account. Detection of UP cell should not be longer than duration of steps 2-7. Note also that in novel AIVs the periodicity of certain common signals/channels for access may vary. These details shall be included in the description of this step duration calculation.
2	Random access procedure	In case random access channel (RACH) preamble is used for the transmission of small payloads, it shall be specified these

		characteristics. In case where collision of random access occurs, most likely for mMTC type traffic, evaluation of this delay component can be more precisely conducted with simulation approach.
3	UL synchronization	Current research points towards the fact that some waveforms may reduce the requirements for UL synchronization. This should be clearly stated in terms of duration. In case of totally asynchronous proposals, this duration shall be equal to zero.
4	Capability negotiation + hybrid automatic repeat request (HARQ) retransmission probability	Capability information may be already available in some of new states potentially introduced by 5G. In case of CP/UP decoupling between two or more cells, capabilities of UP and CP cell needs to be acquired
5	Authorization and authentication/ key exchange +HARQ retransmission probability	Security information may be already available in some of new states potentially introduced by 5G. It shall be specified if the security context is not discarded in the transition between the states.
6	Registration with the BS + HARQ retransmission probability	In case of UP/CP split, UE may register to the cell that is handling CP. In case when UP and CP are located in different RAN domains, UE may also register to both cells. In case of CP multi-connectivity, UE may register in multiple cells which are involved for CP functionalities. If the air interface does not require registration, this step can be omitted, e.g. due to reservation of context from a previous encounter.
7	Radio resource control (RRC) connection establishment/ resume + HARQ retransmission probability	In case of potential new 5G multi-connectivity configurations (e.g. RRC/CP diversity), this step is considered as done when RRC connection allowing for exchange of data information over a desired AIV is established In case if aggregation is located in the CN, RRC connection should be set up over multiple AIVs.

User plane latency

UP latency is defined as the one way transmission time of a packet between the transmitter and the availability of this packet in the receiver. The measurement reference is the MAC layer in both transmitter and receiver side. Analysis must distinguish between UP latency in an infrastructure-based communications and in a direct D2D communication.

Table 2-2: Steps for the user plane latency analysis. Not all steps are required.

Step	Description	LTE (e.g.)	5G aspects for considerations
0	Transmitter processing delay	1 TTI	
1	Frame alignment	0.5 TTI	
2	Synchronization	n.a.	In D2D communications, the UT may need some time for synchronization
3	Number of TTIs used for data packet transmission (includes UE scheduling request and access grant reception)	1 TTI (unloaded condition is assumed)	Assumption of unloaded condition is probably not valid any more, packets with fixed size might be used for specific traffic patterns, i.e. uMTC and mMTC services. Thus, number of TTIs used for each packet transmission depends on channel quality, allocated spectrum resource and exploitation of multi-connectivity. Introduced delay could be better reflected with simulations. However, analysis option is the preferred one. In case of UP multi-connectivity, this delay component should be derived w.r.t. different multi-connectivity configuration, i.e. whether different data streams are transmitted over different links or multiple links are simply used for data redundancy transmission. In 5G, both transmitter and receiver can be user devices considering D2D communication
4	HARQ retransmission	$P_{\mathrm{error}} * 5\ \mathrm{TTI}$	Instead of exploiting error probability of each transmission or retransmission for calculation of this delay component, the characteristics can be more precisely captured if the designed 5G protocol can be properly reflected in simulation. However, analysis option is the preferred option. Both CP and UP multi-connectivity impose impact on this delay component.

5	Receiver processing delay	1 TTI	

mMTC device energy consumption improvement

mMTC device energy consumption improvement is defined as the relative enhancement of energy consumption of 5G devices over LTE-A ones, under the assumption that device is stationary and uploads a 125 byte message every second. If not mentioned explicitly, energy consumption in RRC idle state is assumed the same for LTE-A and 5G devices.

Table 2-3: Steps included in the mMTC device consumption analysis.

Step	Description	5G aspects for considerations
0	Synchronization	5G devices can synchronize faster, depending on the allocation of synchronization signals
1	Transmit scheduling request	5G is expected to have shorter frame lengths enabling faster transmission of scheduling requests
2	Receive grant	5G is expected to introduce shorter frame lengths enabling faster reception of transmission grants
3	Transmit data	5G is expected to introduce shorter frame lengths enabling faster transmission of small payloads
4	HARQ retransmission	5G may enable faster reception of acknowledge/not-acknowledge info comparing to LTE-A solutions

Inter-system handover interruption time

The time duration during which a UE cannot exchange UP packets with any BS during transitions between 5G new AIVs and another legacy technology, like LTE-A which is of mandatory study. Additional other AIVs, including non-3GPP ones, are for future studies (FFS) [3GPP15-152129].

Mobility interruption time

Mobility interruption time is defined as the time span during which a UE cannot exchange UP packets with any BS during transitions [3GPP15-152129]. It can be regarded as intra-system handover interruption time.

Note that in 5G system, handover between adjacent BS may no longer exist due to solutions based on multi-connectivity and CP / UP decoupling.

Peak data rate

The peak data rate is the highest theoretical single user data rate, i.e., assuming error-free transmission conditions, when all available radio resources for the corresponding link direction are utilized (i.e., excluding radio resources that are used for physical layer synchronization, reference signals or pilots, guard bands and guard times). Peak data rate calculation shall include the details on the assumed MIMO configuration and bandwidth.

2.4.3 Simulation method

Simulation methods are applied for 5G KPIs that are heavily dependent on the instantaneous network conditions, such as available infrastructure and related radio resources, number of users, radio conditions, etc. Precise assessment of these KPIs is impossible without system level simulations.

Experienced user throughput

Experienced user throughput refers to an instantaneous data rate between Layer 2 and Layer 3. It is evaluated through system level simulations in respective deployment scenarios proposed in Section 3, according to simulation assumptions from Sections 4.1, 4.2 and 4.3 and using bursty traffic models. Note that experienced user throughput depends on the system bandwidth, and therefore this parameter shall be clearly identified in the simulation analysis.

Experienced user throughput is calculated as:

$$U_{Tput} = \frac{S}{T},$$

where S is the transmitted packet size and T is the packet transmission duration calculated as the difference between the time when the entire packet is correctly received at the destination and the time when packet is available for transmission. Experienced user throughput is calculated separately for DL (transmission from source radio points to UE), UL (transmission from UE to destination radio points) and (potentially) for D2D (transmission directly between involved UEs).

Experienced user throughput is linked with availability and retainability.

Traffic volume density

Traffic volume density is defined as the aggregated number of correctly transferred bits received by all destination UEs from source radio points (DL traffic) or sent from all source UEs to destination radio points (UL traffic), over the active time of the network to the area size covered by the radio points belonging to the RAN(s) where UEs can be deployed. Thus, traffic volume density can have the following units: [Gbps/m2] or [Gbps/km2].

Here active time of the network is the duration in which at least one session in any radio point of RAN is activated.

Traffic volume density evaluated through system level simulations, in respective deployment scenarios proposed in Section 3, and according to simulation assumptions from Sections 4.1, 4.2 and 4.3.

Note that D2D traffic should be evaluated independently from the cellular one. Besides, the link between source and destination may cover multiple hops especially when non-ideal backhaul is taken into consideration.

Again, system bandwidth assumption must be clearly identified.

E2E latency

Different types of latency are relevant for different applications. E2E latency, or one trip time (OTT) latency, refers to the time it takes from when a data packet is sent from the transmitting end to when it is received at the receiving entity, e.g., internet server or other device. Another latency measure is the round trip time (RTT) latency which refers to the time from when a data packet is sent from the transmitting end until acknowledgements are received from the receiving entity. The measurement reference in both cases is the interface between Layer 2 and 3.

Reliability

Refers to the continuity in the time domain of correct service and is associate with a maximum latency requirement. More specifically, reliability accounts for the percentage of packets properly received within the given maximum E2E latency (OTT or RTT depending on the service). For its evaluation dynamic simulations are needed, and realistic traffic models are encouraged.

More specifically, reliability for uMTC is evaluated through the packet reception ratio (PRR), following the 3GPP definition [3GPP15-154981]. PRR is calculated for each transmitted packet as X/Y, where Y is the number of UEs/vehicles located in the range of up to 150 m from the transmitter, and X is the number of UEs/vehicles with successful reception among Y. Distance intervals of 20 m from the transmitter are assumed.

Reliability of uMTC at specific level is achieved when a given PRR (equal to the reliability) can be guaranteed at a specific distance, for the messages successfully received within a specific time interval.

In general reliability is linked with availability and retainability.

Availability

The availability in percentage is defined as the number of places (related to a predefined area unit or pixel size) where the QoE level requested by the end-user is achieved divided by the total coverage area of a single radio cell or multi-cell area (equal to the total number of pixels) times 100.

Retainability

Retainability is defined as the percentage of time where transmissions meet the target experienced user throughput or reliability.

mMTC device density

Given mMTC device density is achieved when radio network infrastructure specified in Section 3.1.2 can correctly receive a specific percentage of messages (equal to availability) transmitted by mMTC devices deployed according to models given in Section 4.4.

RAN energy efficiency

Energy efficient network operation is one of the key design objectives for 5G. It is defined as the overall energy consumption of 5G infrastructure in the RAN comparing to a performance of legacy infrastructure. In order to prove expected energy savings both spatial (entire network) and temporal (24 hours) variations need to be taken into account, therefore direct evaluation in proposed UCs is inaccurate. Exemplary models for evaluation of energy consumption are given in Section 4.6.3.

Supported velocity

Following steps should be taken to evaluate the high velocity support:

1. Run system level simulations with parameters as defined in Section 4.3 with the exception of setting the speed to a given value and using full buffer traffic model to collect the overall statistics for downlink cumulative distribution function (CDF) of pilot signal power.
2. Use the CDF of this received power to collect the given CDF percentile value required by desired availability (e.g., for availability of 95% a 5th percentile value should be chosen).
3. Run the downlink link-level simulations for settings defined in Section 4.3 and given velocity for both LoS and NLoS conditions to obtain link data rate and bit error rate as a function of the pilot signal power.
4. Proposal support desired velocity requirement if obtained link data rate is equal or greater than required value and required bit error rate. It is sufficient if one of the spectral efficiency values of either LoS or NLoS channel conditions fulfils the threshold.

2.5 Mapping of KPIs evaluated with simulations to UCs

Mapping of KPIs evaluated via simulations to UCs is captured in Table 2-4. Requirements are extracted from [MET16-D11] and further details can be found there. Note that as general requirement, network energy efficiency (Joules per bit) must be increased by a factor of 100 as compared with LTE-A in current deployments whereas energy consumption for the RAN of IMT-2020 should not be greater than networks deployed today [ITUR15-M2083].

Table 2-4: Mapping of KPIs to UCs and their requirements as defined in [MET16-D11].

UC	KPI	Requirement
UC1 Dense urban information	Experienced user throughput	300 Mbps in DL and 50 Mbps in UL at 95% availability and 95% retainability
	E2E RTT latency	Less than 5 ms (augmented reality applications)
UC2 Virtual reality office	Experienced user throughput	5 (1) Gbps in DL and UL at 20% at (95%) availability and 99% retainability
UC3 Broadband access everywhere	Experienced user throughput	50 Mbps in DL and 25 Mbps in UL at 99% availability and 95% retainability
UC4 Massive distribution of sensors and actuators	mMTC device density	1 000 000 devices/km^2 transmitting from few bytes per day to 125 bytes per second with 99.9% availability
	Battery life	10 years (assuming 5 Watts-hour battery)
UC5 Connected cars	E2E OTT	5 ms (traffic safety applications) at the 99.999% reliability
	Experienced user throughput	100 Mbps in DL and 20 Mbps in UL (services) at 99% availability and 95% retainability
	Supported velocity	Up to 250 km/h

2.6 Performance evaluation aspects in other 5G-PPP projects

Other projects in 5G-PPP are also addressing different 5G requirements through UCs similar as defined in METIS-II, but also through complementary ones, such as:

- challenges of ultra-reliable broadband communications of Tactile Internet are covered by FANTASTIC-5G (cf. Section F.1) and mmMAGIC (cf. Section F.3),

- demands of high Performance Equipment by Flex5Gware (cf. Section F.2),
- provisioning of broadband to suburban areas through Realistic Extended Suburban HetNet in SPEED-5G (cf. Section F.4),
- capability for reorganization and provisioning of minimal services after disasters in Emergency Communication from 5G-NORMA (cf. Section F.7).

Additionally, KPIs and capabilities of IMT-2020 specified in [ITUR15-M2083] that are out of scope of METIS-II performance evaluation framework captured in this deliverable, are investigated in other 5G-PPP research projects e.g.:

- resilience, i.e. the ability of the network to continue operating correctly during and after a natural or man-made disturbance, such as loss of power, is investigated in 5G-NORMA,
- 5G security and privacy that refers to several areas such as encryption and integrity protection of user data and signalling, as well as end user privacy preventing unauthorized user tracking, and protection of network against hacking, fraud, denial of a service, man in the middle attacks, etc., is analysed in CHARISMA [CHA-Web].

2.7 General system level simulation guidelines

For system level simulations the following principles are recommended.

- System simulations should be based on the deployment scenarios defined in Section 3 and according to the models proposed in Section 4.
- Cell assignment to a user is based on the cell selection scheme proposed by the technology component owner, which must be described. Some examples are:
    - Connection to the station received with highest power, considering a handover margin of 1 dB.
    - Connection to the station received with highest power, considering a handover margin of 1 dB, but with a limit of users per BS.
    - Connection to the station received with highest wideband SINR, with or without a limit of users per BS.
    - Connection to the station whose estimation of the QoS satisfaction is more likely. This could be known based on the SINR estimation, the number of users connected to each station, and their QoS requirements.

  It is allowed to have the CP and UP served by different stations.
- In simulations based on the full-buffer traffic model, packets are not blocked when they arrive into system (i.e. queue depths are assumed to be infinite).

- In bursty traffic simulations, packets that are discarded (e.g. as they can't be transmitted within a given latency requirements) are also included in the overall performance statistics with 0 correctly received bits.
- Packets are scheduled with an appropriate packet scheduler(s) proposed by the proponents for full buffer and bursty traffic models, separately. Channel quality feedback delay, feedback errors, protocol data unit (PDU) transmission errors and real channel estimation effects inclusive of channel estimation error are modelled and packets are retransmitted as necessary.
- The overhead channels (i.e., the overhead due to feedback and control channels) should be realistically modelled.
- For a given drop, the simulation is run and then the process is repeated with the users dropped at new random locations. A sufficient number of drops are simulated to ensure convergence in the user and system performance metrics. For mMTC simulations, due to the large number of devices, only one drop is sufficient.
- Performance statistics are collected taking into account the wrap-around configuration in the network layout, noting that wrap-around is not considered in the UC2.

3 Deployment scenarios

This section contains assumptions on deployment scenarios that should be applied for simulation evaluations of 5G. Section 3.1 contains information on synthetic deployment scenarios while Section 3.2 presents a set of realistic deployment scenarios.

3.1 Synthetic deployment scenarios

Table 3-1 contains general information on proposed synthetic deployments (Indoor hotspot (InH), HetNet consisting of Urban macro (UMa) and Outdoor small cells (OSC), UMa, and Rural macro (RMa)). Further details for those are available in this subsection and in Annex A.

Table 3-1: Synthetic deployment scenarios for system level simulations.

Deployment scenario	Indoor hotspot	Urban macro	HetNet Outdoor small cells	Rural macro
BS antenna height	3 m, mounted on ceiling	25 m, above rooftop	10 m on the lamppost / below the rooftop	35 m, above rooftop
Number of BS antennas elements (TX/RX) (FFS)	Up to 256/256 >6 GHz Up to 16/16 <6 GHz	Up to 32/32	Up to 256/256 >6 GHz Up to 16/16 <6 GHz	Up to 32/32
Number of BS antenna ports (FFS)	Up to 8	Up to 16	Up to 8 < 6GHz	Up to 8
BS antenna gain	5 dBi (per element)	17 dBi	5 dBi (per element)	17 dBi
Maximum BS transmit power	40 dBm EIRP for >6 GHz (in 1 GHz), 21 dBm for <6 GHz (in 20 MHz)	49 dBm per band (in 20 MHz)	40 dBm EIRP for >6 GHz (in 1 GHz), 30 dBm <6 GHz (in 20 MHz)	49 dBm per band (in 30 MHz)
BS noise figure	5 dB	5 dB	5 dB	5 dB

Carrier center frequency for evaluation (per BS) [1]	3.5 GHz and 70 GHz	2 GHz for UC4 and UC5, 3.5 GHz for UC1	25 GHz in UC1 5.9 GHz for RSU in UC5	800 MHz
Carrier bandwidth for evaluation (per BS) [1]	100 MHz at 3.5 GHz and 1 GHz at 70 GHz	Up to 10 MHz at 2 GHz for UC4 and UC5 Up to 100 MHz at 3.5 GHz for UC1	1 GHz at 25 GHz in UC1 10 MHz at 5.9 GHz for RSU in UC5	30 MHz at 800 MHz, assuming Carrier Aggregation with other bands
Inter-site distance	20 m	200 m for UC1, and 500 m for UC4 and UC5	> 20 m	1 732 m

3.1.1 Indoor hotspot

The InH scenario consists of one floor of a building. The height of the floor is 3 m. The floor contains 16 rooms of 15 m × 15 m and a long hall of 120 m × 20 m.

Proposed BS network layout consists of small cells placed in the corridor, 6 along one long edge and 6 more along the other long edge. The six stations in one edge have an ISD of 20 m, with the first site placed at 10 m with respect to the left side of the building (cf. Figure 3-1).

InH BSs can operate in two configurations:

- Above 6 GHz band – frequencies of 70 GHz with the available bandwidth of 1 GHz.
- Above 6 GHz and below 6 GHz band – same configuration as above and additional 100 MHz bandwidth in 3.5 GHz band.

Each InH is equipped with omnidirectional antenna at the height of 3 m.

[1] The spectrum information used in this document on carrier center frequencies and carrier bandwidth sizes per each base station and access point are given as examples to be used only for 5G radio technology performance evaluation purposes. The amount of spectrum needed for 5G and what spectrum bands would be used for 5G are still under study.

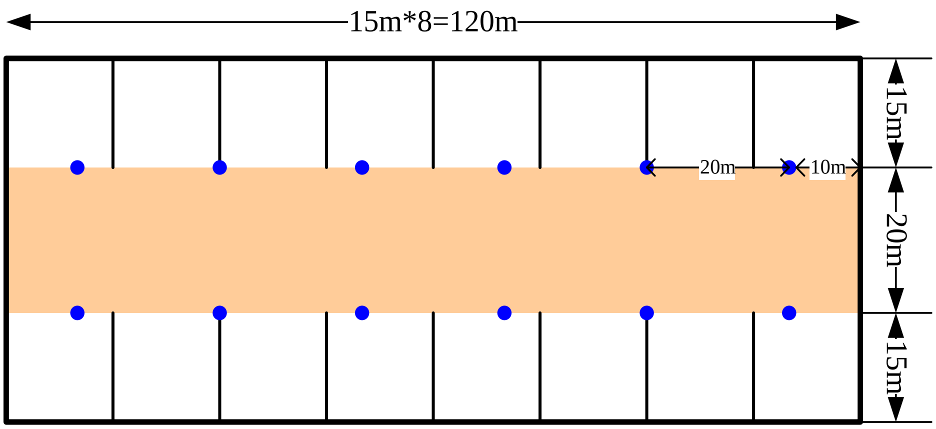


Figure 3-1: Sketch of InH deployment.

3.1.2 Urban macro

UMa BSs are deployed with fixed ISD of 200 m for UC1, and 500 m for UC4 and UC5 in a regular, hexagonal grid as depicted in Figure 3-2. BSs are connected to a set of 3 sector antennas, whose characteristics are defined in Section 3.1.5. Antennas are mounted at the height of 25 m, above the rooftop.

UMa BSs operate at frequency 2 GHz for UC4 and UC5 and at the 3.5 GHz band in UC1, with a bandwidth of up to 100 MHz at 3.5 GHz and up to 10 MHz at 2 GHz.

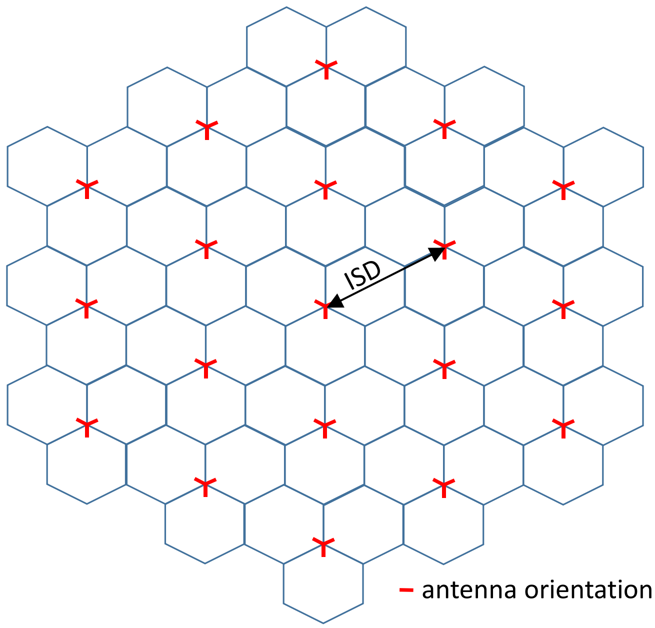


Figure 3-2: UMa and RMa BS deployment and antenna orientation.

3.1.3 HetNet / Outdoor small cells

The HetNet scenario consists of two layers: UMa BSs and OSC. OSCs are deployed as outdoor BSs and are only considered as a part of HetNet deployment scenario. For UC1 each UMa cell (deployment as in Section 3.1.2, but with ISD = 200 m) is complemented with 8 OSCs randomly placed in the coverage area of the UMa sector. The constraint for the OSC deployment is that the distance between the OSC and the UMa BS must be greater than 55 m and the distance between the OSC (inter and intra UMa cells) shouldn't be smaller than 20 m (as OSCs are deployed as outdoor BSs, most likely by mobile network operators, it is very likely that similar limitations could be enforced by the operator). Number and deployment of OSCs configured in UC5 is FFS.

Each OSCs is equipped with omnidirectional antenna at the height of 10 m and operates in the frequency range of 24-27 GHz with available bandwidth of 1 GHz for UC1, and at 5.9 GHz and 10 MHz bandwidth for UC5, in which they operate as Road-Side Units (RSU).

3.1.4 Rural macro

RMa BSs are deployed with the ISD of 1732 m in a hexagonal cell layout presented in Figure 3-2. As BSs have to cover large areas, antennas are mounted on a transmission mast at the height of 35 m, above the rooftop. Sector antennas have characteristics as described in Section 3.1.5.

RMa BSs operate at frequency of 800 MHz where 30 MHz bandwidth is available.

3.1.5 BS antenna pattern

For UMa and RMa BS sector, the horizontal antenna pattern is specified as:

$$A(\theta) = -min\left[12\left(\frac{\theta}{\theta_{3dB}}\right)^2, A_{mh}\right]$$

Where $A(\theta)$ is the relative antenna gain in horizontal direction (dB), θ is the horizontal angle, θ_{3dB} is the 3 dB beamwidth and A_{mh} is the maximum attenuation of the antenna in the horizontal plane. For system level simulations in UMa values of θ_{3dB}=65^0 and A_{mh}=30 dB shall be used [3GPP15-36897], whereas for RMa θ_{3dB}=70^0 and A_{mh}=25 dB [3GPP10-36814].

For elevation angle antenna pattern is defined as:

$$A_e(\emptyset) = -min\left[12\left(\frac{\phi - \phi_{tilt}}{\phi_{3dB}}\right)^2, A_{mv}\right]$$

where $A_e(\phi)$ is the relative antenna gain in the elevation direction (dB), ϕ is the elevation angle, ϕ_{3dB} is the elevation 3 dB beamwidth, A_{mv} is the maximum attenuation of the antenna in the vertical plane and ϕ_{tilt} is the tilt angle that can be adjusted in each deployment scenario. For system level simulations in UMa values of ϕ_{3dB}= 65^0 and A_{mv}= 30 dB shall be used [3GPP15-36897], whereas for RMa ϕ_{3dB}= 10^0 and A_{mv}= 20 dB [3GPP10-36814].

The combined antenna pattern is computed as:

$$-\min\left[-\left(A(\theta)+A_e(\phi)\right),A_m\right]$$

where A_m is a maximum attenuation of the antenna equal to 30 dB for UMa and 25 dB for RMa.

For the InH and OSCs, the antenna pattern is assumed omnidirectional.

3.2 Realistic deployment scenarios

3.2.1 Indoor office

A realistic office environmental model is attained by explicitly considering walls, screens, desks, chairs and people. The environmental model geometry is given by the dimensions of the rooms, cubicle offices and tables. The width and depth of these objects are illustrated in the (3D sketch shown in Figure 3-3, and the 2-dimensional (2D) sketch shown in Figure 3-3.

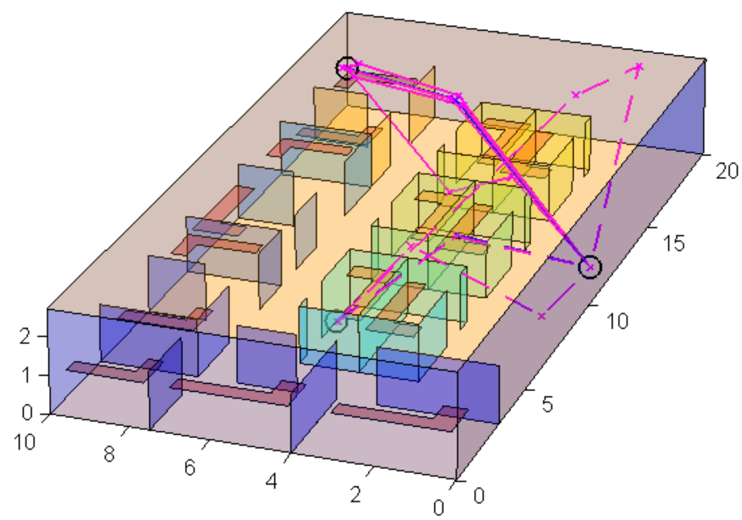


Figure 3-3: 3D sketch of the realistic indoor office.

BSs have up to 256 antenna elements in above 6 GHz bands and up to 16 in below 6 GHz. Further information on the model can be found in Section A.1.

3.2.2 Madrid Grid

Madrid Grid is a realistic extension of a popular Manhattan Grid model [ETSI-125951]. Its basic elements are regular, multi-storied blocks of different sizes and heights, park area, roads and pavements. This environment was developed in METIS project [MET13-D61] for the purpose of capturing dynamic traffic variations (in both space and time) in a typical European dense urban environment. More details can be found in Section A.2.

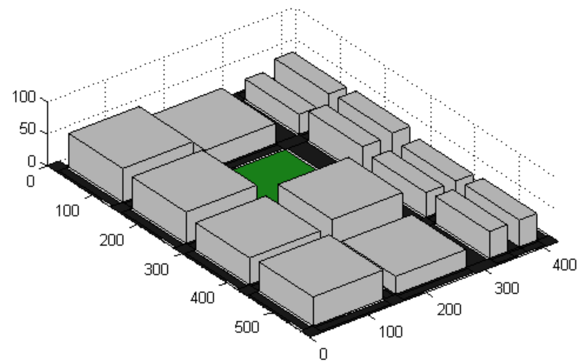


Figure 3-4: 3D visualization of the Madrid grid.

3.2.3 Suburban and rural realistic scenarios

Past experience has shown that in congested scenarios system performance evaluated under real conditions can differ significantly from synthetic scenarios. This has motivated the adoption of real scenarios for xMBB dense urban (UC1) and indoor hotspot (UC2) cases. However, there is not a clear need for such realistic considerations in suburban or rural scenarios where coverage is the main challenge rather than the management of interferences. In this sense, METIS-II has not focused on the development of a realistic model for the equivalent of the RMa deployment. For interested readers, the closest model used in 5G-PPP (with some differences related to focus on suburban environment instead of rural one) is the Extended Suburban model developed in SPEED 5G project (cf. Section F.4).

4 System level simulation models for individual use cases

In each individual UC, both synthetic and realistic deployment scenarios are considered. Therefore, simulations models are described in this section for both types of deployment scenarios. Table 4-1 overviews on system level synthetic simulation models that should be used for evaluation of individual UCs. On the other hand, Table 4-2 links the set of UCs with the corresponding realistic deployment scenario. Additional details of the models can be found in remaining part of this section.

Table 4-1: System level simulation models for synthetic deployment scenarios.

Use case	UC1 Dense urban information society	UC2 Virtual reality office	UC3 Broadband access everywhere	UC4 Massive distribution of sensors and actuators	UC5 Connected cars
BS synthetic deployment	HetNet	InH	RMa	UMa	HetNet (Urban) RMa (Motorway)
UE deployment	10 UEs per macro cell and 5 UEs per small cell	cf. Section 4.2.2	10 UEs per cell	24000 per cell	< 1000 cars per square km (Urban) < 100 cars per km (Motorway)
UE height	cf. Section 4.1.2	1.5 m	1.5 m	cf. Section 4.4.2	1.5 m
UE antenna pattern	2D Omni-directional	2D Omni-directional	2D Omni-directional	2D Omni-directional	2D Omni-directional
Number of UE antenna elements (TX/RX) (FFS)	16/16	16/16	8/8	2/2	2/4

Number of UE antenna ports (TX/RX)(FFS)	8/8 for <6 GHz 4/4 for >6 GHz	8/8 for <6 GHz 4/4 for >6 GHz	4/4	1/1	1/2
UE antenna gain	0 dBi	0 dBi	0 dBi	0 dBi	3 dBi
UE noise figure	9 dB	9 dB	9 dB	9 dB	9 dB
UE maximum transmission power	24 dBm	24 dBm	24 dBm	21 dBm	23 dBm
UE speed for fast fading calculation	3 km/h in OSC and 30 km/h in UMa	3 km/h	120 km/h	3 km/h	60 km/h for Urban and 140 km/h for Motorway
UE position	Fixed	Fixed	Fixed	Fixed	Explicitly modelled
Min 2D UE-BS distance	10 m for OSC BS and 35 m for UMa BS	10 m	35 m	35 m	35 m
Indoor / Outdoor ratio	80/20	100/0	0/100	80/20	0/100
Channel model	< 6 GHz 3GPP UMa 3D, >6 GHz 5GCM	< 6 GHz 3GPP InH 2D, >6 GHz 5GCM	3GPP RMa 2D	3GPP UMa 3D	cf. Section 4.5.5
Traffic model	Full buffer and bursty traffic	Full buffer and bursty traffic	Full buffer and bursty traffic	Bursty traffic (periodic)	Bursty traffic (periodic + event driven)

Table 4-2: Recommended realistic deployment scenario for specific UCs.

Use case	UC1 Dense urban information society	UC2 Virtual reality office	UC3 Broadband access everywhere	UC4 Massive distribution of sensors and actuators	UC5 Connected cars
Realistic deployment scenario	Madrid Grid	Indoor Office	n.a.	Madrid Grid	Madrid Grid

4.1 Dense urban information society

4.1.1 Deployment scenario

BSs are dropped according to synthetic deployment scenario of HetNet configuration from Section 3.1.2 and 3.1.3 or in a Madrid Grid realistic model described in Section 3.2.2.

4.1.2 User deployment

In synthetic deployment scenarios UEs (xMBB devices) are uniformly distributed across the cells. There are 10 UEs per macro cell and 5 UEs in OSC. Outdoor UEs are deployed at the height of 1.5 m. Indoor UEs are uniformly distributed with the height of:

$$h_{UT} = 3\left(n_{fl} - 1\right) + 1.5$$

In equation above n_{fl} denotes the number of floors with uniform distribution between 1 and N_{fl}, where N_{fl} is the maximum floor number uniformly distributed between 4 and 8. Minimum distance between BS and UE for macro BS and OSC (2D) is equal to 35 m and 10 m respectively.

For realistic deployment scenario 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 (total for outdoor and indoor).

4.1.3 Mobility model

In the synthetic deployment scenario, users' position doesn't change along the simulation if not explicitly required for the purpose of evaluation (e.g., due to mobility related evaluation), but a speed of 3 km/h for OSC and 30 km/h for macro cells users is assumed in the channel modelling to take into account fast fading effects.

For the realistic deployment scenario, UEs move according to models defined in Section A.2.3 .

4.1.4 Traffic model

For evaluation of capacity, full buffer traffic model in the synthetic deployment is used, in which an infinite amount of data is awaiting for transmission in the buffers. For evaluation of traffic volume density, experienced user throughput, latency and reliability, real traffic models are recommended, in particular the 3GPP File Transfer Protocol (FTP) Model 3 [3GPP13-36872] depicted in Figure 4-4-1. 3GPP FTP Model 3 defines bursty traffic where packets of fixed file size S arrive to the same source (UE, BS) according to a Poisson process with mean inter-arrival time D. Start of packet transmission is counted since the time it arrives at the queue.

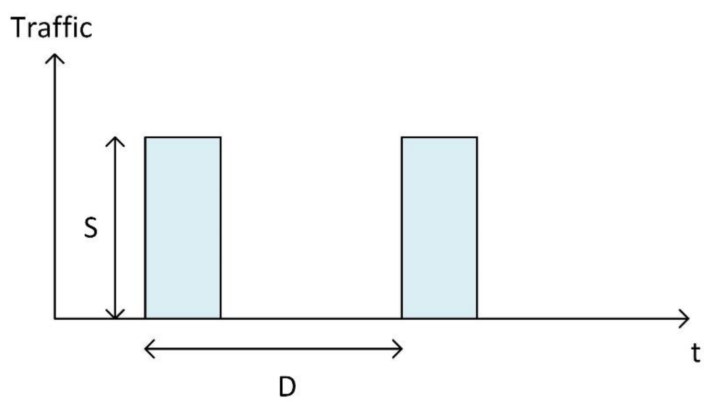


Figure 4-4-1: Traffic generation of 3GPP FTP Model 3.

To calculate supported traffic volume density, file size S is fixed to 3.5 MB, and load is increased by decreasing the packet inter-arrival time, D, down from the arbitrary value. Traffic volume density is calculated using maximum packet inter-arrival time when experienced user throughput of devices at the level of 300 Mbps in DL and 50 Mbps in UL (or higher) and 95 % availability and retainability as defined in [MET16-D11]. For evaluation of latency and reliability it is assumed that once a file of 3.5 MB is generated, it reaches the radio access network as a burst of IP packets of 1518 bytes, assuming for those packets a data rate transmission over the backhaul of 10 Gbps.

Up to 10% of traffic can be transmitted using a D2D link.

4.1.5 Channel models

Concerning synthetic evaluations, for frequencies above 6 GHz, which corresponds to small cells, UMi extensions of ITU-R models provided in [5GCM15] are selected. For frequencies below 6 GHz, 3GPP UMa 3D from [3GPP15-36873] is recommended. For D2D transmissions [3GPP14-36843] models are recommended for frequencies below 6 GHz.

For realistic deployment scenarios ray-tracing based pathloss traces are recommended (cf. Section A.2.2). Concerning small scale parameters characterization, this should be added on top of ray-tracing based pathloss traces. The models for small scale are the same of the synthetic case, that is [5GCM15] for above 6 GHz and [3GPP15-36873] for below.

4.2 Virtual reality office

4.2.1 Deployment scenarios

The synthetic scenario for this UC is the InH described in section 3.1.1, while the realistic scenario for this UC is the Indoor office described in section 3.2.1.

4.2.2 User deployment

According to the mean user density required in [MET16-D11] (1/10 users/m^2) and the area of the scenario (200 m^2 in realistic scenario and 6000 m^2 in synthetic scenario), 20 and 600 UEs (xMBB devices) should be generated in the scenario, respectively. However, in synthetic deployments in order to reduce the simulation complexity 10 UEs per cell could be used (120 per total simulation area). The minimum distance between BS and UE (2D) is equal to 10 m.

Realistic scenario

All rooms are occupied by 1 user except rooms R4 (2 users), R8 (2 users), and R12 (4 users). See the numbering of the rooms in Figure 4-2.

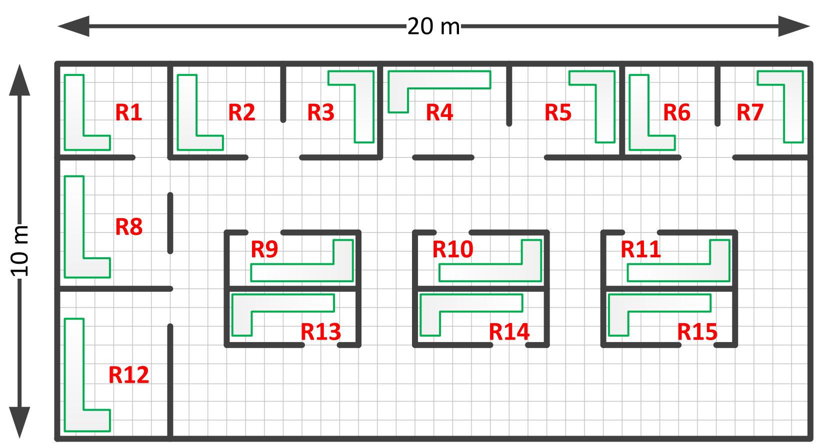


Figure 4-2: Room numbering in realistic indoor office scenario.

Synthetic scenario

Users are randomly and uniformly distributed over the area, considering a minimum distance of 3 meters (in the horizontal plane) with any BS.

4.2.3 Mobility model

Position of the users does not change along the simulation if not explicitly required for the purpose of evaluation (e.g., due to mobility related evaluation), but a speed of 3 km/h is assumed in the channel modelling to take into account fast fading effects.

4.2.4 Traffic model

Traffic is defined as in 4.1.4 with exception that experienced data rate for DL and UL as well as availability and retainability values are taken from Table 2-4 for this UC. To reach supported traffic volume of 0.1 Gbps/m^2 defined in [MET16-D11], average packet inter-arrival time for UL and DL should be equal to 29.3 ms for each 600 UEs in synthetic deployment scenario or 20 UEs in realistic deployment scenario.

4.2.5 Operating frequency bandwidth

BSs may work at central carrier frequencies of 3.5 GHz, 70 GHz, or a combination of them. Available bandwidth is 100 MHz at 3.5 GHz and 1 GHz at 70 GHz.

4.2.6 Channel models

Synthetic scenario

3GPP InH model in [3GPP10-36814] is proposed for the 3.5 GHz with 3D distances. In 70 GHz updates proposed in [5GCM15] are recommended.

Realistic scenario

For the simulation of indoor propagation, a real layout of the walls and materials used within the building is needed to compute the real losses with ray-tracing.

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. Such information is provided in Section A.1.1.

Finally, METIS-II recommends a set of path loss maps derived from ray tracing in the indoor scenario for a set of positions of the stations, specifically for the five positions described in Section 3.1.1 (cf. Section A.1.2). On top of path loss, small scale effects can be added according to [5GCM15].

4.3 Broadband access everywhere

4.3.1 Deployment scenario

BSs are dropped according to synthetic deployment scenario of RMa configuration from Section 3.1.4.

4.3.2 User deployment

There are 10 UEs (xMBB devices) per cell. These are uniformly distributed across the cells. All UEs are deployed at the height of 1.5 m. The minimum distance from BS to UE (2D) is equal to 35 m.

4.3.3 Mobility model

Position of the users does not change along the simulation if not explicitly required for the purpose of evaluation (e.g., due to mobility related evaluation), but a speed of e.g. 120 km/h is assumed in the channel modelling to take into account fast fading effects.

4.3.4 Traffic model

Traffic models are the same described in Section 4.1.4 with exception that experienced data rate for DL and UL as well as availability and retainability values are taken from Table 2-4 for this UC.

4.3.5 Channel models

The 3GPP RMa channel model from [3GPP10-36814] is recommended. 3D distances are used to compute for the path losses.

4.4 Massive distribution of sensors and actuators

4.4.1 Deployment scenario

Macro BSs are dropped according to synthetic deployment of UMa configuration from Section 3.1.2 or in a Madrid Grid model described in Section 3.2.2 (Macro stations only).

4.4.2 User deployment

UEs (mMTC devices) are uniformly distributed across the UMa cell. Such cell cover the area of ~0.072 km^2 and assuming a typical case of 3 operators per such area, 24 000 mMTC devices per single operator and cell are considered. Outdoor UEs are deployed at the height of 1.5 m.

Indoor UEs are uniformly distributed with the height

$$h_{UT} = 3(n_{fl} - 1) + 1.5$$

In equation above n_{fl} denotes the number of floors with uniform distribution between 1 and N_{fl}, where N_{fl} is the maximum floor number uniformly distributed between 4 and 8. Minimum distance between BS and UE is equal to 35 m.

4.4.3 Mobility model

Users are assumed to have a fixed position during single simulation drop, if not explicitly required for the purpose of evaluation (e.g., due to mobility related evaluation), but mobility vector of 3 km/h is assumed in the channel modelling to take into account fast fading effects.

4.4.4 Traffic model

Devices upload 125 bytes every second. Uniform time offset between 0 and 1 sec is assumed at the beginning of the simulation to ensure even random traffic distribution in time.

4.4.5 Channel models

3GPP UMa 3D model from [3GPP15-36873] is recommended. For indoor UEs O2I penetration losses is added for each link, modelled as 20 dB + 0.5 * x [dB], where x is an independent uniform random value between 0 and 25.

4.5 Connected cars

The connected cars UC considers two different scenarios: an urban scenario and a highway scenario. In the urban scenario, both synthetic and realistic options are considered while only a synthetic case is defined in the highway scenario. The realistic scenario considers three types of vehicles: cars, buses and pedestrians. On the other hand, the synthetic scenarios only consider cars.

4.5.1 Deployment scenario

In the urban synthetic scenario, BSs are dropped according to synthetic deployment of HetNet configuration from Sections 3.1.2 and 3.1.3.

In the urban realistic scenario, the base stations are placed according to the Madrid Grid realistic model described in Section 3.2.2.

In the highway (synthetic) scenario, BSs are dropped according to synthetic deployment of RMa configuration from Section 3.1.4.

4.5.2 User deployment

In the urban synthetic scenario vehicles are dropped in roads in urban environment. Considered road configuration is shown in the Figure 4-3 and has been defined according to the 3GPP model captured in [3GPP15-36885] for urban environment. Every road between the buildings contains two lanes per each direction (3.5 m width). Vehicles are dropped on roads according to a spatial Poisson process with an average inter-vehicle distance of 41.67 m (distance covered in 2.5 s at a speed of 60 km/h) in the middle of each lane. The number of vehicles is determined by the total length of roads and the mentioned average inter-vehicle distance. The total road length within the 433x250 area formed by 1 building, its surrounding sidewalk and rings of lanes, is equal to 2684 m. Therefore, in each of these areas, 64.4 cars should be placed in average which is equivalent to 595 vehicles per km^2 in considered scenario. It is worth noting that [MET16-D11] foresees user vehicular densities in urban environments up to 1000 users per km^2. Therefore, the number used in this scenario is within the range set by [MET16-D11].

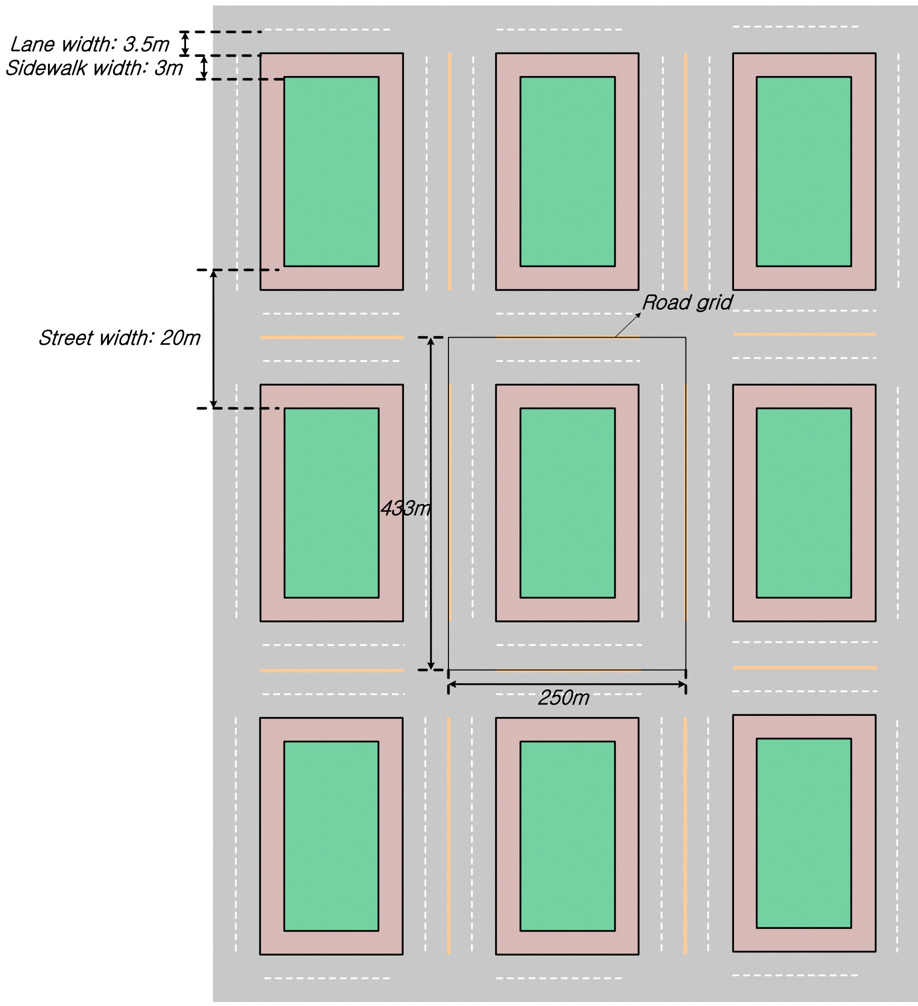


Figure 4-3: Road configuration for urban traffic efficiency and safety evaluation [3GPP15-36885].

In the urban realistic scenario, cars are dropped in the roads of the Madrid Grid uniformly and placing the same number of users in each lane segment, where a lane segment is the part of a lane between two contiguous street crossings. Concerning the buses, one bus is dropped initially in the road segment of each bus stop. Finally, pedestrians are uniformly dropped in the sidewalks. The number of buses is determined by the number of stops in the Madrid Grid, i.e. 8, but the number of cars and pedestrians is configurable.

In the highway synthetic scenario, vehicles are dropped in the lanes of a highway deployment from [3GPP15-36885] illustrated in the Figure 4-4. The depicted highway presents 3 lanes in each direction, with a lane width of 4 m. It is required to have a highway length of at least 2 km. Vehicles are dropped in the roads according to a spatial Poisson process with an average inter-vehicle distance of 97.22 m (distance covered in 2.5 s at a speed of 140 km/h). Therefore, 61.72 vehicles will be placed in average per each kilometre of highway. This value is in consonance with the values reflected in [MET16-D11].

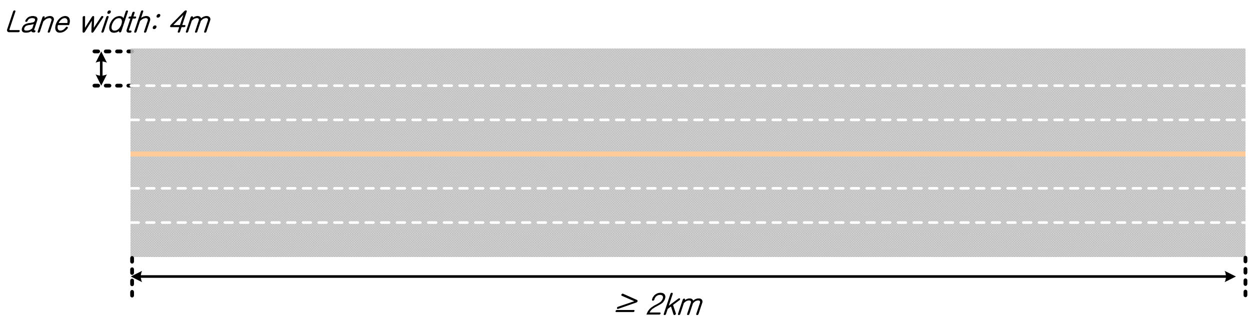


Figure 4-4: Road configuration for highway traffic efficiency and safety evaluation [3GPP15-36885].

Figure 4-5 depicts the exact location of the highway with respect to the Rural macro deployment scenario described in Section 3.1.4.

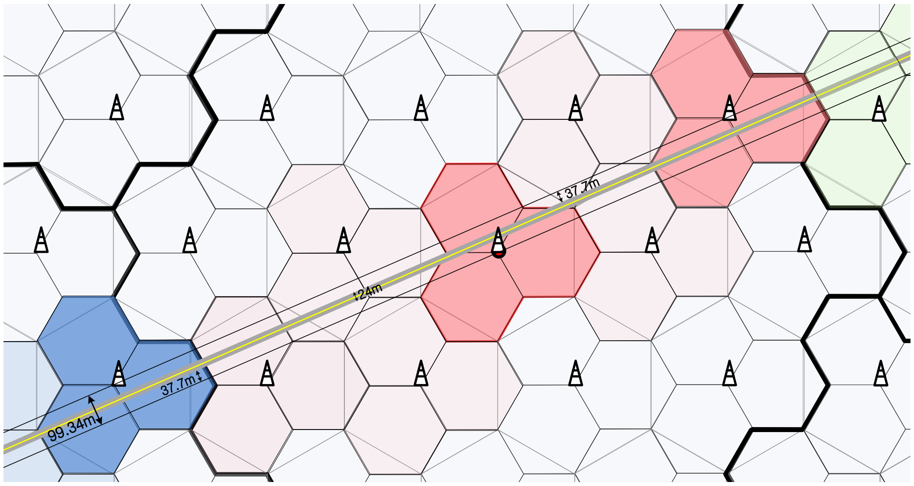


Figure 4-5: Location of the highway in the deployment scenario [3GPP15-36885].

4.5.3 Mobility model

In the urban synthetic deployment scenario, vehicles move along the streets at 60 km/h. At the intersections, vehicles have 50% probability to go straight and 25% probability of turning left or right. Vehicle position is updated every 100 ms on the simulation.

In the urban realistic scenario, cars, buses, and pedestrians are dropped and move within the Madrid Grid according to car mobility models and traces described in Sections A.2.3 and A.2.4.

In the highway (synthetic) scenario, vehicles move along the lanes of the highway at 140 km/h. Vehicle position is updated every 100 ms of the simulation.

4.5.4 Traffic model

[MET16-D11] considers, for traffic safety applications, the following models:

- Periodic broadcast traffic consisting of at least 1600 payload byte (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 5-10 Hz.
- Event-driven broadcast traffic consisting of at least 1600 payload byte with repetition rate of at least 5-10 Hz (for transmission of information related to 10 detected objects resulting from local environment perception and the information related to the actual vehicle).

In 3GPP [3GPP15-36885] following assumptions are used:

- Periodic broadcast traffic consists of one 300 payload byte followed by four 190 byte messages. Message generation period is equal to 100 ms and the time instance of 300 byte size message is randomized among the vehicles.
- Event-triggered traffic is triggered by event following Poisson process with varying arrival rate (up to individual choice). Each event generate 6 messages, 800 byte each, with space of 100 ms

4.5.5 Channel models

In this section both the vehicle-to-vehicle channel and the vehicle-to-macrocell channel is considered. In addition, channel models have to be specified for the three considered scenarios.

In the urban synthetic scenario, for the vehicle-to-vehicle channel model, WINNER+ B1 Manhattan Grid layout model shall be used for pathloss calculation. Pathloss at 3 m is used if the distance is less than 3 m. Shadowing should be lognormal with 3 dB standard deviation for LOS and 4 dB for NLOS. Shadowing should be spatially correlated according to the process defined in [3GPP15-36885] with correlation distance of 10 m. Fast fading should be implemented according to NLOS in Section A.2.1.2.1.1 or A.2.1.2.1.2 in [3GPP14-36843] with fixed large scale parameters during the simulation. Channel is updated every 100 ms (after location update). The updating process is explained in [3GPP14-36843].

In the urban synthetic scenario, for the vehicle-to-macrocell channel model, UMa model in [3GPP15-36873] is used.

In the urban realistic scenario, for the vehicle-to-vehicle channel model, the default model for UMi in Manhattan scenarios [ITUR08-M2135] can be still applicable, with lower transmitter height plus 10 additional dB of attenuation in case of having other cars in the middle of the communication channel.

In the urban realistic scenario, for the vehicle-to-macrocell channel model, pathloss traces are provided in METIS-II and are to be used (cf. Section A.2.4). Concerning small scale parameters characterization, this should be added on top of ray-tracing based pathloss traces.

In the highway scenario, for the vehicle-to-vehicle channel model, WINNER+ B1 LOS shall be used for pathloss calculation with antenna height of 1.5 m. Pathloss at 3 m is used if the distance is less than 3 m. Shadowing should be lognormal with 3 dB standard deviation. Shadowing should be spatially correlated according to the process defined in [3GPP15-36885] with correlation distance of 25 m. Fast fading should be implemented according to NLOS in Section A.2.1.2.1.1 or A.2.1.2.1.2 in [3GPP14-36843] with fixed large scale parameters during the simulation. Channel is updated every 100 ms (after location update). The updating process is explained in [3GPP14-36843].

In the highway scenario, for the vehicle-to-macrocell channel model, 3GPP RMa model defined in [3GPP10-36814] with 3D distances is recommended.

4.6 General considerations

4.6.1 L2S level mapping curves

Most of the system level simulators, in order to evaluate performance of a given solution, exploit (to some degree) information on calculated SINR (or SIR) values. On the other hand, link level simulators, which are essential for analysis of performance of the air interface, also utilize SINR (or more often Eb/No - energy per bit to noise power spectral density ratio) to calculate frame error rate (FER), packet error rate (PER), block error rate (BLER) or bit error rate (BER) statistics. These two means for carrying out simulations separate two different (but closely related) problem domains and allow for time efficient performance evaluation. In order to benefit from the link level simulation results, system level simulator need to rely on the certain abstraction of the physical layer through mapping of calculated SINR to certain performance metrics. Especially in multicarrier systems (e.g., in OFDM) additional challenge comes from the fact that individual carriers (or physical radio blocks (PRBs)) experience different SINR conditions. Solutions to those problems are effective SINR mapping functions, and two most widely utilized ones are exponential effective SINR mapping (EESM) [3GPP03-031303], [3GPP04-25892] and mutual information effective SINR mapping (MIESM) [BAS05].

In the second method, MIESM, two variants can be distinguished. First one, received bit mutual information rate (RBIR) is based on a mutual information per received symbol normalized to yield the bit mutual information. Second variant, mean mutual information per bit (MMIB), directly computed the bit mutual information. In both approaches mutual information metric is computed based on a set of samples of SINR values calculated in system level simulations for received encoder symbol SINR. When having those mutual information calculated it is possible to calculate respective BLER values using appropriate look-up tables [IEEE08-004].

It has been shown that MIESM can outperform EESM when simulating coding block with mixed modulations or HARQ [3GPP203-C30], although EESM works better when simulating lower code rates [BAS05], [MO06]. According to [KZD+09] MIESM can be also extended or even generalized for non-orthogonal multicarrier systems. Having above mentioned arguments MIESM method is recommended as the default one for 5G evaluation process.

4.6.2 RAN architectural considerations

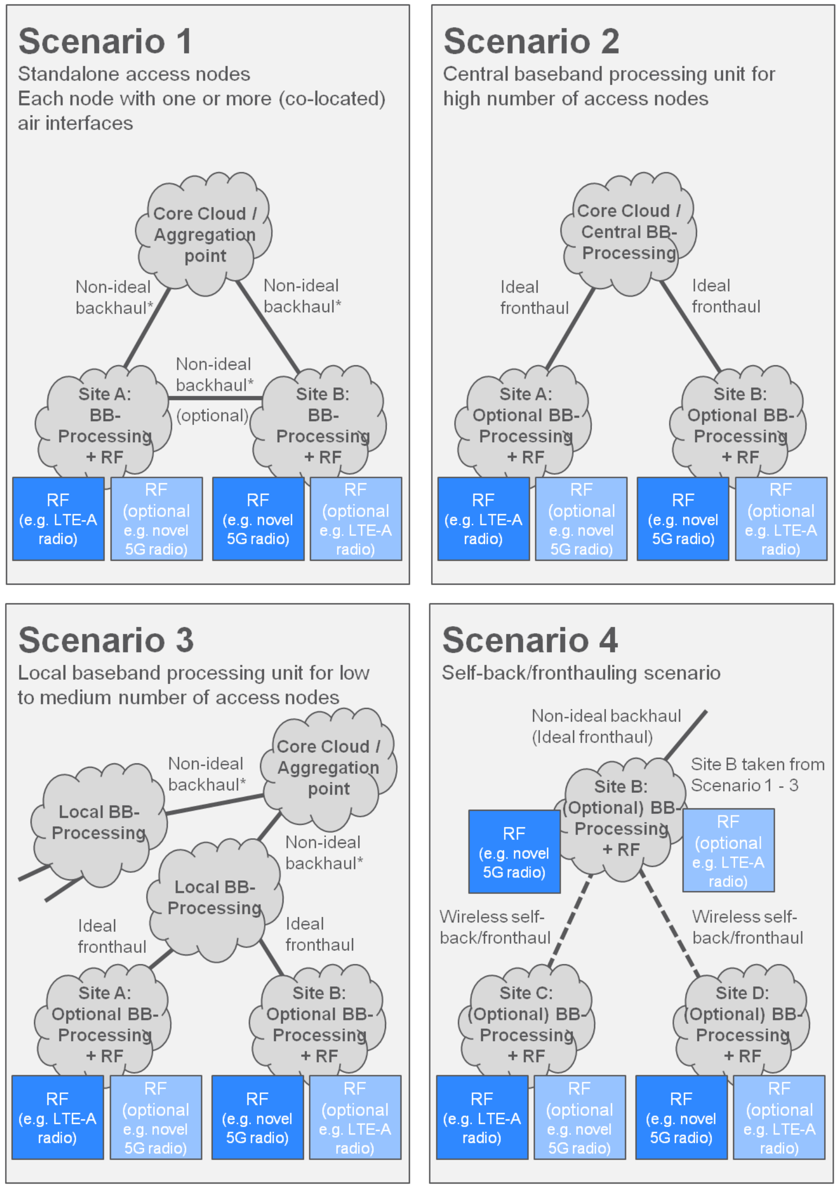
For evaluation of technical concepts in different level of RAN centralizations, four architectural options can be considered, as depicted in Figure 4-6. These considerations could be used to test given solution against different possible realizations of RAN architecture. For evaluation purposes, the following assumptions can be used:

- For wireless self-backhaul/fronthaul, same technology as for radio access is used
- For non-ideal backhaul, values of [1, 5 and 30 ms] and [0.05, 0.5 and 10 Gbps] can be used for one way latency and throughput, respectively, are recommended.

Evaluation of different RAN architectural scenarios is recommended to check the feasibility and suitability of a given feature/solution for e.g. standalone or centralized/cloud processing.

4.6.3 Network energy consumption model

Improvements on network energy efficiency are necessary in order to provide fast and economically justified rollout of future networks that will need to handle massive traffic increase in 2020 and beyond. Several organizations have already set the ambitious targets related to network energy efficiency. In [ITUR15-M2083] network energy efficiency is defined as one of the eight key capabilities of 5G system and more than 100 times improvement is envisioned. In [NG15] a factor of x2000 for entire network is recommended in the next 10 years. In general, improvements for this KPI are necessary in order to bring down the overall network power consumption for the reason of reducing carbon dioxide ($CO2$) footprint and costs related with running the network related power consumption.



* Non-ideal backhaul could be modeled as in TR 36.932

Figure 4-6: Physical RAN architecture scenarios considered.

However, showing full 5G potential w.r.t. improvements of energy efficiency, through straightforward reuse of assumptions of individual UC may be difficult, as these are designed to show the network operations in high load conditions (e.g., rush hour, huge supported traffic volume density, etc.), while potential network features that will allow power consumption savings will be based on (partial) deactivation of some nodes or its unused elements during medium and low network load conditions. Therefore a proper evaluation of this KPI requires taking into consideration these temporal (e.g. 24 hour) and spatial load variations. Details of this evaluation approach are still being discussed and findings are expected to be included in METIS-II deliverable D2.3 'Performance evaluation results' that will be issued in February of 2017. The rest of this section contains first considerations in this topic.

In order to quantify network energy performance, proposed 5G network power consumption model should consider following aspects:

- Power consumption behaviour of various deployments.

  The impact of key radio components (e.g., carriers, antenna ports), key radio utilization variables (e.g., bandwidth load level, power load level), and different network architectures (e.g., site types, centralized/distributed processing units).

- Parameterization capability and flexibility.

  In 5G system, deployment solution, site types, network architectures could be highly dependent on the specific scenario, performance requirements and technical solutions. Therefore, the power consumption model should be highly parameterized in order to describe the network's power consumption behaviour flexibly.

Hence, introduction of a simple and highly flexible power consumption model is proposed to describe the actual power consumption behaviour of the whole network under different deployment solutions and network status.

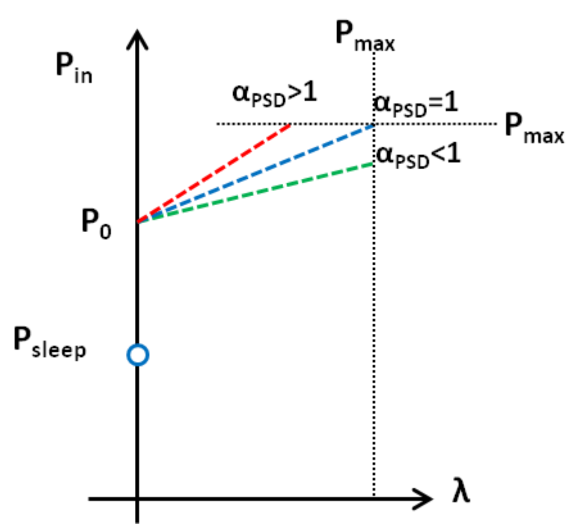


Figure 4-7: Illustration of power consumption behaviour of a BS.

As shown in Figure 4-7, a BS's instantaneous power consumption is basically proportional to the bandwidth load level λ. As the bandwidth load level grows, the overall power consumption of BS increases accordingly. P_{max} is the maximum radio unit output power, while P_0 is the power consumption at the minimum non-zero output power due to load independent operation. Furthermore, base station can switch off some components when the load is very low, thus the overall power consumption will further decrease to P_{sleep}, which denotes BS power consumption in a sleep mode. Note that the actual power consumption of the BS is not only dependent to the bandwidth load level, but also tightly connected with the power load level, or equivalently, to the power spectrum density ratio α_{PSD}, which is defined as the ratio of the actual power spectrum density to the one with maximum transmit power averaged on the whole bandwidth.

According to Figure 4-7, the overall power consumption behaviour of BS is denoted as

$$P_{in}\begin{cases} N_{sec}\left(P_0 + \Delta_p P_{max}\lambda\alpha_{PSD} + P_1\lambda\right), & 0 < \lambda < 1 \\ N_{sec}P_{sleep}, & \lambda = 0 \end{cases}$$

Where N_{sec} is the number of sectors in the BS, Δ_p is the slope of the load dependent power consumption largely determined by the radio unit efficiency, P_1 is baseband related power consumption. The related parameters mentioned above and examples from real equipment are listed in Table 4-3.

Table 4-3: Key parameters of BS power consumption model.

Name	Unit	Macro (2010)	Micro (2010)	Pico (2010)	Macro (2020)	Micro (2020)	Pico (2020)
P_{max}	W	46.0	38.0	21.0	46.0	38.0	21.0
P_0	W	185.5	96.8	23.5	44.7	20.8	3.2
Δ_p	a.u. (ratio)	5.6	2.5	3.3	3.5	1.8	2.2
P_1	W	20.6	13.1	2.5	2.2	1.4	0.3
P_{sleep}	W	141.2	77.1	18.3	27.1	14.2	2.2

5 Conclusions

5G will push the user experience with regard to data rates and availability in future networks to new extremes. It will also span the wireless connectivity to new areas such as IoT or ITS. Although solutions addressing these domains already exist, 5G will cater for them under the umbrella of one system. The level of integration of different AIVs supporting different 5G UCs is still under discussion in many organizations, vendors and research projects (first findings of METIS-II project on this matter will be available in June 2016 in form of deliverable D2.2 'Draft overall RAN design'). Therefore, it is of uttermost importance to provide a unified evaluation framework that can be used to fairly assess proposed technical solutions with respect to the main 5G KPIs. This document provides such framework on behalf of METIS-II project. The proposed methodology covers all relevant aspect of next generation wireless systems. All three 5G UC families are addressed. Traffic ranges from exchange of small packets to large files are assessed, frequency bands from below 1 GHz up to the mmW range are evaluated, and the infrastructure simulated spans from ultra-dense to sparse deployments, etc. The proposed framework is also simple (vide synthetic deployment scenarios), which is essential to guarantee a widespread adoption of this approach, but provides also necessary data to assess technical concept in more advanced tools, e.g. for visualization purposes (vide realistic deployment scenarios and propagation, mobility traces).

The models described in this document will be used to evaluate different technical solutions and it is possible that some aspects will be a subject to fine tuning. Corrections, if any, and further parametrization of 5G KPIs assessment methods will be available along with the evaluation results in METIS-II deliverable D2.3 'Performance evaluation results' that will be issued in February 2017.

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A Further considerations on the proposed models

A.1 Realistic indoor office

Basic information on realistic Indoor Office has been introduced in Section 3.2.1. Section below contains more detailed assumption on the model.

A.1.1 Environment

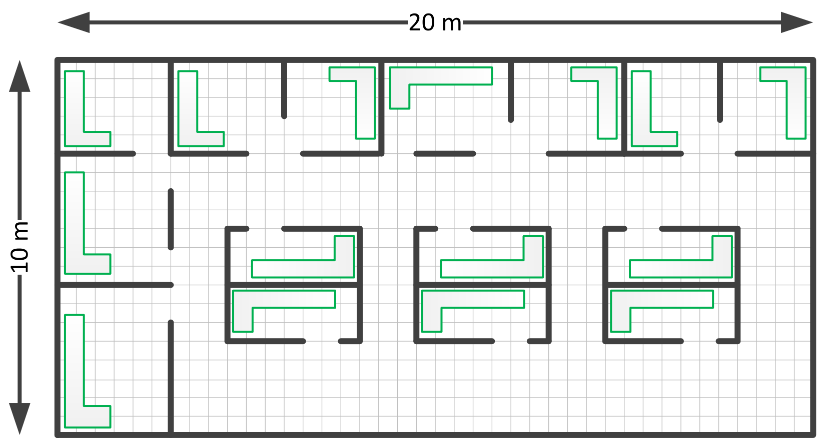


Figure A-1: 2D sketch of the realistic Indoor Office.

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

Table A-1: List of heights of objects in the office.

Object	Height [m]
Room	2.9
Cubicle	1.5
Table	0.7

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. The materials of the objects in the realistic scenario are given in the following table.

Table A-2: List of materials in the Indoor Office realistic scenario.

Object	Material
Room	Concrete
Cubicle	Wood
Table	Wood

For the materials used in the realistic scenario, some parameters are given in the following table.

Table A-3: Propagation characteristics of the materials used in Indoor Office.

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, R_{perp}, is given by

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

and the parallel coefficient, R_{par}, is given by

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

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

A.1.2 Deployment

Several network layouts are proposed:

a) One main station, ceiling-mounted in the center position of the scenario, i.e. coordinates (10,5), with fiber backhaul connection (see Figure A-2).

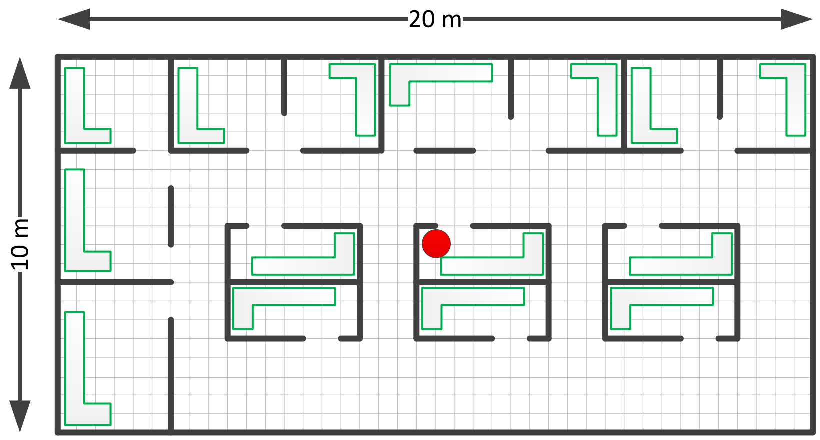


Figure A-2: Realistic Indoor Office layout a).

b) Five stations, ceiling-mounted in coordinates (2,2), (2,8), (18,8), (18,2), and (10,5), with fiber backhaul connections (see Figure A-3).

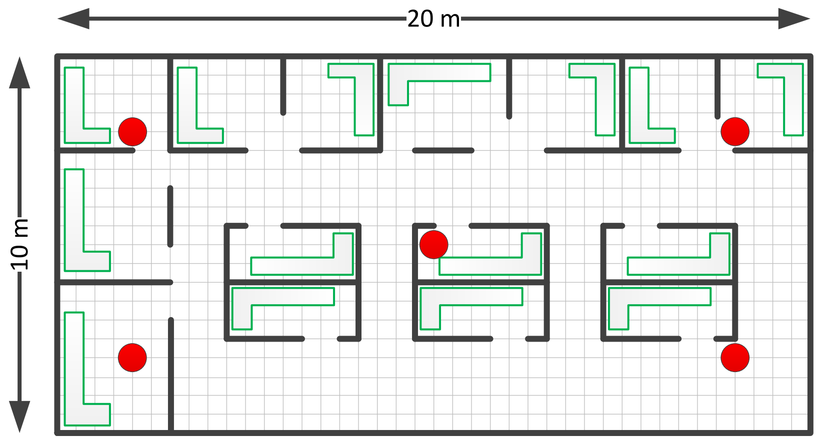


Figure A-3: Realistic Indoor Office layout b).

c) Combinations of the above options such as a) with low frequencies plus b) at high frequencies.

Ray-tracing based pathloss traces for 5 stations case and 60 GHz carrier frequency is available in [MET-WEB].

A.2 Madrid Grid

Basic information on realistic Madrid Grid has been introduced in Section 3.2.2. Section below provides further details on the model.

A.2.1 Environment

Environment of Madrid Grid was proposed in METIS [MET14-D13]. In proposed approach the building elements of proposed environment layout consist of:

- Square shaped buildings. Both length (east-west/horizontal orientation) and width (south-north/vertical orientation) are equal to 120 m
- Rectangle shaped buildings. Length is equal to 120 m and width is 30 m

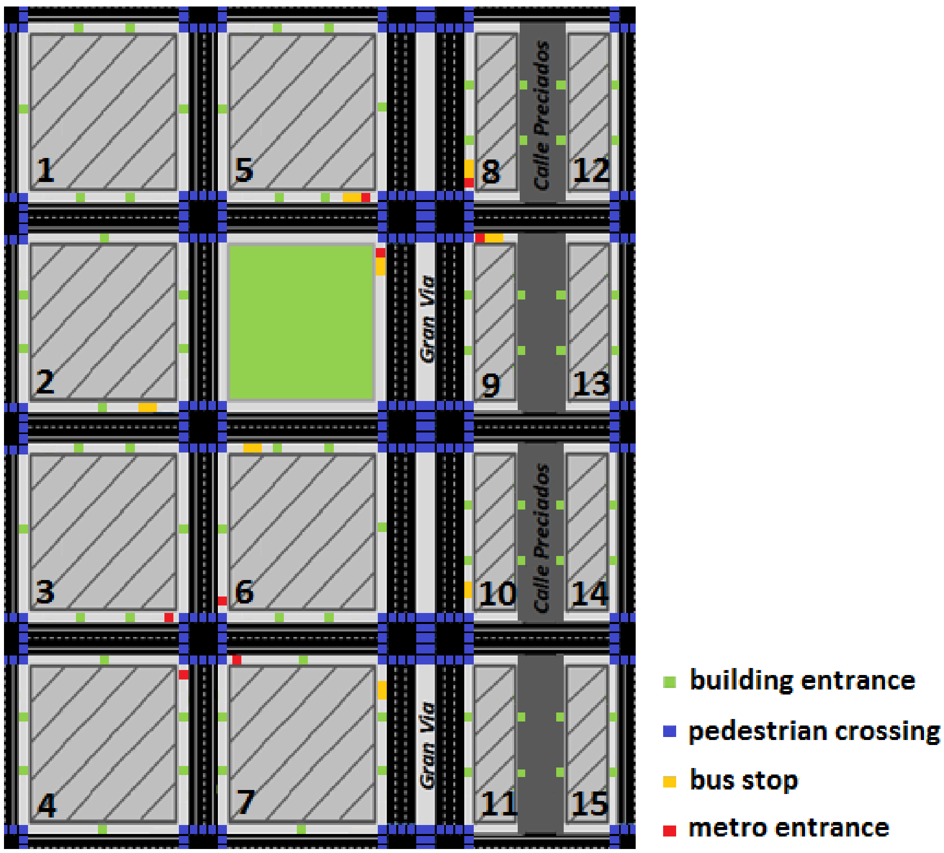


Figure A-4: Madrid Grid outdoor layout.

- 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 entrance configuration. Each building side with east-west orientation has two entrances with the centre positioned 40.5 m from the closest building corner (cf. Figure A-4). Facades with south-north orientation have only one entrance with the centre in the middle of the wall.

- Vertical entrance configuration. Each building side with south-north orientation has two entrances with the centre positioned 40.5 m from the closest building corner. Facades with east-west orientation have only one entrance with the centre in the middle of the wall.

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.

- 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 centre of each one is positioned 4.5 m away from the closest building corner. The position of each metro entrance is given in Figure A-4.
- 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 centre of each one is positioned 15 m from closest building corner. The position of each bus stop is represented in Figure A-4 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 rectangles 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 Table A-4. Index (of the building) correspond to the Madrid Grid layout, type of the building denotes square (S) or rectangular (R) blocks, entrance configuration can either represent 2 and 1 entrances in horizontally and vertically oriented sides (H) or 2 and

1 entrances vertically and horizontally oriented sides (V). Number of floors is given in the last row.

Table A-4: Physical properties of Madrid Grid buildings.

Index	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Type	S	S	S	S	S	S	S	R	R	R	R	R	R	R	R
Entrance	H	V	H	V	H	H	V	V	V	V	V	V	V	V	V
Floors	15	14	12	13	9	15	8	9	13	11	12	13	14	11	12

A.2.2 Deployment

In order to limit the border effect, the environment model may be extended by placing considered simulation area in the broader area as depicted in Figure A-5. The broader area consists of nine identical representations of simulated area. Surrounding copies are used to create the realistic (i.e. not isolated) simulation environment for instance interference profile.

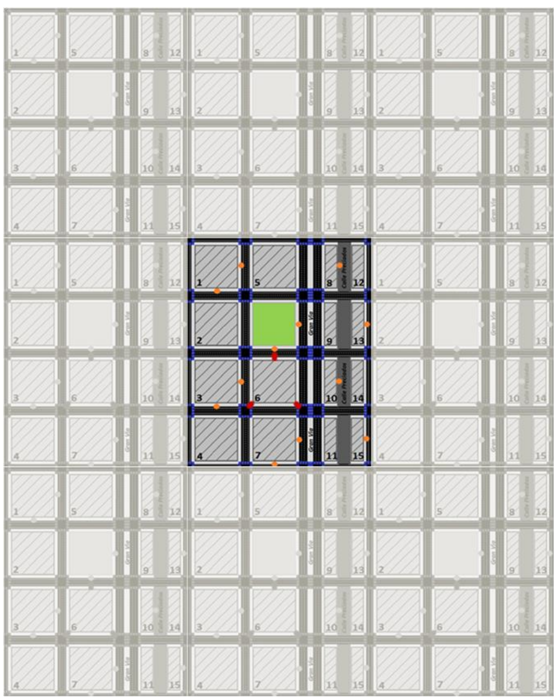


Figure A-5: Wrap approach for Madrid Grid. Shadowed area used to avoid border effects.

Remaining part of the subsection presents baseline layout for Madrid Grid proposed in METIS [MET13-D61]. It should be noted that it is not fully inline in with METIS-II recommendations for dense urban information society (e.g. with respect to a number of outdoor small cells (micro/pico

BSs or operating frequencies). However, it could be used as a starting point for evaluation of dense urban information society. Additionally, for 800 MHz for macro cells and 2.6 GHz for small cells, a set of ray-tracing based pathloss traces are available in [MET-WEB] (METIS TC2).

Exemplary network infrastructure for basic layout of Madrid Grid is depicted in the Figure A-6.

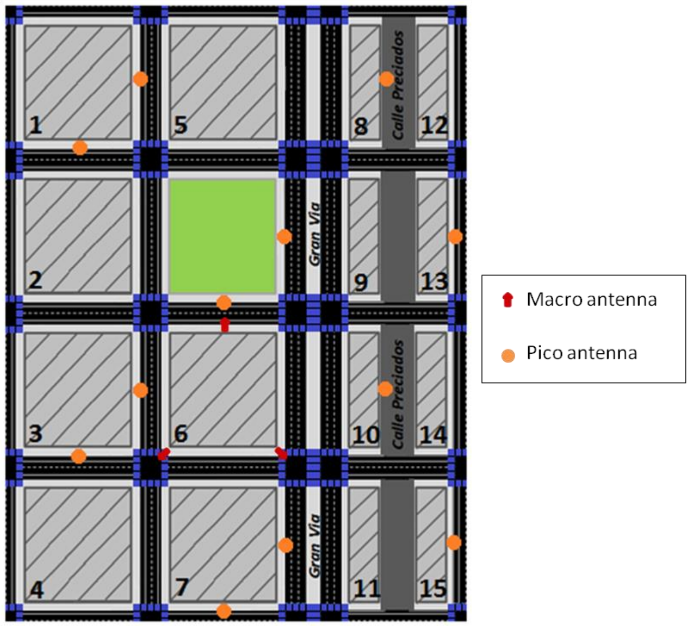


Figure A-6: Baseline deployment for Madrid Grid.

Basic network layout consists of a single macro station operating in 3 sectors on a central carrier frequency of 800 MHz or 3.5 GHz. 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 150, mechanical tilt 7^0
- Antenna 2: azimuth $120^{0,}$ electrical tilt 150, mechanical tilt 18^0
- Antenna 3: azimuth 240^0, electrical tilt 150, mechanical tilt 18^0

The macro cells in baseline deployment are complemented with 12 micro/pico cells operating at central carrier frequency of 2.6 or 25 GHz. 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 A-6. Two cells per micro BS point toward the main street with the same antenna pattern as macro cells.

A.2.3 Mobility model

The Madrid Grid basic layout is depicted in the Figure A-4 where the main elements having an impact on the mobility model are represented.

The Madrid Grid basic layout has 5 horizontal streets numbered from H1 to H5, where H1 is the upper street, and 4 vertical streets, numbered from V1 to V5, where V1 is the leftmost street.

There are only bus stops at H2, H3 and V3.

The METIS-II mobility model for the Madrid Grid scenario considers three different cases: indoor mobility, outdoor pedestrian mobility and vehicular mobility. Next, these models are detailed. First, the traffic light model having an impact on both vehicular and pedestrian models is explained.

Traffic light model

All vehicular traffic lights in the grid switch simultaneously with a pattern which repeats every 90 s. The switching pattern for vehicular traffic lights is described as follows

- 0-37 seconds: horizontal streets lights green, vertical streets lights red
- 37-42 seconds: horizontal streets lights yellow, vertical streets lights red
- 42-45 seconds: both horizontal and vertical streets lights red
- 45-82 seconds: horizontal streets lights red, vertical streets lights green
- 82-87 seconds: horizontal streets lights red, vertical streets lights yellow
- 87-90 seconds: both horizontal and vertical streets lights red

A minimum yellow phase duration of 4.5 s has been calculated as the time needed by a bus driving at a speed of 50 km/h to stop before the traffic light considering a specific deceleration of 4 m/s^2 and a reaction time of 1 s. To be conservative a phase of 5 s is considered.

Also, a minimum duration of 2.5 s for the red phase overlap between horizontal and vertical traffic lights has been calculated as the time needed by a bus driving at a speed of 50 km/h to go over a distance equal to the largest street width plus the width of a pedestrian crossing and the bus length (42 meters in total). To be conservative, we have considered a phase of 3 s.

The switching pattern for pedestrian traffic lights is as follows:

- 0-41 seconds: horizontal streets crossing lights red, verticals streets crossing lights green
- 41-45 seconds: horizontal streets crossing lights red, vertical streets crossing lights blinking green
- 45-86 seconds: horizontal streets crossing lights green, vertical streets crossing lights red

- 86-90 seconds: horizontal streets crossing lights blinking green, vertical streets crossing lights red

The blinking phase duration can be calculated as the time needed by a pedestrian moving at 3 km/h to go over a sidewalk of 9 meters, obtaining a value of 3.6 s. We have considered a duration of 4 s to be conservative.

Outdoor vehicular mobility

A configurable number of cars, with dimensions 1.8 m x 4.3 m, are uniformly distributed in the scenario. Each car has a number of users inside chosen uniformly from the interval [1,5].

Cars maximum velocity is 50 km/h, while car acceleration is 2.9 m/s^2 and deceleration is 7.5 m/s^2.

Cars do not turn at cross streets, but move always along the same street. When cars reach the scenario borders, they bounce back and drive along the opposite lane, in the opposite direction.

Collisions with potential vehicles are avoided. In fact, cars stop at red traffic lights and also when there is another vehicle less than 2.5 m in front.

Figure A-7 depicts the vehicular routes in the Madrid Grid. In the horizontal streets the vehicle routes are shown as yellow ellipses, in the vertical streets as red ellipses, and an additional outer route is shown in orange. Similar routes can be defined in the extended Madrid Grid shown in Figure A-7.

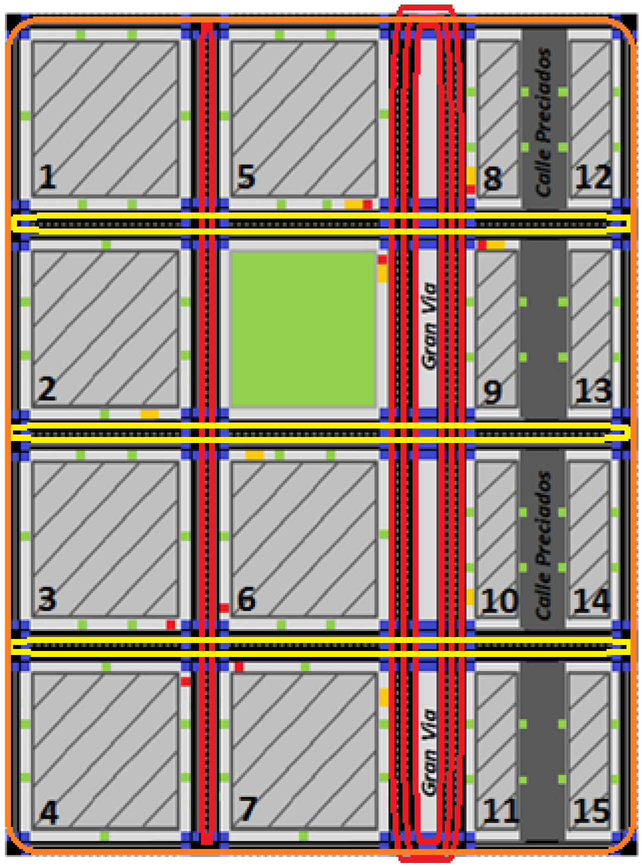


Figure A-7: Car mobility routes.

Buses have dimensions 12 m x 2.5 m, and a number of users chosen uniformly from the interval [1,50].

Buses maximum velocity is 50 km/h, while bus acceleration is 1.2 m/s^2 and deceleration is 4 m/s^2.

Likewise cars, buses do not turn at cross streets and bound back at scenario borders.

One bus is included in each horizontal street with bus stops, whereas four buses are included in the vertical street with bus stops. In total, six buses are considered.

Buses only stop at red traffic lights, when there is another vehicle less than 2.5 m in front, or in bus stops for 20 s.

Figure A-8 depicts the bus routes in the Madrid Grid placed only in H2, H3, and V3. Similar routes can be defined in the extended Madrid Grid shown in Figure A-8.

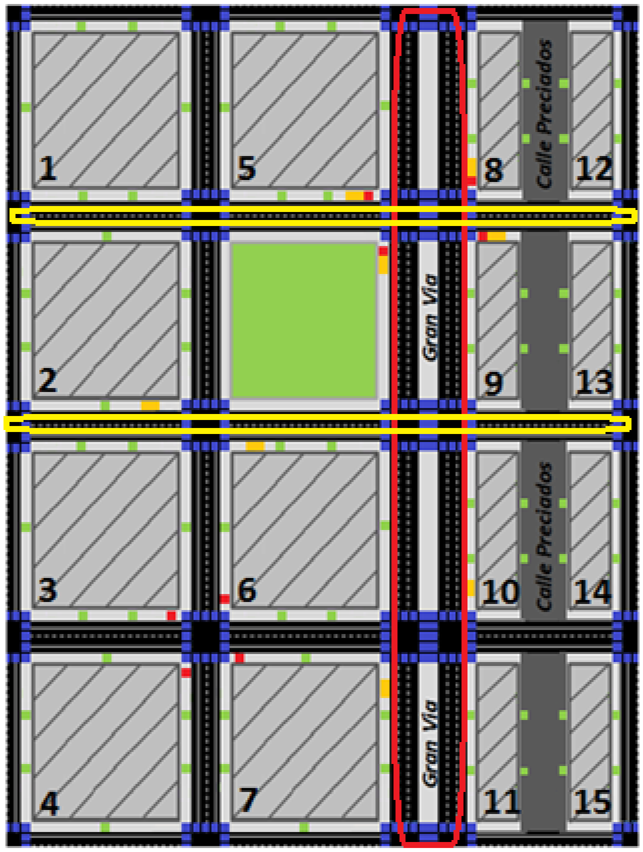


Figure A-8: Buses mobility routes.

Pedestrian mobility

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 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 A-9. The turning probability, *TurnProb* is fixed to 0.5.

Collisions between pedestrians are avoided. With this aim:

- Sidewalks have two lanes, one for each direction

- One pedestrian can overtake another pedestrian by using the opposite lane if there is no pedestrian using this lane.
- Once the overtaking is done, the pedestrian returns to its original lane.

At boundaries of the simulation environment, pedestrians bounce back with the same speed.

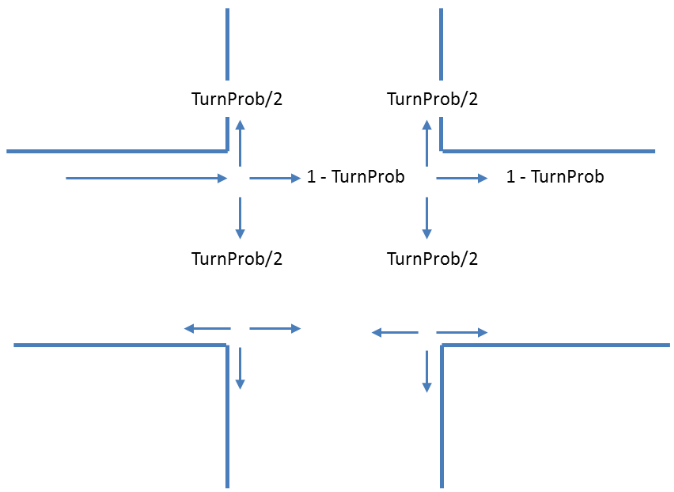


Figure A-9: Pedestrian mobility at cross streets. The turning probability, TurnProb, is 0.5.

Indoor mobility

A uniform distribution of users per building is generated (including the special case of 0 users per building).

A.2.4 Mobility traces

Vehicular traces are generated with "Simulation of Urban MObility", or SUMO for short, an open-source road traffic simulator. It allows to simulate how a given traffic demand which consists of single vehicles moves through a given road network. The simulation is purely microscopic: each vehicle is modelled explicitly, has an own route, and moves individually through the network. Simulations are deterministic by default but there are various options for introducing randomness.

Simulation output is obtained by means of XML file, and the position of each vehicle is given for each simulation time step (configurable parameter). Each vehicle position is essentially determined by the attributes in the next table (note that SUMO provides internal parameters which are not relevant for vehicle positioning):

Table A-5: Physical properties of Madrid Grid buildings.

Name	Type	Description
timestep	(simulation) seconds	The time step described by the values within this timestep-element
x	---	The absolute X coordinate of the vehicle. The value depends on the given geographic projection
y	---	The absolute Y coordinate of the vehicle. The value depends on the given geographic projection
id	id	The id of the vehicle
type	id	The name of the vehicle type
speed	m/s	The speed of the vehicle
angle	degree	The angle of the vehicle

Please note that the orientation angle is in the range [-180,180]. The convention for the orientation is: 180º means north direction, 90º means east direction, 0º means south direction, and -90º means west direction.

XML output file structure is as follows:

```
<fcd-export>

  <timestep time="<TIME_STEP>">
     <vehicle id="<VEHICLE_ID>" x="<VEHICLE_POS_X>" y="<VEHICLE_POS_Y>"
angle="<VEHICLE_ANGLE>" type="<VEHICLE_TYPE>"
     speed="<VEHICLE_SPEED>"/>

     ... more vehicles ...

 </timestep>

 ... next timestep ...

</fcd-export>
```

Pedestrian traces can either be generated with SUMO or other external tool, but in any case the output file should follow the SUMO format.

SUMO XML mobility traces (vehicular and pedestrian) can be easily integrated into network simulators or Unity3D visualization platform. It is up to implementation's best criteria whether to use the XML file format or to parse the data to a specific file format.

Figure A-10: Exemplary utilization of mobility traces in Unity3D visualization platform.

Figure A-11: Exemplary utilization of mobility traces in Unity3D visualization platform.

A.3 D2D channel model

The channel models for D2D links are considered, for example, in Virtual reality office and Dense urban information society UCs. D2D indoor to indoor channel models specified in [3GPP14-36843] can be reused for the channels used in D2D links below 3.5 GHz.

The D2D indoor to indoor channel models include pathloss, LOS probability, shadowing standard deviation, shadowing correlation and fast fading. The pathloss of D2D indoor to indoor channel is referenced to case (3) of UE to RRH/Hotzone in Table A.2.1.1.5-1 in [3GPP10-

36814], where the pathloss is a function of distance. LOS probability is referenced to ITU-R IMT UMi scenario in Table A.1-3 in [ITUR08-M2135] where LOS probability is also a function of distance. For the shadowing, the D2D indoor to indoor channel is modelled using a log-normal distribution with a standard deviation of 3 dB for LOS case and a standard deviation of 4 dB for NLOS case, respectively [3GPP14-36843]. Besides, the shadowing correlation is independent and identically distributed (i.i.d.). For the fast fading, the D2D indoor to indoor channel is modelled using the ITU-R InH model for LOS and NLOS cases [ITUR08-M2135] where the clustered delay line (CDL) model can be used in the fast fading model for D2D indoor to indoor channel. The CDL model is a geometry-based stochastic model and it defines power, delay, and angular information where the angular information includes angle of arrival (AoA), angle of departure (AoD), angle spread of arrival (ASA), and angle spread of departure (ASD).

B Supplementary material

Next table comprises the specific information used for obtaining wideband SINR in DL for specific use cases. Applicable parameters are in the corresponding Section 3 and Section 4. Results shown below can be used as a starting point for calibration of METIS-II UCs, additional material in the form of a excel sheet with all CDF values is available at METIS-II webpage [MET-WEB2]. Extended evaluations statistics obtained from multiple partners will be provided in METIS-II deliverable D2.3.

Table B-1: Evaluation parameters for deployment scenarios.

Deployment scenario for the evaluation process	**Indoor hotspot**	**Urban macro cell**	**Outdoor small cells**	**Rural macro cell**
BS antenna pattern	2D Omni-directional	3D, referring to 3GPP TR36.897	2D Omni-directional	3D, referring to 3GPP TR36.819
BS antenna gain	5 dBi (per element)	17 dBi	5 dBi (per element)	17 dBi
BS transmit power	21 dBm in 20 MHz band	49dBm in 20 MHz band	30 dBm in 20 MHz band	49 dBm in 30 MHz band
UE antenna height	1.5 m	1.5	1.5 m	1.5 m
UE antenna pattern	2D Omni-directional	2D Omni-directional is baseline	2D Omni-directional	2D Omni-directional
UE antenna gain	0 dBi	0 dBi	0 dBi	0 dBi
UE noise figure	9 dB	9 dB	9 dB	9 dB
Carrier frequency for evaluation	3.5 GHz	2 GHz	3.5 GHz	800 MHz
Simulation bandwidth	20 MHz	20 MHz	20 MHz	30 MHz
Thermal noise level	-174 dBm/Hz	-174 dBm/Hz	-174 dBm/Hz	-174 dBm/Hz

Table B-2: Evaluation parameters for specific use cases.

Use case	Dense urban information society	Virtual reality office	Broadband access everywhere	Massive distribution of sensors and actuators	Connected cars
BS deployment	UMa+UMi (HetNet)	InH	RMa	UMa	UMa, RMa
User deployment	Randomly and uniformly distributed over area	Randomly and uniformly distributed over area	Randomly and uniformly distributed over area	Randomly and uniformly distributed over area	Randomly and uniformly distributed over the road layout of urban and motorway
Indoor / Outdoor ratio	80/20	100/0	0/100	80/20	0/100
Channel model	3D UMa [TR36.873] for macro to UE, 3D UMi [TR 36.873] for small cell to UE, both with 3D distance between TX/RX	ITU InH [referring to Table B.1.2.1-1 in TR36.814] with 3D distance between TX/RX	ITU RMa [referring to Table B.1.2.1-1 in TR36.814] with 3D distance between TX/RX	3D UMa [TR36.873] with 3D distance between TX/RX	See Section 4.5.4

B.1 Dense urban information society

Figure B-1 shows the CDF of the wideband SINR of the heterogeneous deployment that characterizes the dense urban information society scenario. In the urban macro cellular scenarios eight small cells are randomly deployed.

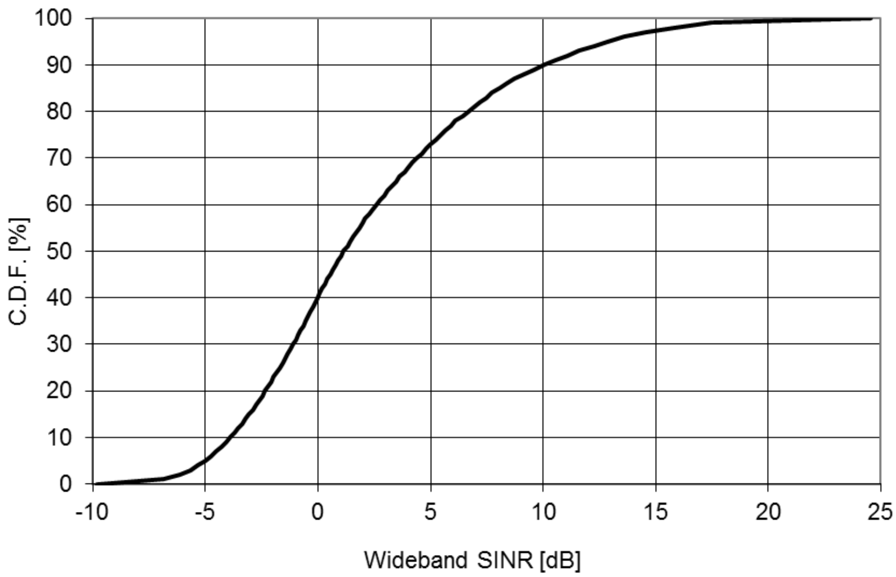


Figure B-1: CDF of downlink wideband SINR for dense urban information society.

B.2 Virtual reality office

For calibration purposes, the deployment in this scenario is assumed to be done exclusively at 3.5 GHz. Next figure plots the wideband SINR for this scenario.

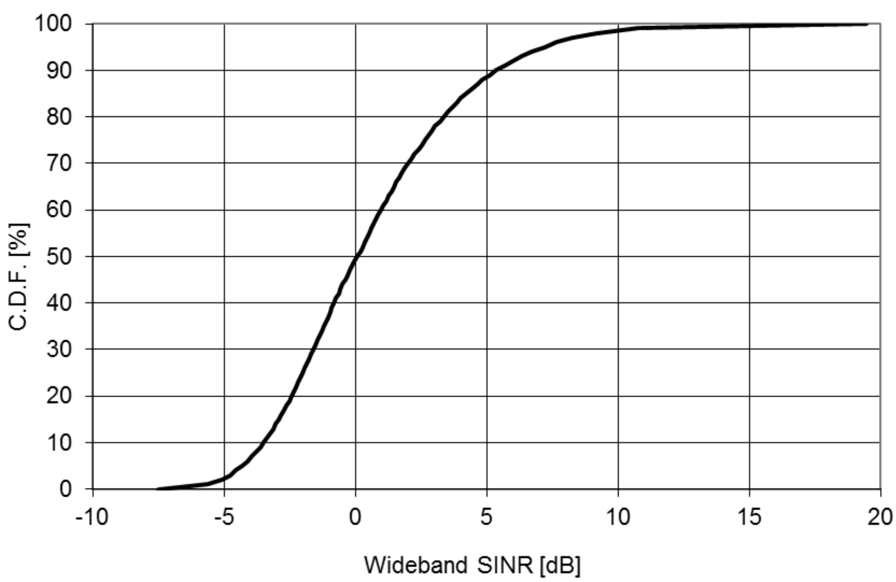


Figure B-2: CDF of downlink wideband SINR for virtual reality office.

B.3 Broadband access everywhere

This section focuses on the calibration setting for the Broadband access everywhere UC.

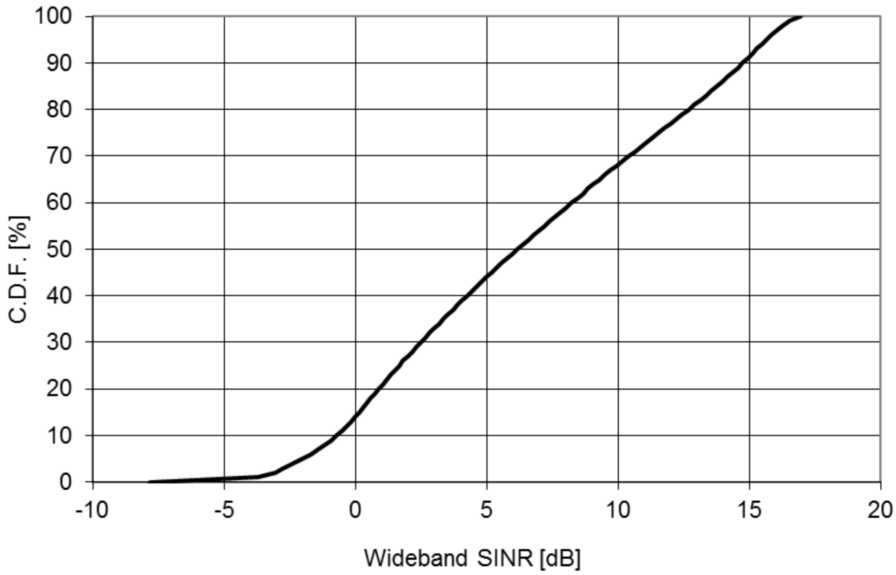


Figure B-3: CDF of downlink wideband SINR for broadband access everywhere.

B.4 Massive distribution of sensors and actuators

Concerning the UC Massive distribtutions of sensors and actuators, Figure B-4 represents the wideband SINR value assuming a single antenna element in both transmitter and receiver side, and zero downtilt in the base station.

B.5 Connected cars

Finally, Figures B-5 and B-6 depict the wideband SINR for the Connected cars use case for the two synthetic cases described in Section 4.5, that is, for the urban and for the highway case, respectively.

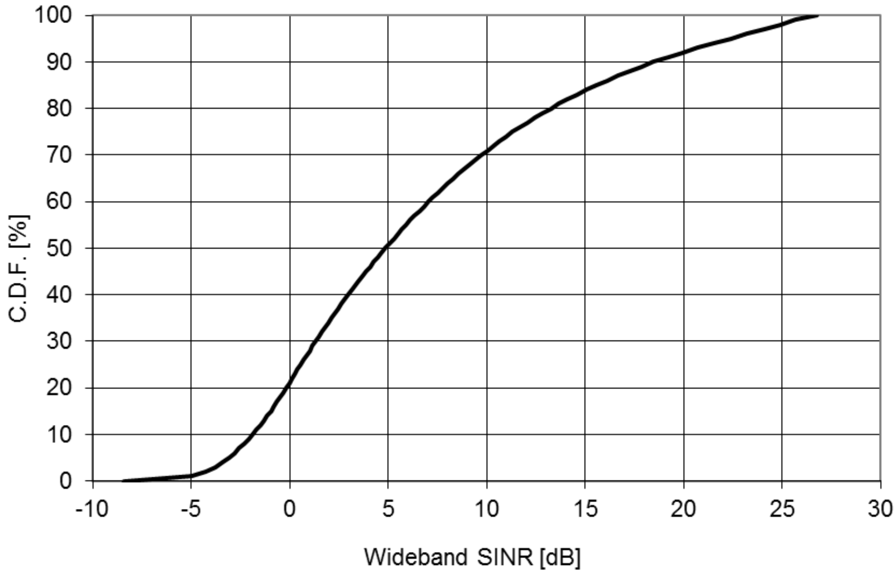


Figure B-4: CDF of downlink wideband SINR for massive distribution of sensors and actuators (single antenna element with zero downtilt).

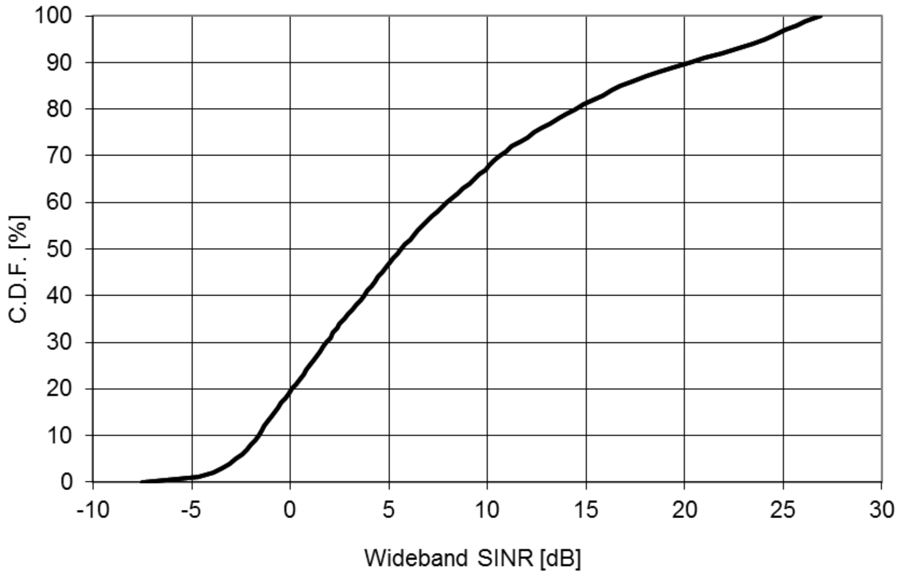


Figure B-5: CDF of downlink wideband SINR for connected car in urban case.

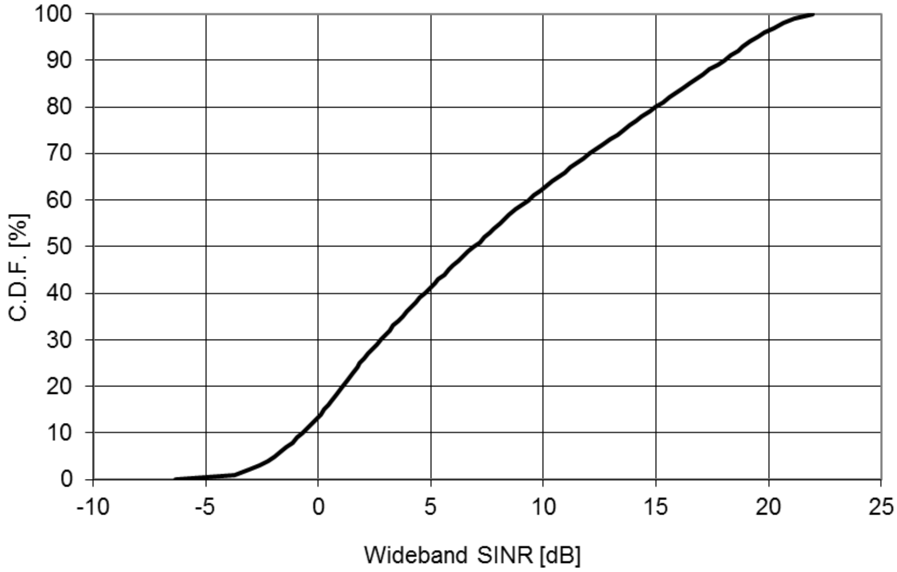


Figure B-6: CDF of downlink wideband SINR for connected car in highway case.

C IMT-A evaluation process

C.1 Overview

IMT-Advanced (IMT-A) is recognized as the 4th generation (4G) of wireless networks that could provide high data rates to enable various mobile broadband (MBB) applications. In 2007-2008 timeframe, ITU-R Working Party (WP) 5D developed the evaluation guideline for IMT-A for its performance assessment, and defined its performance metrics and technical performance requirements. Summary of these can be found in two ITU-R reports, i.e., the report ITU-R M.2135 "Guidelines for evaluation of radio interface technologies for IMT-Advanced" [ITUR08-M2135], and the report ITU-R M.2134 "Requirements related to technical performance for IMT-Advanced radio interface(s)" [ITUR08-M2134].

The report ITU-R M.2135 defined a complete framework for IMT-A evaluation. It includes three components:

- Test environments, which consist of:
  - Traffic model that is characterized by the service to be evaluated.
  - Deployment scenario, which provides the geographical characteristics where the service is deployed (e.g., indoor hotspot, dense urban area).
  - Evaluation configuration, i.e., the assumed evaluation parameters applied to the selected traffic (service) and deployment scenario.
- Evaluation methodology and procedure for each of performance metrics:
  - High level assessment method for each of the performance metrics, e.g., inspection, analytical, and simulation.
  - Detailed evaluation method and procedure.
- Evaluation models, e.g., channel model, etc.

The following subsections give more detailed information on these three IMT-A evaluation components.

C.1.1 IMT-A test environments

IMT-A focused on MBB scenarios, where provision of high data rates and voice service were the main UC, and the human communication environments are the typical application environments for MBB. Accordingly, IMT-A defined four test environments, which are listed in Table C-1. The "indoor" and "microcellular" are representatives for high user density scenarios in indoor (e.g., office) and dense urban area, respectively. The "base coverage urban" and "high speed" represent the wide area coverage scenarios with lower user density, but higher user mobility, in urban and rural area, respectively. The corresponding deployment scenarios are also shown in Table C-1. One could refer to [ITUR08-M2135] for more details.

Table C-1: Test environments and deployment scenarios of IMT-A.

Test environment	Indoor	Microcellular	Base coverage urban	High speed
Deployment scenario	Indoor hotspot scenario (InH)	Urban micro-cell scenario (UMi)	Urban macro-cell scenario (UMa)	Rural macro-cell scenario (RMa)

Traffic models employed for IMT-A evaluation were full buffer and Voice over Internet Protocol (VoIP) traffic, representing the capacity and the voice service challenge, respectively.

C.1.2 Evaluation method and procedure of IMT-A

IMT-A employed three types of high-level assessment method, i.e., inspection (by reviewing the functionality and parameterisation of the proposal), analytical (via a calculation), and simulation. Table C-2 lists the corresponding method for some of the performance metrics defined in [ITUR08-M2134]. The performance metrics that need quantitative evaluation but could not be derived by calculation were evaluated through simulation. In [ITUR08-M2135], the procedure of system-level simulation was defined. Figure C-1 illustrates the abstracted simulation procedure according to the principles defined in [ITUR08-M2135].

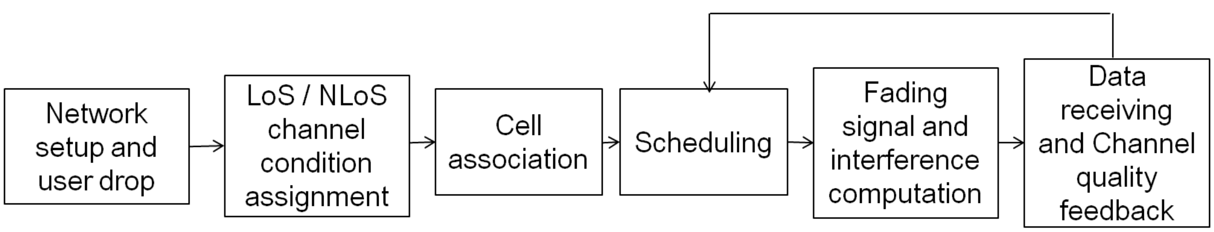


Figure C-1: Illustration of the system-level simulation procedure of IMT-A [ITUR08-M2135].

An important issue is to identify which of the metrics will be evaluated simultaneously. It depends on which of the requirements need to be fulfilled simultaneously. In IMT-A, cell spectral efficiency and cell edge spectral efficiency were evaluated jointly, due to the need for IMT-A systems need to provide good cell capacity along with good fairness among users.

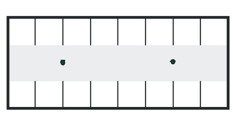
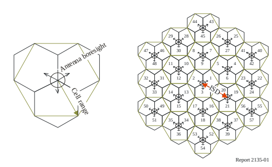
Table C-2: Evaluation method of IMT-A (for some of performance metrics).

Performance metric	Method
Cell spectral efficiency	Simulation (system level)
Peak spectral efficiency	Analytical
Bandwidth	Inspection
Cell edge user spectral efficiency	Simulation (system level)
Control plane latency	Analytical
User plane latency	Analytical
Mobility	Simulation (system and link level)
Inter-system handover	Inspection
VoIP capacity	Simulation (system level)

C.1.3 Evaluation configurations and evaluation models of IMT-A

To obtain a fair comparison of results among different proponents, the evaluation configuration and evaluation models for each of the test environment were defined. Table C-3 summaries the primary evaluation configurations and evaluation models employed in IMT-A. More details can be found in [ITUR08-M2135].

Table C-3: Evaluation configurations and models for system-level simulation of IMT-A [ITUR08-M2135]

Parameters/Test environments	Indoor	Microcellular	Urban base coverage	High speed
Traffic model	Full buffer (for cell spectral efficiency and cell edge spectral efficiency); VoIP (for VoIP capacity)			
Network layout				

User distribution	Randomly and uniformly distributed over area			
	100% of users indoor	50% users outdoor and 50% users indoor	100% of users outdoors in vehicles	100% of users outdoors in high speed vehicles
Inter-site distance	60 m	200 m	500 m	1 732 m
Simulation bandwidth	20+20 MHz (FDD), or 40 MHz (TDD)	10+10 MHz (FDD), or 20 MHz (TDD)	10+10 MHz (FDD), or 20 MHz (TDD)	10+10 MHz (FDD), or 20 MHz (TDD)
Carrier frequency	3.4 GHz	2.5 GHz	2 GHz	800 MHz
Antenna configuration	Up to 8 antennas at base station (BS) Up to 2 antennas at user terminal (UT)			
User mobility	3 km/h	3 km/h	30 km/h	120 km/h
BS transmit power	21 dBm/20 MHz	41 dBm/10 MHz	46 dBm/10 MHz	46 dBm/ 10 MHz
UT power class	21 dBm	24 dBm	24 dBm	24 dBm

C.2 Updates needed for 5G

Based on the information from Annex C.1 and 5G UC definitions provided in Section 2.3, it becomes evident, that in comparison to evaluation method proposed for 4G/IMT-A by ITU-R in [ITUR08-M2134], [ITUR08-M2135], performance evaluation framework proposed by METIS-II for evaluation of 5G solutions in 5G-PPP should bring several key differences and additions.

Deployment scenarios. New synthetic deployment scenario, HetNet is introduced to reflect the importance of heterogeneous deployments and new connectivity options. Realistic deployment scenario Madrid Grid captures the need to validate gains of static and dynamic solutions in real-like deployments and may be crucial in evaluations of higher frequency bands solutions that require e.g., realistic cell borders.

Other deployment scenarios were adjusted to reflect e.g. higher number of antennas (justified by moving to higher frequency regimes) or TDD configuration that mirrors the expectation of wireless community for this duplexing method to be an important transmission mode in case of small cell deployments.

In addition, new parametrization is required to evaluate the mMTC and uMTC UC families which were not considered in IMT-A evaluation.

KPIs. As indicated in [5GI15] and [MET15-D66] 5G will bring new UC families (mMTC, uMTC) that need new KPIs to be used for benchmarking of individual solutions. As an example device energy consumption will be of a prime consideration for mMTC, reliability for uMTC, etc. Also xMBB which was a focus area of 4G candidates will require new or updated metrics such as network energy efficiency, ability to exploit heterogeneous environment, etc. Multiplicity of connectivity options and possible solutions (as well as maturity of cellular ecosystem that manifest in existence of multiple network/service operators) incline the importance of cost and complexity analysis that will allow the choice of economically justified solutions. In addition, the KPI definition needs to accommodate new technology trends to keep it technology-agnostic, and some of the KPIs defined in IMT-A may need update to achieve this.

Higher frequency bands. New frequency bands (especially in the mmW region) require substantial redefinition of channel models, both for small scale (fast fading) and large scale (slow fading). Importance of higher frequency band is also reflected in the addition of realistic deployment scenarios.

Traffic. Although prediction of future applications and related traffic models is always incurred with considerable errors, several trends for future 5G solutions can be outlined. First of all, full buffer metrics may not be sufficient to capture all the relevant user experience statistics. Full buffer evaluation is a very good mean for quantification of maximum capacity. However, when evaluating e.g. cell edge user experience or fulfilment of QoS requirements, bursty traffic models are more suitable. They are also needed for mMTC and uMTC services.

In METIS-II, technology solutions are developed to meet the requirements of different services in different UCs of xMBB, uMTC and mMTC. Thus, different evaluation criteria are necessary for performance evaluation.

D State-of-the-art overview

This section captures the SOTA overview of the status of organizations and projects relevant for 5G as of September 2015.

D.1 3GPP

3GPP uses IMT-A evaluation methods (cf. Annex C.1) as the baseline for evaluation of mobile broadband services for Long Term Evolution (LTE). However, along the evolution of LTE standard, several enhancements to evaluation models were proposed, that were necessary to assess the gains of key enhancement of 4G, such as heterogeneous network deployment scenarios [3GPP10-36814] or small cell operations [3GPP13-36932]. Mentioned documents focus on system level simulations, while link level evaluation considerations (needed e.g., for performance evaluation of advanced receivers) can be found in [3GPP12-36839].

Apart from mobile broadband, 3GPP has also recognised the importance of MTC and V2X services, and extended its evaluation framework on these services ([3GPP11-37868] and [3GPP15-36885] respectively).

Architectural and deployment options can be found in several 3GPP documents. [3GPP10-36814] apart from recalling IMT-A deployments, highlights also homogenous and heterogeneous access node layout for the purpose of system level evaluation.

For homogeneous hexagonal layouts, case 1 (500 m ISD) and case 3 (1732 m ISD) are used for the evaluation of a regular access network grid with the same type of access nodes. For heterogeneous deployments (macro for coverage enhanced with small cells for capacity over limited area) several options of small cell deployments are considered (see Table D-1).

Table D-1: 3GPP heterogeneous network deployment scenarios [3GPP10-36814].

Case	Environment	Deployment Scenario	Non-traditional node
5.1	Macro + Indoor	Macro + femtocell	femtocell
5.2		Macro + indoor relay	Indoor relay
5.3		Macro + indoor remote radio head (RRH)/Hotzone	e.g. indoor pico
6.1	Macro + Outdoor	Macro + outdoor relay	outdoor relay

6.2		Macro + outdoor RRH/Hotzone	e.g., outdoor pico

Additional architectural and deployment considerations can be found in [3GPP13-36932]. This report highlights also important aspects of access node operation with non-ideal backhaul (e.g., achievable throughput and latency for a certain type of backhaul topology, such as fibre, Digital Subscriber Line (DSL), cable or wireless). They are summarized in Table D-2.

Table D-2: Most important (prio 1) options for realization of non-ideal backhaul as defined by 3GPP in [3GPP13-36932].

Backhaul technology	Latency (one way)	Throughput
Fiber Access 1	10-30 ms	10 Mbps-10 Gbps
Fiber Access 3	2-5 ms	50 Mbps-10 Gbps
DSL Access	15-60 ms	10-100 Mbps
Wireless Backhaul	5-35 ms	10-100 Mbps typical, maybe up to Gbps range

Report [3GPP13-36842] provides also possible dual connectivity options for heterogeneous deployments. Solutions presented in Figure D-1 were selected by 3GPP for further evaluation studies [3GPP14-140002].

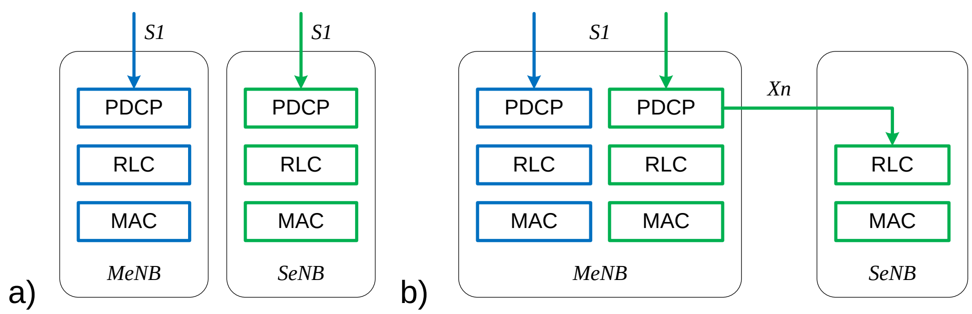


Figure D-1: Dual connectivity options alternatives selected by 3GPP [3GPP13-36842] a) user plane terminates in both master eNB (MeNB) and secondary eNB (SeNB), b) user plane terminates in MeNB and is routed to SeNB using X2 interface.

3GPP report [3GPP10-36814] introduces **traffic models** for evaluation of mobile broadband services in 4G RAN. 3GPP approach extends IMT-A evaluation assumptions on traffic types ([ITUR08-M2134] assumes only full buffer model and VoIP) and introduces burst buffer (also known as finite buffer or bursty traffic) models and corresponding metrics. These traffic models were introduced to overcome shortcomings of the IMT-Advanced full buffer model (e.g., to better capture the characteristics of broadband services such as web browsing).

First model, File Transfer Protocol (FTP) traffic model 1, characterize the traffic source with file size *S* of 2 MB (0.5 MB is optional to speed-up the simulation) and a user arrival rate with Poisson distributions with mean of 0.12, 0.25, 0.37, 0.5 and 0.625 (can be further adjusted).

Second model, FTP Traffic Model 2, is characterized by the file size of 0.5 MB, fixed number of users equal to [2, 5, 8, 10, 14] (can be further adjusted), and the reading time *D* with exponential distributions:

$$f_D = \lambda e^{-\lambda D}, D \geq 0, \lambda = 0.2$$

The reading time *D* is the time interval between end of download of previous file and the user request for the next file.

For FTP Model 2, the packet inter-arrival time is given by *Tt* + *D* where *Tt* is the file transfer time and $\lambda = 1/(Tt + D)$.

Third model, FTP traffic model 3, is based on FTP model 2 with the exception that packets for the same UE arrive according to a Poisson process and the transmission time of a packet is counted from the time instance it arrives in the queue [3GPP13-36872].

Additionally, 3GPP defines file dropping criteria that can be used to avoid overloading and instability in high load situations. If generated packets are not transferred within 8 s in case of 0.5 MB files (or 32 s in case of 2 MB), then they are discarded from the simulation. Packets are also dropped if a number of maximum HARQ retransmissions is exceeded when Radio Link Control (RLC) layer is not explicitly modelled.

Improvements for low-cost machine-type devices are also subject of 3GPP investigations. In [3GPP11-37868] several simulation assumption are given for MTC traffic support in LTE-A. Proposed traffic models and device density are captured in Table D-3.

Table D-3: MTC traffic characteristics and device distribution [3GPP11-37868].

Characteristics	Traffic model 1	Traffic model 2
Number of MTC devices	1000, 3000, 5000, 10000, 30000	1000, 3000, 5000, 10000, 30000
Arrival distribution	Uniform distribution over T	Beta distribution over T
Distribution period (T)	60 s	10 s

Until recently, the 3GPP focused only on 2D **channel modelling**, which means that all spatial properties related to modelling of propagation characteristics (such as position of the cluster, angular properties of multipath components) were distributed in horizontal plane only. Also, the position of the UE was limited to the street level. Based on these assumptions, three distinctive environment models for Spatial Channel Model (SCM) were identified [3GPP14-25996]. However, for the description and evaluation of physical layer enhancements needed for meeting IMT-A requirements by 4G RAN [ITUR08-M2135], 3GPP used channel models proposed in [3GPP10-36814] that are defined for

- Indoor hotspot (InH)
- Urban macro (UMa)
- Urban micro (UMi)
- Rural macro (RMa)

These models were developed for different carrier frequencies, average ISDs, operating bandwidth (BW), penetration losses and UE speeds, and allowed modelling of up to 8x8 multiple input multiple output (MIMO) transmission scheme.

In 2013, the 3GPP recognized the importance of multi-antenna techniques abilities in exploiting also vertical (elevation) dimension. This necessitates modelling of vertical sectorization or radio signal properties for user's located indoors on higher floors. As a result, a three dimensional (3D) channel model was developed [3GPP15-36873]. Two (three) environments were selected as important from the perspective of deployment possibilities for full dimension MIMO. Basic parameter sets for these models are captured in Table D-4.

Table D-4: Basic parameters for the evaluation of 3D channel model in 3GPP [3GPP15-36873].

		Urban Micro cell with high UE density (3D-UMi)	**Urban Macro cell with high UE density (3D-UMa)**	**Urban Macro cell with one high-rise per sector and 300 m ISD (3D-UMa-H)**
Layout		Hexagonal grid, 19 micro sites, 3 sectors per site	Hexagonal grid, 19 macro sites, 3 sectors per site	Hexagonal grid, 19 macro sites, 3 sectors per site
UE mobility (movement in horizontal plane)		3 km/h	3 km/h	3 km/h
BS antenna		10 m	25 m	25 m

height				
Total BS transmit power		41/44 dBm for 10/20 MHz	46/49 dBm for 10/20 MHz	46/49 dBm for 10/20 MHz
Carrier frequency		2 GHz	2 GHz	2 GHz
Min. UE-BS 2D distance		10 m [other values for future studies (FFS)]	35 m	35 m
UE height (hUT) in meters	general equation	hUT=3(nfl – 1) + 1.5	hUT=3(nfl – 1) + 1.5	hUT=3(nfl – 1) + 1.5
	nfl for outdoor UEs	1	1	1
	nfl for indoor UEs	nfl ~ uniform(1,Nfl) where Nfl ~ uniform(4,8)	nfl ~ uniform(1,Nfl) where Nfl ~ uniform(4,8)	nfl ~ uniform(1,Nfl)3)
Indoor UE fraction		80%	80%	80%
UE distribution (in x-y plane)	Outdoor UEs	uniform in cell	uniform in cell	uniform in cell excluding high-rise building
	Indoor UEs	uniform in cell	uniform in cell	50% of indoor UEs within 25 m radius of the high-rise building centre, rest are outside the 25 m radius
ISD		200 m	500 m (FFS: 200 m)	300 m

In comparison to previous models used in 3GPP, proposed 3D channel model allows for the simulation of users located up to 8th floor indoor, calculation of line-of-sight (LOS) probability depending on the vertical position of the user and introduces zenith angular spread at arrival and departure.

In Release 12, the 3GPP has also recognized the importance of **energy savings** in the infrastructure side. Investigations are summarized in [3GPP14-36887] and analysis of several solutions is highlighted using criteria formulated in Table D-5.

Table D-5: Evaluation criteria for 3GPP Rel 12 energy saving solutions [3GPP14-36887].

Criteria	**Description**
Complexity	Candidate solutions should not be too complex when implemented in practice. This criterion evaluates on how many messages exchanging or calculations or network/eNodeB states visible in the interfaces are needed for the solutions.
Potential energy savings gain	The potential gain of candidate solutions for saving the energy should be evaluated. Quantitative indication based rough calculation of energy saving gain should be added relative to the energy saving scenarios described in [3GPP14-36887].
Specification impact	The specification impact shall be described and evaluated.
Operations and maintenance (OAM) impact	The OAM impact shall be described and evaluated.
eNB impact	The eNB impact shall be described and evaluated.
UE impact	The UE impact and requirement for optional UE features shall be described and evaluated. The aspect of UE power consumption shall be taken into account.

D.2 IEEE 802.11ax

Institute of Electrical and Electronics Engineers (IEEE) is the association responsible for development of numerous communication standards. Among these, 802.11ax is the next generation of wireless local access network (WLAN) technologies and a successor of 802.11ac that addresses broadband throughputs of 1 Gbps and more using combination of OFDM and MU-MIMO. New standard amendment focuses on improving spectral efficiency in dense network deployments exploiting 2.4 and 5 GHz bands, and is often referred to as high efficiency WLAN (HEW). Dense deployments are problematic for 802.11 standards as back-off parameters of its collision avoidance mechanism can be far from optimal in certain network configurations. Full approval of the standard is expected early 2019 [IEEE-WEB]. 802.11ax standard solutions could be used indoors and outdoors to offload xMBB broadband traffic.

[IEEE15 0980] describes 5 test environments for the 802.11ax: Residential, Enterprise, Indoor Small Basic Service Set (BSS) Hotspot, Outdoor Large BSS Hotspot, Outdoor Large BSS Hotspot + Residential.

Evaluation methodology for 802.11ax captured in [IEEE15-0571] highlights two performance evaluation methodologies. First one focus on link level, point to point simulations that are used to capture packet error rate (PER) statistics. Second methodology aims at system level simulations defined for three options:

- PHY assessment with simplified MAC layer,
- MAC layer with simplified PHY, e.g., averaged white Gaussian noise (AWGN) channel
- PHY and MAC simulations showing close-to-reality details accuracy

D.3 IEEE 802.11ad

802.11ad (WiGig) and its successor 802.11ay (WiGig 2) are two versions of IEEE 802.11 standard that target operations in 60 GHz band. WigGig family aims at providing xMBB coverage in higher frequency regimes (7GHz of unlicensed spectrum at 60 GHz band). 802.11ad was approved in the end of 2012, while the project authorization request for 802.11ay was approved on March 2015 [IEEE-WEB] and should be available for commercial deployments in similar timeframe as 5G. It should be also noted that IEEE is also working on 802.11aj variant that switch 802.11d to 45 GHz band.

Although 802.11ad methodology covers only indoor test environments [IEEE10-0296], WiGig solutions can be also deployed outdoors.

Each test environment has a precisely defined position of user and access devices. Channel models for 802.11ad are captured in the separate document [IEEE10-0334] and take into account important properties of 60 GHz wireless propagation, such as polarization and non-stationary characteristics such as signal blocking caused by people motion. Models were developed using ray-tracing techniques and real life measurement data. [IEEE10-0334] cover also antenna models associated with these channels (isotropic antenna, basic steerable directional antenna and phased antenna array).

For evaluation of 802.11ad solutions, comparison criteria are based on:

- Average goodput (aggregate and per flow)
- Average per flow delay and number of packets that exceed delay requirements
- Per flow packet loss rate.

For fair evaluation, simulation results should also include description of PHY abstraction and antenna model as well as description of scheduling algorithms.

Aforementioned assumptions for system level evaluation are complemented with guidelines for link level evaluation (PHY performance). Criterion for comparison of different link level solutions is PER vs. SNR characteristic obtained using different modulation and coding scheme (MCS), channel impulse responses defined for above mentioned environments (and AWGN) and antenna combinations (omnidirectional TX and RX (LOS), omnidirectional TX and directional RX (NLOS) and directional TX and RX (NLOS)). Link level simulations must also include hardware impairments such as power amplifier non-linearity and phase noise.

[IEEE10-0334] propose also coexistence assumptions in 60 GHz band. Energy detection, preamble detection or the use of some universal mode to communicate between 802.11ad and other devices of 60 GHz system is assumed. If the interferer is detected WiGig should use beamforming, alternation of available channel or other means to coexist. Performance of such solutions can be measured using effective throughput metric.

D.4 IEEE 802.11p and CONVERGE

802.11p exploits operations on licensed ITS band of 5.9 GHz for vehicle-to-anything V2X ad-hoc communications at high velocities. The MAC layer is equivalent to 802.11e quality of service (QoS) extension, which allows sending messages using access classes with different priorities. 802.11p facilitates direct information exchange between devices without the need of completing association and authentication procedures. Therefore additional security mechanism are needed as defined in IEEE 1609 standards [IEEE06-16091], [IEEE06-16092], [IEEE07-16093], [IEEE06-16094] (jointly 802.11p and IEEE 1609.x are called Wireless Access in Vehicular Environment (WAVE)).

Although there are contributions to IEEE standard related to 802.11p test environment (e.g., dealing with motion related channel model [IEEE05-1176], [IEEE06-1742] there is no commonly agreed test environment framework for 802.11p.Hovever, the performance of 802.11p was studied extensively (e.g. in [FBL+012]), even in Manhattan grid scenarios [Eic07]. This standard was also investigated by Communication Network Vehicle Road Global Extension (CONVERGE) project. In [CON15-D43] system modelling and simulation assumptions are given for evaluation of LTE RAN and 802.11p for provision of vehicular safety applications. For system level simulations two network deployment models are foreseen: motorway and urban. Motorway environment consist of three lanes (per direction) with the length of 20 km and width of 3.5 m each. Road model is complemented with berms (1.5 and 2.5 m for internal and external, respectively) and median (2 m wide). Urban environment consist of regular rectangular grid of Manhattan model with 4 lanes street (per direction), 3.5 m each. Mobility model for urban scenario is same as defined for METIS Dense urban information society [MET13-D61] and for motorway three different speeds are defined for each lane (100, 120 and 180 km/h). Two different data traffic models are assumed. Road hazard warnings are conveyed using Distributed Environment Notification Messages (DENM) [ETSI-1026373] and Cooperative

Awareness Messages (CAM) [ETSI-1026372], 800 B and 270 B each, respectively (for evaluation of LTE solutions additional 8 and 20 B of IP and UDP header need to be added). When on the move, vehicles will transmit CAM messages periodically, every 0.1 s, while transmission of DENM messages is event-triggered.

In CONVERGE project evaluation framework is divided into link and system level simulations. The main outcome of the first group is performance metrics related to BLER vs. SINR. Mapping between link-to-system level is realized using mutual information effective SINR mapping (MIESM) [ETSI-1026372].

D.5 NGMN Alliance

The NGMN (Next Generation Mobile Networks) Alliance [NGM-WEB] is an open forum founded by world-leading mobile network operators. Its goal is to ensure that the standards for next generation network infrastructure, service platforms and devices will meet the requirements of operators and, ultimately, will satisfy end user demand and expectations

NGMN has launched a 5G-focused work programme that will build on and further evolve the NGMN 5G white paper [NGM15] guidelines with the intention to support the standardisation and subsequent availability of 5G for 2020 and beyond. The timeline of the work programme is depicted in Figure D-2.

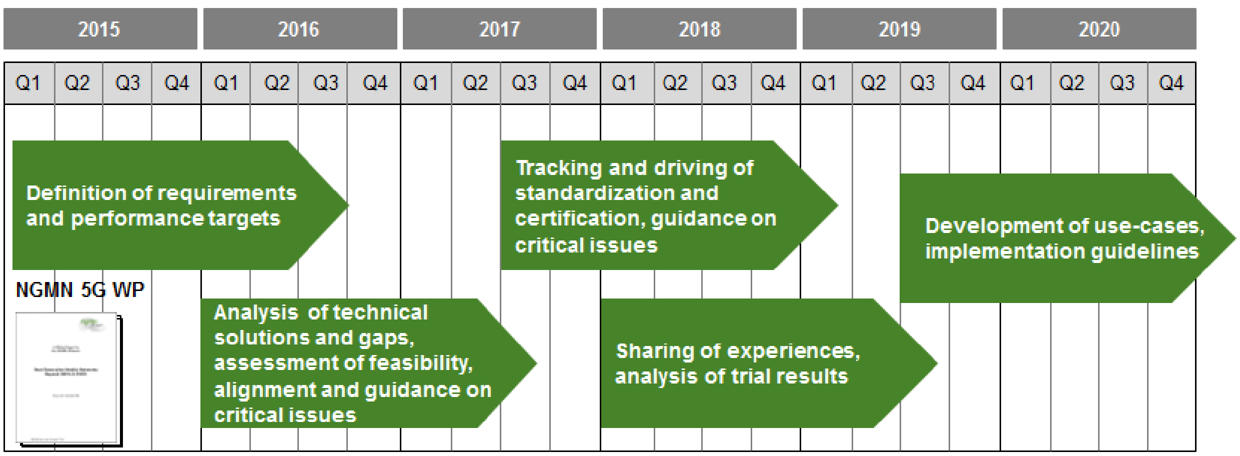


Figure D-2: NGMN 5G work program timeline [NGM-WEB].

Key tasks are the development of 5G requirements and design principles, the analysis of potential 5G solutions, and the assessment of future UCs and business models. The outcome of the work will be shared and discussed with all relevant industry organisations, standard development organizations and research groups, but at present there are no results publicly available which go beyond those described in the NGMN 5G white paper.

NGMN has not considered system level evaluation methods so far. However, in its 5G white paper user experience and system performance requirements are specified for a number of UC categories. These requirements are summarized in Table D-6 for some relevant categories. Comparable METIS test and use cases [MET13-D11], [MET15-D15] are listed in the right column of the table.

Table D-6: NGMN 5G requirements (subset).

	User Experience			**System Performance**		**Comparable METIS test/use case**
	Data rate DL/UL [Mbps]	**E2E latency [ms]**	**Mobility**	**Connection density [devices per km2]**	**Traffic density DL/UL [Gbps/km2]**	
Broadband access in dense areas	300/50	10	0-100 km/h	200-2500	750/125	TC2: Dense urban information society
Indoor ultra-high broadband access	1000/500	10	Pedestrian	75000	15000/ 2000	TC1: Virtual reality office
Broadband access in a crowd	25/50	10	Pedestrian	150000 (30000/ stadium)	3750/7500 (750/1500 stadium)	TC4: Stadium TC9: Open air festival
50+ Mbps everywhere	50/25	10	120 km/h	Sub-urban: 400 Rural: 100	Sub-urban: 20/10 Rural: 5/2.5	Not covered
Mobile broadband in vehicles (cars, trains)	50/25	10	500 km/h	2000 (500 per train x 4 train, 1 per car x 2000 cars)	100/50 (25/12.5 per train, 0.05/0.025 per car)	TC6: Traffic jam TC8: Real-time remote computing (cars)

Massive low-cost/ long-range/ low-power MTC	Low (0.001-0.1)	Second to hours	500 km/h	200000	Not critical	TC11: Massive deployment of sensors and actuators
Ultra-low latency	50/25	<1	Pedestrian	Not critical	Potentially high	D1.5 Tactile internet
Ultra-high reliability & ultra-low latency	0.05-10/few bps-10	1	500	Not critical	Potentially high	TC12: Traffic efficiency and safety
Ultra-high availability & reliability	10/10	10	500	Not critical	Potentially high	D1.5 eHealth, public safety, 3D connectivity

The NGMN 5G requirements might be used as reference for target values in METIS-II as well as for set-up and parameterization of 5G test environments. More details about the definition of KPIs like user experienced data rate and some background information for their application to use cases can be found in the NGMN 5G white paper.

D.6 METIS

One of the major goals of the METIS project was to enable and perform system-level simulations that feed the process of design of the future 5G system. This task started with the establishment of a framework and methodology for system-level simulations. Simulation and evaluation frameworks together with calibration procedures needed to compare system-level simulations performed by the different partners were first documented in METIS deliverable D6.1 [MET13-D61].

Deliverable D6.1 provided simulation guidelines to align assumptions, methodology and simulation reference cases in order to allow for a direct comparison of different technology components. This was 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 was set up.

METIS provided guidelines for the simulation of twelve realistic test cases (in METIS-II the terms use case and test environment is used), ranging from indoor, to Manhattan-like (the so-called Madrid-Grid TC2) and rural environments. The level of complexity of these guidelines was moderate, and made some of the scenarios to be further simplified in subsequent evaluations. Of special relevance are the simplified channel models for macro and microcellular transmitters. Moreover, METIS provided a Matlab implementation of those models (available at https://www.metis2020.com/documents/simulations/) and ray-tracing and mobility pattern files to simplify the adoption of these guidelines. Today, METIS models are widespread and the 5G research community is using them in their evaluation of future technology components.

In a second phase, METIS performed full-system simulations necessary to support the 5G system design. These system evaluations were split into two different parts, focusing first on the horizontal topic impact and afterwards on the full 5G system performance in the set of twelve test cases defined in METIS [MET13-D11].

Subsequent deliverable D6.3 [MET14-D63] summarized the evaluation, following the guidelines described in deliverable D6.1, of the impact of the different horizontal topics on the METIS goals. Results permitted drawing very interesting conclusions, as for instance that the efficiency in the air interface must improve by a factor of 4-5 as compared with LTE in single-input multiple-output mode, to keep the needs of bandwidth within the margin of 10 times the available spectrum. Moreover, device-to-device (D2D) communications are definitively a key pillar for the evolution towards 5G to reduce latency. In D6.3 METIS demonstrated that it is unfeasible to reach the objectives of latency without a significant change in the system architecture.

These intermediate simulation results, together with the self-evaluation performed by innovation WPs 2–5, provided the basis for the selection of technology components in METIS to achieve best system performance. After this selection, and using metrics defined by WP1, full system evaluations were carried out for all the different twelve test cases. Deliverable D6.5 [MET15-D65] aimed at showing whether the METIS 5G system concept was able to achieve the METIS technical objectives or not. In order to learn this, the METIS 5G system concept was evaluated putting together more than forty technology components. The main findings of this huge simulation effort allowed METIS to demonstrate which solutions were the real fundamentals of the 5G mobile and wireless communication system. METIS gave numbers and demonstrated the actual orders of scaling of some of the technology enablers that will make 5G possible.

Finally, METIS provided in Deliverable D6.6 [MET15-D66], its 5G system concept, which included an analysis of three 5G use case families and four main enablers. The three main 5G use case families are extreme MBB (xMBB), massive MTC (mMTC), and ultra-reliable MTC (uMTC). The four main enablers are lean system control plane, dynamic RAN, localized contents and traffic flows, and spectrum toolbox. Moreover, the combination of technology components that was able to fulfil the goals of the 5G was provided. In this fulfilment, use of massive MIMO (impact of 20 times the capacity), additional spectrum bands (impact of 3.4 times the capacity), ultra-densification (impact of 3.65 times the capacity) and D2D communications resulted fundamental.

D.7 Other 5G Initiatives and Projects

D.7.1 The 5G Innovation Centre

The 5G Innovation Centre (5GIC), part of University of Surrey's Institute for Communication Systems, is conceived as an independent test-bed for trialling emerging 5G concepts. In essence, it is the University's partnership with a number of key players in communications, including major vendors, operators and regulators (full list available here: [5GIC-WEB1]).

The key work areas are [5GIC-WEB2]:

- Content and User/Network Context
- New Air-interface
- Light MAC and radio resource management (RRM)
- Multi-cell Joint Processing
- Antennas and Propagation
- System Architecture and Coexistence
- Testbed and Proof of Concept

5GIC's starting point is user QoE, mindful of the type of communication (human to human, human to device, D2D), and focused on providing a perceived "infinite" capacity. Of special relevance to METIS-II is the work on the new air-interface as well as the 5G architecture "revolution", this latter being termed the Flat Distributed Cloud (FDC). FDC is a dynamic cloud-based architecture that separates the user plane and control plane and is much flatter [5GIC-WEB3]. The main design objective is a more context-aware network that predicts popular content, collates group content and gets user data ready 'just in time' by harvesting user profile information that is traded between user and service and/or networks. The architecture brings legacy Internet of Things with it and adds new 5G supervisory control and data acquisition (SCADA)-like control system capabilities to the cellular framework. The considerably more efficient resulting network is designed to employ the evolving Network Functions Virtualization (NFV)/Software Defined Networks (SDN) implementations.

The main objective in the air interface area is a design for dense small cells with the focus on higher spectral efficiency, reduced latency, relaxed synchronisation requirements, flexibility in spectrum aggregation and bandwidth and higher energy efficiency. 5GIC studies both non-orthogonal and enhanced orthogonal wave forms. Other physical layer areas of potential interest to METIS-II include massive MIMO, use of larger bandwidths and flexible implementation of spectrum aggregation. 5GIC looks also at different duplexing methods, and the capability for the already mentioned D2D communications.

In addition to collecting white papers and press releases of the mobile network operator and vendor communities, the Centre publishes its own white papers. These can be found at [5GIC-WEB3].

D.7.2 5GNOW

5GNOW has targeted 5G mobile communications systems and had impact to the 5G pre-standardization process. The consortium consisted of leading industrial and academic partners. The project started in September 2012 and has been finished in February 2015 [5GNOW-WEB].

5GNOW stands for 5th Generation Non-Orthogonal Waveforms for Asynchronous Signalling. The mission of 5GNOW has been to investigate the inherent trade-offs between possible relaxations in orthogonality and synchronization and their corresponding impact on performance and network operation/user experience versus the required signal processing capabilities.

5GNOW has been started with questioning some of the fundamental design choices of LTE such as enforcing strict synchronism and orthogonality. Having this in mind 5GNOW has focused on 3 scenarios: support of MTC traffic in coexistence with MBB traffic, coordinated multipoint (CoMP) in highly heterogeneous settings and efficient use of fragmented spectrum. Being a small and medium-scale focused research project 5GNOW had to concentrate on physical layer elements of the air interface such as waveform and frame design, transceiver options and access mechanisms.

The targeted system is based on the assumption that the UE is not exactly synchronized to the uplink channel framing structure [5GNOW13-D21]. Furthermore, the UE may have certain frequency offsets. This allows the development of cheap devices with extremely low battery consumption, which is essential for the IoT. Consequently, 5G system level modelling concentrates on this aspect, namely the L2S interface for devices with time and frequency offsets.

In 5GNOW, the modelling of the L2S is based on the well-known effective SINR mapping function.

$$\gamma_{eff} = \psi^{-1}\left(\frac{1}{L}\sum_{l=1}^{L}\psi(\gamma_l)\right)$$

The goal of this function is to derive one effective SINR value γ_{eff} out of a set of SINR samples $\gamma_l,\ l = 1 \dots L$. The set of values is obtained by, e.g. taking samples of SINR values for a transmitted transport block. The effective SINR value is then used for the calculation of a block error rate (BLER).

It is recommended to use the mutual information function for ψ, which does not require an extensive parameter tuning in order to match between link level BLER curves for different channels and the BLER curves obtained based on the effective SINR mapping.

The 5GNOW project proposed filtered waveforms (e.g. filter bank multicarrier (FBMC), generalized frequency division multiplexing (GFDM), universal filtered OFDM (UF-OFDM)) in order to reduce interference between transport blocks that use adjacent sub-bands. One of these candidate waveforms is non-orthogonal per design (GFDM). UF-OFDM and FBMC on the other side are orthogonal per design (the former in complex domain the later in real domain) but are affected by additional interference terms when facing delay spread channels. For UF-OFDM this additional interference is negligible for reasonable settings (e.g. for settings comparable to LTE with VehA channel the additional distortion is 40 dB below signal level). For FBMC the L2S interface considers the additional interference caused by frequency selective channels by introducing an additional distortion factor (see [WKB+13]). Consequently, a typical SINR sample is replaced by an SNIDR sample with

$$SNIDR = \frac{P_s}{P_i + P_n + P_d}$$

P_s, P_i and P_n are the well known signal, interference, and noise energy, respectively. P_d is the additional distortion generated by the filtered waveform. For FBMC the additional distortion can be calculated based on the channel frequency response and the filter used for reducing the out of band emission [WKB+13]:

$$P_d(l) = \frac{2P_s}{N_c^3} \left\| \frac{H'_l(\omega)}{H_l(\omega)} \right\| C_f$$

with H_l and H'_l being the channel frequency response of subcarrier l and its derivate, respectively. C_f is the filter applied to the subcarrier.

Furthermore, 5GNOW proposes to use models for the interference emitted into neighbour resources by timing and frequency offsets mainly caused by IoT devices. These offsets generate an additional interference power that depends on the amount of these offsets. As an example, Figure D-3 depicts this so called interference coupling factor comparison between cyclic prefix (CP) OFDM and UF-OFDM. The figure shows that for timing offsets smaller than the cyclic prefix duration CP-OFDM has zero emission into adjacent resources, while for higher offsets, UF-OFDM clearly outperforms CP-OFDM.

Furthermore, 5GNOW defines KPIs that shall be considered and evaluated by system simulations for the different system concepts [5GNOW14-D22]. Key performance parameters are signalling overhead, capacity, MTC RACH overhead, out-of-band radiation, and local oscillator relaxation.

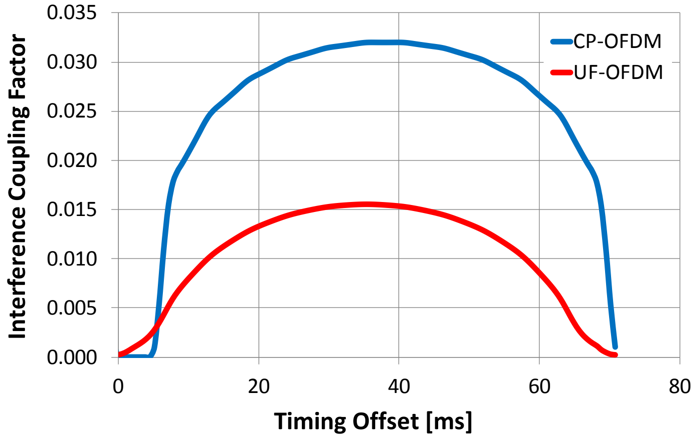


Figure D-3: Coupling of interference into neighbor resources depending on the timing offset between adjacent transmissions for CP-OFDM and UP-OFDM.

D.7.3 MiWaveS

The European project MiWaveS analyses and studies the key technologies for the implementation of mmW wireless access and backhaul in future 5G heterogeneous cellular mobile networks [MiW-WEB]. Its work program follows a holistic approach of these applications by covering system level studies, algorithm design, hardware design and manufacturing, as well as demonstration. The latter is one of the main objectives of the MiWaveS project with the integration of innovative mmW transmission concepts that are developed during the project time frame in a comprehensive demonstrator of backhaul and access links Figure D-4). The frequency bands of interest are the V-band (57-66 GHz) and the E-band (71-76 and 81-86 GHz).

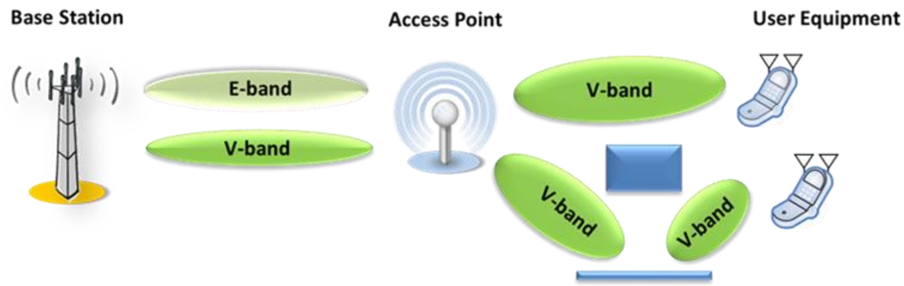


Figure D-4: MiWaveS demonstration goal.

MiWaveS final demonstrations are based on a digital platform developed by National Instruments including a proprietary PXI chassis along with a real-time host controller, a FPGA processing module on which the signal processing algorithms are implemented, and high-throughput DAC and ADC modules. The digital platform is interfaced with the radio transceivers and reconfigurable antennas [OK15], [FFK+15].

The following features are being developed in order to enable the experiments:

- Lower MAC / link control: uplink and downlink closed loop operation with real-time reconfigurable control and feedback channels; TDD access with flexible uplink / downlink loads supporting real-time resource control; real-time beam steering and radio frequency control interfacing to external components through high speed IO modules; running on a real-time controller connected to the PHY through a high-rate, low latency bus.
- PHY / baseband: multi-FPGA based real-time signal processing capable of multi Gbps throughput; single carrier based modulation scheme; pilot, control and payload channels; real-time configurable PHY parameters, e.g. modulation and coding scheme.
- Digital / analog converter: DAC sampling rate of 1.25 GHz, ADC sampling rate of 1.5 GHz.
- RF transceivers: E-band transceiver with tunable carrier frequency range of 71-76 GHz / 81-86 GHz and max 9 dBm transmit power; V-band transceiver with tunable carrier frequency range (57-66 GHz) and max 9 dBm transmit power.
- Antennas for backhaul links: E-band and V-band antennas with at least 30-dBi gain, beam-switching capability over a ±6° angular sector.
- Antennas for access links: V-band antennas with a gain greater than 5 dBi for the UE and 17 dBi for the AP, beam-steering capability over a ±45° angular sector in azimuth and elevation for the AP.

The demonstrations are intended to measure some of the key KPIs that are important to future mmWave wireless systems such as communication range, maximum throughput, power consumption, beamforming performance, latency, etc.

D.7.4 MiWEBA

MiWEBA addresses the predicted dramatically traffic load increase of more than 1000 x in 2020 on conventional cellular networks. To face this issue of system capacity shortage in cellular networks, MiWEBA started in 2013 and does pioneering work in evolving mmW into future 5G cellular networks by a novel U/C-plane splitting architecture of mmW overlay heterogeneous networks [MiWEBA-WEB]. As a measure to validate the effectiveness of MiWEBA's proposed system architecture, system level simulators were jointly enhanced by European and Japanese project partners. The preliminary versions of the simulators include all fundamental technologies of the proposed novel architecture, i.e. U/C-plane splitting which supports global optimization of resources and many mmW small cell BSs overlaid inside the coverage of conventional LTE macro cells. Especially, the developed system level simulators (SLS) have a useful interface with the link level simulators (LLS) extracting parameters from the SOTA mmW IEEE 802.11ad access link architecture to guarantee the authenticity of the derived system level results.

Moreover, a new mmW channel model based on the measurement campaigns was also adopted into the SLS.

Table D-7: mmW simulation parameters of MiWEBA.

Parameters		Assumption
Deployment		Isolated single cell, dense hexagonal
Traffic type		Full buffer
Bandwidth		2 GHz
Frequency reuse		3
Cell radius		20 m(JP), 50m (EU)
Number of UEs per cell		8(JP), 50(EU)
BS/UE antenna height		4 m / 1.5 m
Transmission scheme		Multi-user MIMO (MU-MIMO)
Channel model		LOS. Free space+O2 absorption (15 dB/km) pathloss
Link adaptation	Outer loop target frame error rate (FER)	10%
Scheduling	Type	Proportional-fair MU greedy scheduling
BS antenna element	Element gain	25.4 dBi (JP), 5 dBi (EU)
	Front2back	36.9dB (JP), 12 dB (EU)
	Horizontal/Vertical beamwidth	10°/10° (JP), 80°/80° (EU)
BS antenna array	Configuration/TX power	8x32 elements / 10dBm(JP), 22dBm(EU)
	Antenna array model	Full adaptive antenna array
UE antenna		Single element, omni-directional

Table D-8: mmW simulation results of MiWEBA.

Scenario	Small cell BS throughput, [Gbps]	Avg. UE throughput, [Mbps]	Cell edge UE throughput, [Mbps]
EU isolated cell	27.0	540	315
JP isolated cell	13.6	1695	927
EU dense deployment	14.9	297	142
JP dense deployment	7.0	876	379

The first numerical results on both full buffer scenario in Europe and Japan; and non-full buffer scenario based on realistic traffic model in Japan show that the proposed novel architecture can definitely support the dramatically increasing data traffic demand in the next 10 years as an effect of introducing sufficient numbers of mmW small cell BSs [MiWEBA14-D41].

One main objective of MiWEBA is to evaluate the performance of future mobile networks based on mmW technologies. In addition to protocol, algorithmic and architectural selections, MiWEBA includes the improvement of LLS and SLS in order to estimate the performance of proposed solutions. The improvement of these simulators requires implementing technological functionalities with sufficient detail in order to provide reliable and accurate results. To avoid getting simulators too complex some analytical models based on a higher level of abstraction were evaluated to allow having synthetic values for the most important performance figures. Examples are directional cell discovery, perceived UE throughput and network energy efficiency or in more detail cell discovery time model (antenna pattern and UE distribution, distribution of number of beam switches before contact according to different search algorithms), resource sharing model (user intensity, SINR distribution and SINR rate mapping, BS activity factor, average UE perceived throughput) and BS activation probability (mmW BS coverage, UE and mmW deployment density, BS activation probability) [MiWEBA15-D42].

In addition different interference mitigation and CoMP schemes have been investigated for deployment scenarios in an isolated cell and a dense deployment for Europe as well as Japan to evaluate the lower and upper bounds of mmW small cell overlay network performance. It shows that investigated interference mitigation schemes might give substantial gain for both average and cell edge user throughputs. The relative throughput increase in mmW systems is much more than in low frequency bands due to exploiting high gain and highly directional multi-element antenna arrays [MiWEBA15-D43].

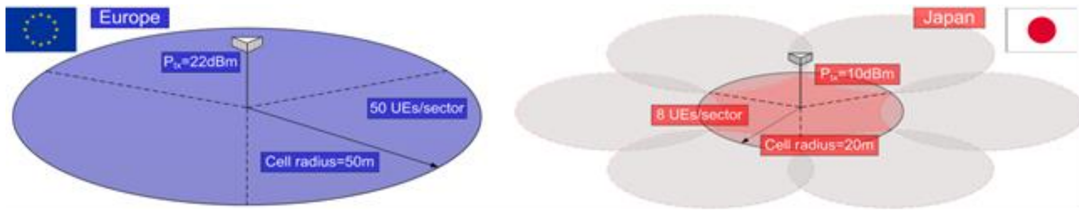


Figure D-5: MiWEBA deployment scenarios for Europe and Japan.

Final overall system performance evaluation results will become available by October 2015.

To reveal the potential of millimetre wave overlay heterogeneous networks, the following evaluation factors have been applied in MiWEBA

Average UE throughput defined as the total amount of received data divided by the evaluation period.

$$\text{User throughput [bps]} = \frac{\min(\text{Instantaneous received data [bit], User traffic demand [bit]})}{\text{Evaluation period [s]}}$$

Cell edge UE throughput defined as the 5 percentile value of the UE throughput cumulative distribution function (CDF). Cell edge UE throughput indicates the minimal user experience of the network.

System rate specified as a sum of the user throughput within one macro cell area showing the total network capacity.

System rate gain is defined as the ratio of system rate between the proposed mmW overlay heterogeneous network and conventional homogeneous network without small cells.

D.7.5 GreenTouch

GreenTouch [GT-WEB] is a consortium of leading Information and Communications Technology (ICT) industry, academic and non-governmental research experts dedicated to fundamentally transforming communications and data networks for a significantly reduced energy consumption and carbon footprint. Two factors motivated the formation of GreenTouch: Data traffic in ICT networks increases with a near-exponential growth, especially for wireless data traffic, while equipment efficiency improvements are slowing as limits to historical capacity and scaling laws loom.

GreenTouch completed its mission in June 2015 and presented [GT-WEB] a wide portfolio of technologies to sustain the evolution in the mobile access, the fixed access and the core network. These technologies include the “Green Meter study” and the “Base Station Power Model”, as discussed next.

To quantify the energy saving potentials, GreenTouch has developed a specific methodology (Green Meter) to understand the energy performance of all these technologies. The 5-year research effort demonstrates that it is possible to improve the network energy efficiency in mobile networks by a factor 10000, in fixed access networks by a factor 254 and in core networks by a factor 316 compared to the 2010 reference scenarios defined by GreenTouch. The findings will be instrumental for achieving a definition of 5G technologies with a focus on energy efficiency [GT15-WPa].

Many approaches to energy efficiency can be found in recent literature, but most of them are lacking a quantitative analysis of energy performance on a large scale system level. The reason is that there is no widely agreed power model of BSs and in simulations often full buffer traffic models are used that do not allow application to real world networks with a given traffic demand. A first attempt was taken by EARTH E^3F [AGD+11].

The Green Meter study of the GreenTouch consortium has worked out a complete framework that enables a quantitative evaluation of concepts like heterogeneous networks (HetNets), CoMP and interference alignment, or massive MIMO. The framework [GT13-WP], [GT15-WPb] defines 20 typical scenarios (4 user densities and 5 traffic levels) for system level performance simulations, following well accepted 3GPP modelling. The main additional components of the framework are summarised in Table D-9.

Table D-10 lists the most important modelling parameters.

Table D-9: Simulation model components.

Power model	A widely scalable BS power model, building on detailed hardware architectures, semiconductor roadmaps and research trends.
Traffic model	Traffic demand of 0.2-16 GB/month/subscriber (over a diurnal cycle, scaling from 2010 to 2020), distribution of users with 30-2000 user/km² in rural to dense urban areas [GT13-WP], [GT15-WPb], [ETSI-203229], [BAW14]. Hot areas cover 75% of urban traffic, concentrated in 24.4% of DU areas [KSB+14]. 2 MB file size or a session volume distribution between 10 kB and 2 MB [GT15-WPb].
QoS	Cell edge user throughput performance of 4 Mbps (5%ile of users).
Deployment	Hexagonal three-sectorised macro cells, small cells in dedicated hot spots and hot zones. Macro-ISD is limited by UL and DL link budget to 1300-4300 m [LTZ+14].
2010 Reference network	A full coverage LTE network with hardware available on the market in 2010 and typical deployment densities (500-4300 m ISD for DU to Ru areas). Its global power consumption is in line with the 2010 GSMA power consumption report [GSMA12]

Table D-10: Simulation assumption for mobile network scenarios

BS antennas	3 sectorised 3D antennas ([3GPP10-36814]), mounted in 32 m height, downtilted 2-15° according to ISD. Small cells with omni-antennas in 5 m height.
Playground	Interference from 20 macro cells (one tier of macro cells), using wrap around
Shadowing	Log-normal with 6-10 dB standard deviation (varying between Ru to DU)
Indoor	All users indoor, wall penetration 15-20 dB (varying between Ru to DU).
Path Loss	3GPP 36.942 PL = A + B*log10 (R[km]). R is the distance between BS and UE. A=117-140 dB. B=37.6-39.6 dB (varying between 800 MHz-2 GHz and DU to Ru)
Backhaul	Optical fiber or microwave. For 2020 cascaded BiPON network with 0.3W/BS site [GT15-WPb].

The framework has been applied in the Green Meter study [GT-WPa], [GT-WPb], [GT13-WP], [BAW13], [LTZ+14] to quantitatively evaluate energy efficiency gains and energy saving potentials for LTE and 5G networks in 2010 to 2020. Massive MIMO, antenna sleeping, interference control, small cells and a separate signalling network are found to be the preferable technologies to be used in 5G standardization.

The energy consumption of mobile networks is dominated by the BSs, and the amount of BSs will continue to increase when implementing 5G and IoT. A models quantifying the BS power consumption over a diversity of scenarios are essential to develop energy enhancement techniques for future communication networks.

In GreenTouch, an advanced power model has been developed which predicts the BS power consumption over a broad range of operating conditions and cellular BS types. The model covers conventional BS types such as macro- and pico-cells, but also supports disruptive types such as massive MIMO architectures (aka LSAS [GT-WPb]) [DDL14]. This diversity of supported BS types is essential because mobile networks are increasingly heterogeneous, and the energy behaviour fundamentally differs over different BS types.

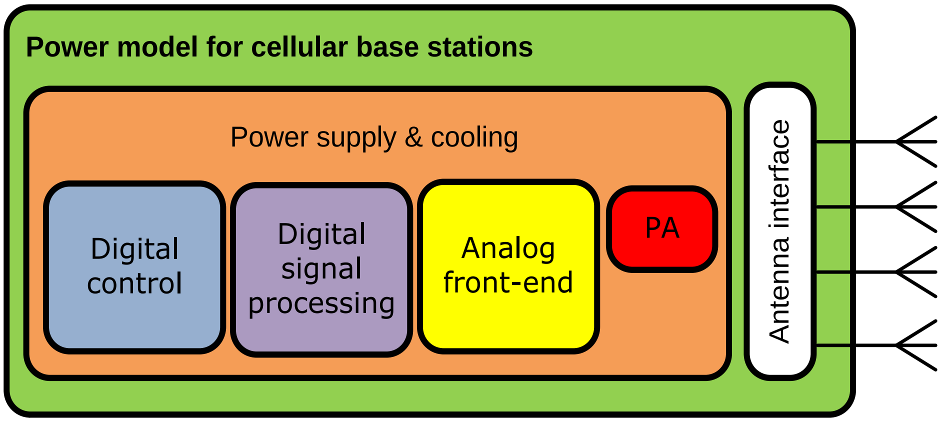


Figure D-6: The BS model builds on its (sub-)components [DDL13].

For each BS type, the model considers five main components [DDL13]: the power amplifier, the analogue front-end, the digital baseband, the digital control and network connection, and the power supply system, as shown in the Figure D-6. The power behaviour and dependency of each of these components have been implemented in the model via reference values and scaling equations [DDL15]. Backhauling is not included.

The GreenTouch model also predicts the power consumption values, features and functionalities of the BSs at any technology generation between 2010 and 2020 [DDL15]. This enables network providers and operators to define the deployment strategy for today's and future networks, and provides clear design guidelines for component and BS manufacturers.

To support the investigation of BS sleeping, the model also provides realistic transition times to (de-)activate the BS components, and identifies multiple BS deactivation levels and corresponding transition times and power consumptions [DDL15].

Table D-11 lists a number of example configurations, varying the type of BS (macro, pico), the year of deployment (2010 vs. 2020), the number of antennas and sectors and the radiated power. The table gives power levels for full load, no load (neither data nor signalling) and 4 sleep modes. The sleep modes are characterized by their total transition time (deactivation plus reactivation) of 1 OFDM symbol (74 µsec, for LTE compliant micro-DTX), 1 subframe (1msec, for subframe blanking), 1 radio frame (10msec, for long DTX) or 1 sec (into standby mode).

To make the power model generally available, an online web-tool has been created [DDG-WEB]. This web-tool can be used for free after registration and offers all features and functionality of the power model. Via this tool, the GreenTouch BS power model is becoming a global reference offering a uniform and fair comparison for energy optimization in the mobile network. Figure D-7 shows a screenshot of the web-tool available on www.imec.be/powermodel.

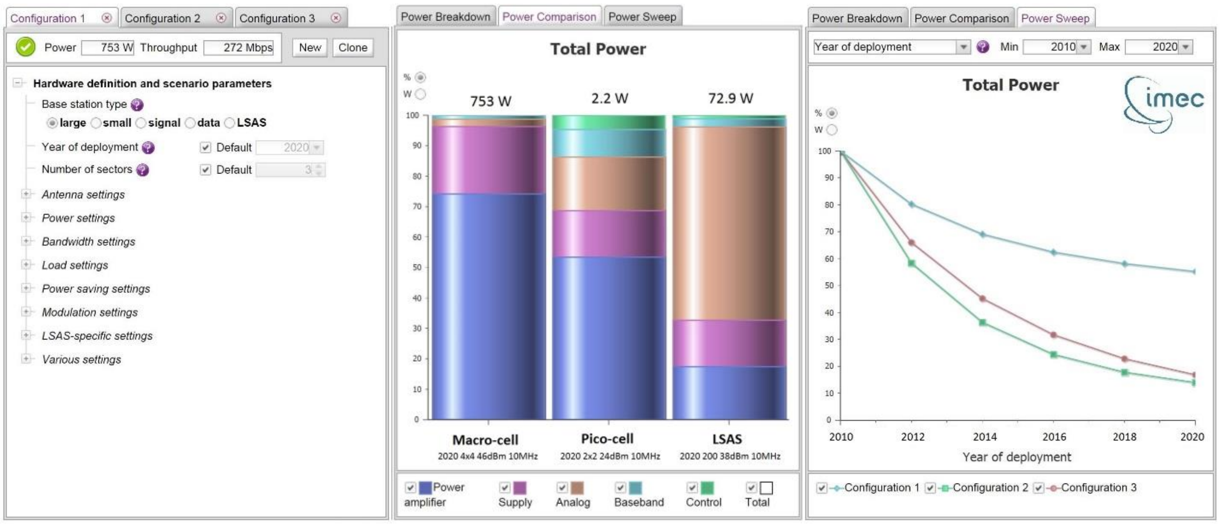


Figure D-7: Screenshot of the online power model tool.

Table D-11: Example power consumption values for different BS types and load situations.

BS configuration and radiated power [dBm]	Standby 1 sec	10 msec sleep	1 msec sleep	Micro sleep	'NoLoad' <1% of subcarriers	'FullLoad' 100% of subcarriers
2010 2x2 10 MHz (with 2008 components and 3 dB feeder loss) 3x46 dBm radiated	N.A.	N.A.	N.A.	N.A.	545.4 W	1197 W
2020 2x2 20 MHz 3x49 dBm radiated Single User MIMO	5.3 W	6.0 W	8.6 W	76.5 W	114.5 W	702.6 W
2020 4x2 20 MHz 3x49 dBm radiated Single User MIMO	6.2 W	7.8 W	12.8 W	86.8 W	139.3 W	733.3 W
2020 8x2 20MHz 3x49 dBm radiated Single User MIMO	8.2 W	11.2 W	21.4 W	107.4W	188.6 W	793.0 W
2020 Pico 20 MHz 1x1 W radiated	0.2 W	0.3 W	0.4 W	1.5 W	2.3 W	6.9 W

E Interface to visualization tool

The use of the visualization tools will be mainly used for a simplified simulation of the technology components developed in METIS-II and other research projects allowing for the real time interaction with the person operating the tool. If detailed simulation accuracy is needed, the second alternative of use will be via precomputed traces obtained with sophisticated simulation tools. The visualization tool will be then fed with these traces, allowing for a low-interactive demonstration of the outputs of these simulations.

While developing the serious game-based simulation tool in Unity3D, performance evaluation results, if **generated according to the guidelines defined in D2.1**, will be visualized using Unity 3D platform [MET15-R71]. A group of so-called editors will be able to modify existing visualization of defined use cases in order to reflect the impact of selected solutions on a given metrics (both coming from user and infrastructure). Results coming realistic environments can be represented.

In the visualization, different kind of logical layers of information could be added according to the selection of the operator. While the simulation trace is represented and users/cars are moving around, the viewer can switch to a system mode of operation in which the information layer represents global aspects, like congestion, coverage, average satisfaction and so on. By using a context menu, one or several KPI can be depicted on top of the simple layer of physical elements in the scenario. Most of the performance metrics described in Section 2.4 corresponds to this view mode, and it is therefore expected to represent results like CDF or average values. Upon request of the viewer, the visualization can change to the details of a certain transmitter, either a BS a MS or a moving node. In this case, the visualization layer can switch to a first-person mode, illustrating the real time performance stored in the traces, including for instance active links, instantaneous throughput, latency, and so on. It is too early to state all the parameters to be represented in the different views, but there is a general consensus in the fact that this mode of operation with the visualization tool still presents a good degree of interaction with the game operator.

Next section will describe the current status of the visualization tool, whereas Section E.2 summarizes the views currently considered for the evolution of this visualization.

E.1 Current status of the visualization tool

Currently, the visualization tool is able to show the Madrid-Grid scenario with a set of pedestrians, cars and buses moving around. Over this real view, other logical information can be depicted, including coverage areas represented by a hemispherical transparent helmet and links represented by lines with different colours and styles. The characteristics of the links are currently being computed by simple distance to the set of active transmitters. On top of this views, current visualization tool shows an information layer comprising valid information about the project structure and research approach. This slide-like representation is quite useful for the support of the discourse, and is currently controlled by a configurable menu.

E.2 Different views to be implemented

E.2.1 Global view

The first view is the global one, in which the camera is far enough to have a quick look to the whole scenario. A set of visualization parameters will be displayed and selected, being in principle possible to select some of them simultaneously. Figure E-1 shows an example of this view. Among the possible layers, we include the following:

- Coverage by transmitter: shows in different colours a layer indicating the area where each transmitter is the best server. In a second layer of control, the viewer can activate or deactivate some of the transmitters to simplify the view.
- Service area analysis: on clicking over this layer, further information should be provided. The viewer selects then the set of services that what to visualize and then a new 2D layer with identification of service area is depicted, showing the positions in which a certain service could be potentially provided. An example of some services could be
    - Data rate over 100 Mbps
    - VoIP
    - V2V communications 1600B E2E latency < 100ms
- Throughput distribution: this 2D layer represents a map with different colours a group of throughput values.
- User throughput distribution: in this case, users/machines/vehicles modify their colour according to the previous legend. This is not a 2D map as before, Figure E-1 but rather a colour activation of users.
- Quality distribution: this is a 2D map representing different levels of reliability, in terms of packet error rate, maximum latency, or a combination of both.
- Connectivity: in this view, users are linked with a line with all the transmitters from or towards which they have data exchange. Different colours are used to distinguish the links. Of course the same user can be connected with different sources/sinks. This view allows also distinguishing D2D links, moving network, and cellular links, using different kind of lines. Figure E-2 shows a simplified illustration of this idea.

Under this view, it could be also possible to depict general CDF and average values, as those defined in Section 2.4.

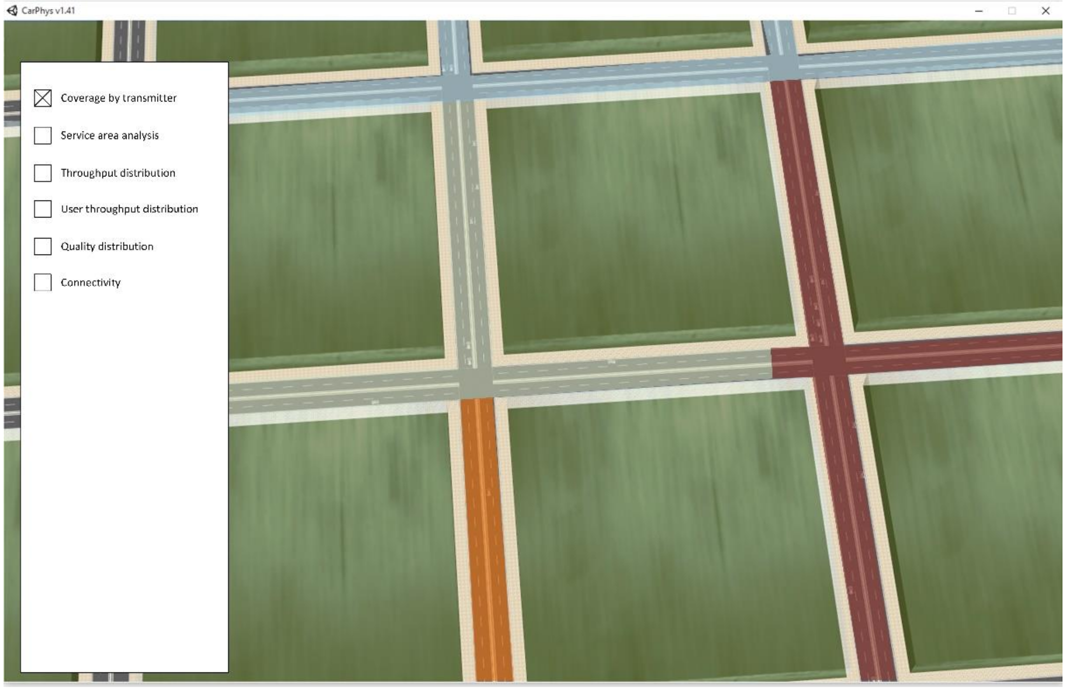


Figure E-1: Example of the global view.

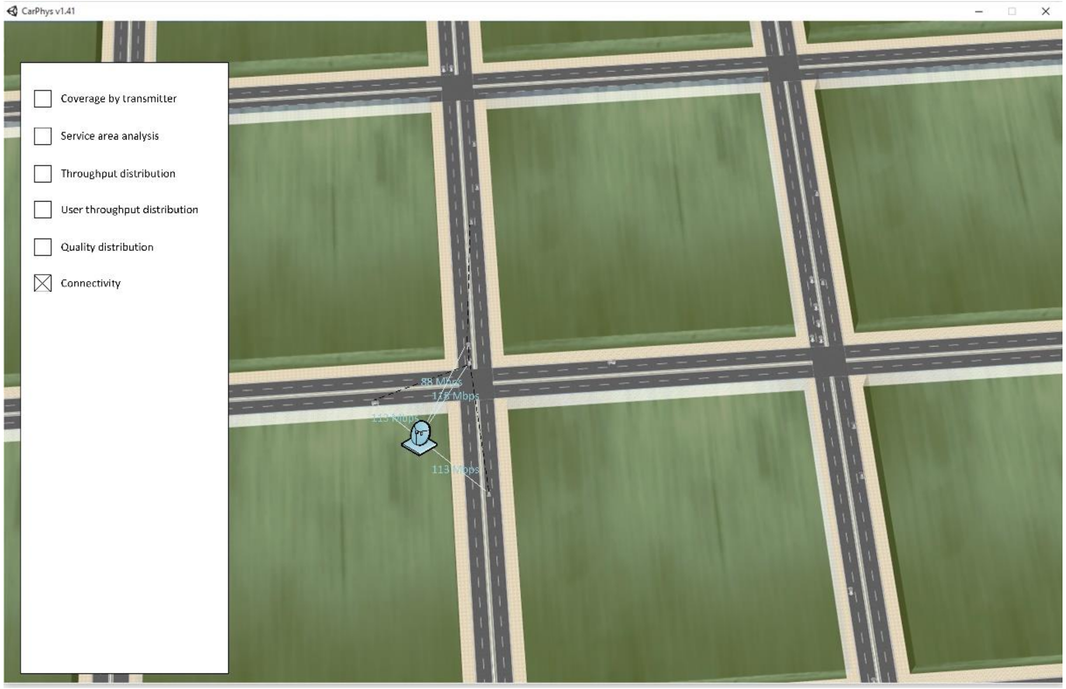


Figure E-2: Connectivity in the global view.

E.2.2 MS focus view

On clicking over a specific UE/vehicle/machine the view changes by zooming to the specific user. This view is well-suited to represent the active links of the user (see Figure E-3), plus other parameters of interest per link, like the frequency band, throughput, signal level, noise plus interference level, SINR, latency, and reliability, among others. Note that the representation of these metrics could be just a simple instantaneous value, or also another graphical representation including the instantaneous value and some statistics, like the average, maximum value, minimum and standard deviation.

Figure E-3: Example of MS focus view.

E.2.3 MS first person view

On a different clicking mode (for instance double-clicking), the view switch to a first person view. This view also allow for a dynamic representation of the experience of the user for a certain service. Therefore, apart from the previous parameter, additional representations of end user experience could be represented on top. As an example, Figure E-4 shows a capture of the first view in a car, in which a film is being played. Transmission errors or latency could affect the end-user experience of the film visualization, which will be seen as the end user in the live more.

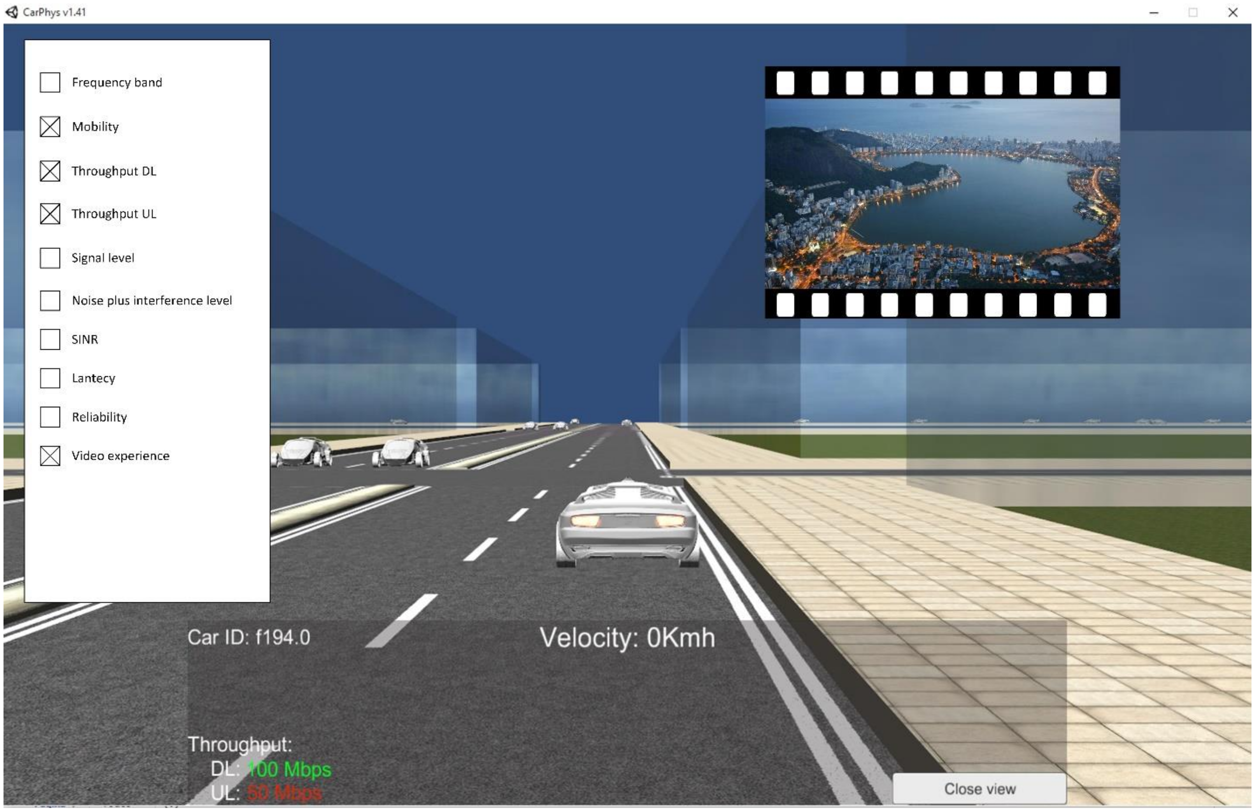


Figure E-4:Example of view in first-person mode.

E.2.4 Cell view

On clicking over a specific cell, the view changes by zooming to its coverage area. Under this view, the transmitter and all user/machines/vehicles connected to it are identified with the same colour. We can see cell-specific statistics and instantaneous values like the load of the cell, SINR experienced by users in the cell, throughput in DL and UL, latency, reliability and coverage. Again, instantaneous values could be accompanied with bars representing the statistics of the whole set of values. We could also play with colours to highlight the outage status, as show in Figure E-5, where red font colour is used to depict a throughput below the outage threshold.

Figure E-5: Example of cell view.

E.3 Realistic to visualization scenario interface

Simulation results obtained from realistic deployment scenario can be easily plugged to METIS-II visualization tool. The specific format should be agreed upon the partners, and currently includes the following items:

- Mobility traces
- Loss maps and Loss maps parameters
- Packet generation/reception files
- Per mobile entity KPIs file
- Per station KPIs file
- Global KPIs file

The file format for the first two items is quite mature. However, for the remaining items there is only a preliminary consensus. Therefore, the description in the following sections for those items should be considered a preliminary approach subject to changes in the future.

E.3.1 Mobility traces

In the visualization platform, we assume the existence of three different kinds of mobile entities: cars, buses, and pedestrians.

There will be one mobility trace file for each kind of mobile entity. The mobility traces describe the evolution of the position, speed and orientation of each mobile entity in the simulation. In the mobility traces, one row contains the data for one entity.

The data within one row consists of tuples of four values containing: time stamp in seconds, X coordinate in m, Y coordinate in m, orientation in degrees. Each field is delimited by a blank space.

The orientation angle is in the range [-180,180]. The convention for the orientation is: 180º means north direction, 90º means east direction, 0º means south direction, and -90º means west direction.

We assume that a fixed time step is used to obtain the position samples. Therefore, in general, the time stamps for the same entity will have a fixed time step. Additionally, we assume that at each sampling time the position of all the entities is recorded. Therefore, all the rows will have the same number of elements, and the time stamp values in the same column will be equal to each other.

E.3.2 Loss maps

A loss map represents the losses in dB from the position of the fixed station to a set of points distributed over an x-y plane in a specific z coordinate.

In the visualization platform, we assume the existence of a loss map for each fixed station in a set of relevant z coordinates.

The relevant z coordinates are assumed to be a sequence of values having a fixed spacing, with the first z coordinate having an offset with regard to the ground level (coordinate 0). This offset is used to represent the actual position of wireless communication devices.

The set of points whose loss values are represented in a loss map are assumed to be the central points of the rectangles obtained as a result of the division of the scenario under study in a grid with a specific x-spacing and y-spacing.

See in the next figures two exemplary illustrations of the Madrid Grid scenario divided in rectangles through the definition of a grid whose x-spacing is “sample_size_x”, and whose y-spacing is “sample_size_y”. The circles in the second figure represent the centre point of each rectangle where losses are calculated. The scenario is assumed to be divided into I rows and J columns.

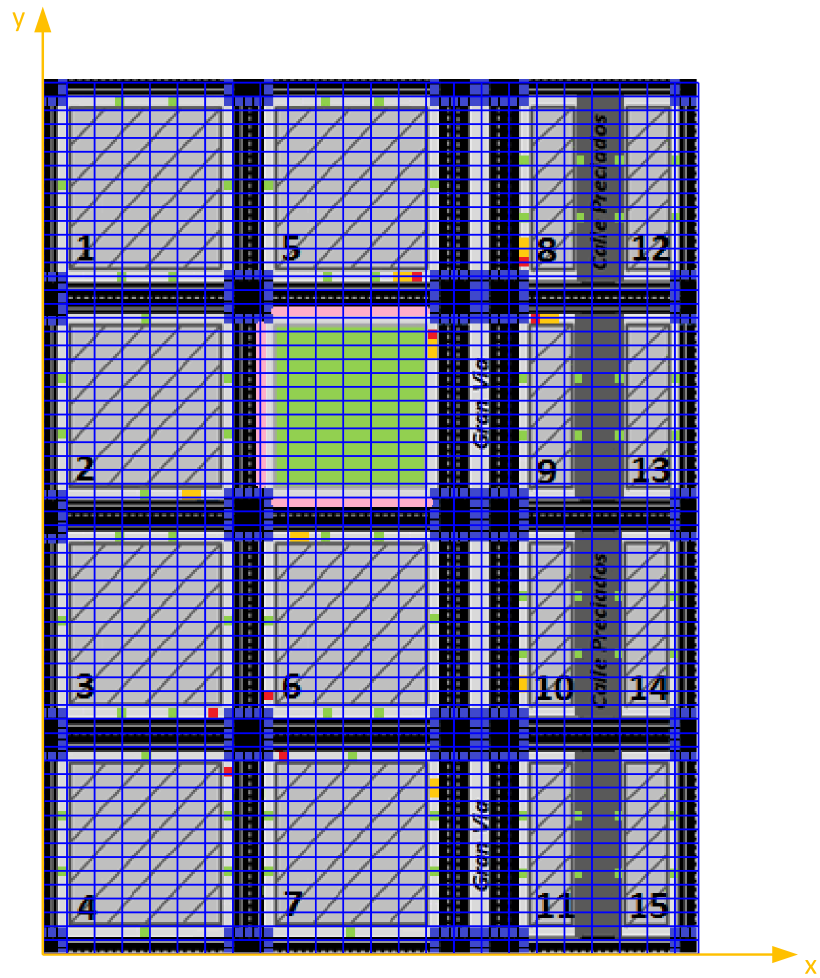


Figure E-6: Set of samples in the Madrid Grid scenario for the path losses.

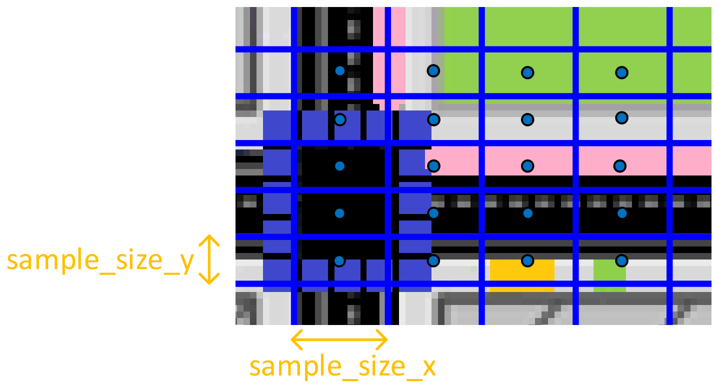


Figure E-7: Detail of the raster position for the path losses.

The loss map file is a txt file with as many rows as loss samples in y-axis, and as many columns as loss samples in x-axis. An increasing row index means an increasing y position, while an increasing column index means an increasing x position. Specifically, given a row index i, with $i \in [0, I-1]$, and a column index j, with $j \in [0, J-1]$, the corresponding Cartesian coordinates are:

$$x = \frac{sample\_size\_x}{2} + (j-1) * sample\_size\_x$$

$$y = \frac{sample\_size\_y}{2} + (i-1) * sample\_size\_y$$

A set of common parameters used to obtain the loss maps are gathered in a "loss_maps_info.xml" file. This is an xml file meant to describe how the loss maps where obtained, and to simplify or enable its interpretation. See its format and an example in the next table.

```
<info>
    <nb_x_samples> I </nb_x_samples>
    <nb_y_samples> J </nb_y_samples>
    <sample_size_x> x </sample_size_x>
    <sample_size_y> y </sample_size_y>
    <nb_z_samples> nb_floors </nb_z_samples>
    <z_offset> offset </z_offset>
</info>
```

The file naming for the loss maps is the next: "lossmap_station[i-th]_floor[j-th].txt".

E.3.3 Packet generation/reception files

In order to store information about the generation and reception of individual application layer packets, two file formats are defined in this section.

The packet generation file is a txt file with 3 columns and multiple rows. Each row represents a generated packet. The first column indicates the generation time of the packet with a time_stamp in seconds (precision of microseconds). The second column is a packet identifier that cannot be equal for two different packets. The third column is the identifier (id) of the entity that has generated the packet.

The id of the transmitting/receiving entities should be in the range $[0, nbStations - 1]$, where the $nbStations$ is the number of cars plus the number of buses and the number of pedestrians.

The mobile entities are assumed to be numbered from 0 to $nbStations - 1$, starting with the cars, next the buses and finally the pedestrians. It is also assumed that the row with the mobility trace of each entity is ordered in the mobility trace file in ascending order of identifier.

The packet reception file is a txt file with 3 columns and multiple rows. Each row represents the correct reception of a packet by a simulated receiver. The first column indicates the reception time of the packet with a time_stamp in seconds (precision of microseconds). The second column is the packet identifier. The third column is the id of the entity that has received the packet.

The different entries (rows), of both the packet generation and reception files, are assumed to be sorted by ascending order of generation time.

E.3.4 Per mobile entity KPIs files

We envision is a file per KPI with as many columns as mobile entities (cars, buses, and pedestrians) plus an additional column with a time_stamp.

One example is a PRR file for Connected cars UC.

E.3.5 Per station KPIs files

We envision a file per KPI with as many columns as stations plus an additional column with a time_stamp.

One example is a throughput file.

E.3.6 Global KPIs files

We envision a file with as many columns as global KPIs plus an additional column with a time_stamp.

An additional file would indicate the name of the KPIs in the same order they appear in the global KPIs file.

F 5G-PPP

F.1 FANTASTIC-5G

Flexible Air iNTerfAce for Scalable service delivery within wireless Communication network of the 5th Generation (FANTASTIC-5G) is an ongoing project within the framework of Horizon2020 designing the air interface for 5G (below 6 GHz) and gathering a multitude of key players of wireless communications both from industry and academia. Following recent market trends/forecasts the project has two main ambitions for designing the air interface:

Enable efficient multi-service support (coexistence) [SSS14] and [SSS+15]
Improve user rates (both cell edge and per-user) where and when needed

To rate the designs from FANTASTIC-5G link- and system-level simulations will be carried out. Additionally, selected technology components will be integrated and demonstrated.

The selected scenarios and use cases (ongoing work at the date of this report) are dictating the environment models and KPI targets.

The FANTASTIC-5G project identified two reference tools through which performing system level simulations, evaluating the limits that the current broadband technologies (i.e., LTE and LTE-A) meet when dealing with future cellular scenarios/services, and showing the performance gain offered by novel solutions developed in the 5G context. The first one is provided by the WINGS company. The second one, namely LTE-Sim (https://github.com/lte-sim/lte-sim-dev), is developed by the Polytechnic of Bari (POLIBA). These system-level simulators have the ability to model and simulate 5 core services related to Mobile Broadband (MBB), Massive Machine Communications (MMC), Mission Critical Communications (MCC), Broadcast/Multicast Services (BMS) and V2X.

High-level architecture takes into account:

- Environment models
- System features
- Analysis

Regarding environment models the impact of traffic, mobility and radio conditions are taken into account in the system-level simulators. Specifically, it is possible to generate in the simulators 1000x more traffic (compared to previous years), usage of massive number of devices, ultra-dense infrastructures, D2D communications, high mobility etc. Certain components will be developed that control the configuration of network topology, traffic distribution to cells, distribution of cells and users in space, traffic distribution in space and time, etc. Compliance with benchmarks and 3GPP standards (release 12 plus selected relevant features from release 13 is the reference) will be sought in order to ensure valid simulations.

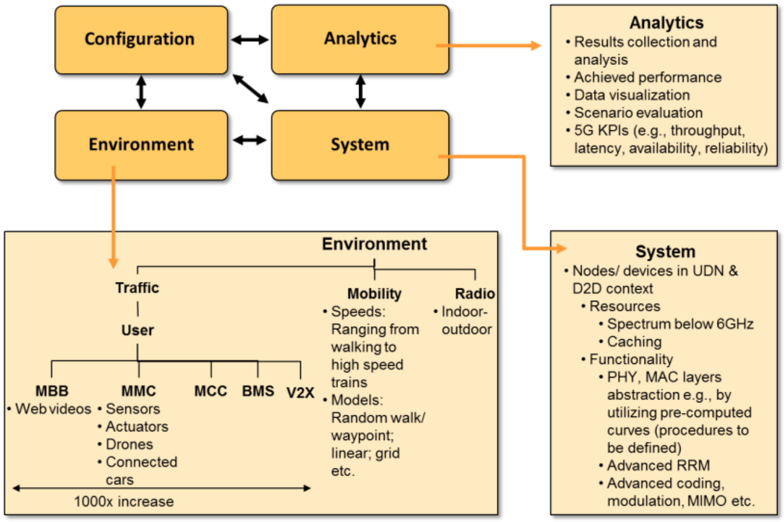


Figure F-1: FANTASTIC-5G high-level performance evaluation framework.

Regarding system features the usage of spectrum in frequency bands below 6 GHz is taken into account (due to the fact that FANTASTIC-5G does not cover mm-wave research), dense network deployments, impact of modulation, coding, MIMO etc. Moreover, suitable abstractions of PHY and MAC layers in order to define system behaviour models and limit complexity aspects of simulations will be taken into consideration. For instance, the project will model the PHY layer aspects on the simulator tools by utilizing pre-computed mapping curves e.g., of spectral efficiency versus signal quality indicators, block error rate versus signal to noise and interference ratio, physical data rate versus signal to noise and interference ratio, and so on. These lookup tables will be filled with values obtained from link level simulation results. Moreover, the simulation tools will provide the means for analysing and providing results related to the targeted KPIs including throughput, latency, packet losses, bit error rate, low energy consumption etc.

Preliminary versions of the simulation tools developed by both WINGS and POLIBA are under development. With reference to the tool provided by WINGS, the following screenshots visualize indicatively, the user's density and the QoS (e.g., achieved throughput) by using different colour codes depending on how high or low the throughput is.

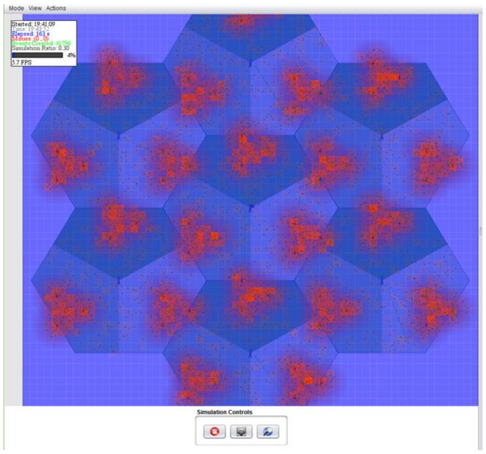


Figure F-2: Visualization of user's density

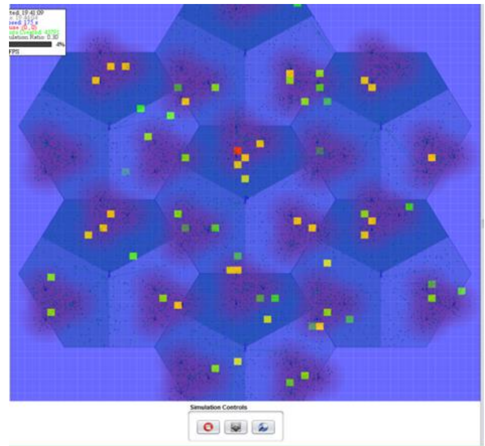


Figure F-3: Visualization of QoS (achieved throughput)

The preliminary version of the simulator developed by POLIBA is already available on-line (as an open source project): https://github.com/lte-sim/lte-sim-dev. The tool already implement the most important features of both LTE and LTE-A technologies and is widely used in the worldwide research activity (as demonstrated by the number of citations achieved by the reference scientific paper [PGB+11]. Of course, it is going to be extended for modelling 5G core services and other technological advancements that will be introduced into the FANTASTIC-5G project.

Well established standards and references (e.g., 5G white papers) [NGM15], [3GPP13-23887], [3GPP15-23179], [3GPP15-23246] are taken into account for the definition of necessary requirements, models and technologies which should be utilized for the successful realization and evaluation of a highly flexible, versatile and scalable air interface for the forecasted multitude of service classes and device types with reasonable complexity and highest efficiency for frequency bands below 6 GHz.

F.2 Flex5Gware

Flex5Gware will perform research, development and prototyping on key building blocks of 5G network elements and devices both in the hardware (HW) and software (SW) domains. These research, development and prototyping activities entail many system design challenges that will be solved through disruptive approaches and resulting technologies. Precisely, in Flex5Gware, design and development of analogue components to enable massive in mmW spectrum bands will be carried out. In the mixed signal and conversion stages domain, important research and results will be obtained related to crucial 5G components like full duplex communications (simultaneous transmission and reception), high-speed broadband converters, etc. In the digital domain, drastic progress in the area of building HW components will be achieved for important features like FBMC transceivers, LDPC (low-density parity check) codes, etc. Moreover, a sophisticated, HW-agnostic, SW platform will be developed, capable of deciding the optimal splitting of functionality between HW and SW. This will yield powerful HW/SW systems, with interface abstractions, for flexible control and management, across heterogeneous wireless devices and access networks.

The overall objective of Flex5Gware is to deliver highly reconfigurable HW platforms together with HW-agnostic SW environments, targeting both network elements and devices, and taking into account the need for increased capacity, reduced energy footprint, as well as scalability and modularity for enabling a smooth transition from 4G mobile wireless systems to the 5G era.

Design requirements for 5G wireless networks and applications are expected to differ markedly from previous generations. Exponential growth in mobile data traffic, combined with a rapidly increasing diversity of traditional mobile devices, and new low-bitrate and low-power machine-to-machine devices, require enhanced HW/SW platforms for greater flexibility and efficiency.

Flex5Gware research will aim to improve technology in several key areas, including:

- QoE (e.g., capacity, latency, resilience)
- energy efficiency
- scalability, modularity, versatility and re-configurability for multiple radio access technologies

Flex5Gware will evaluate and demonstrate the developed 5G technologies, through proofs-of-concept, which will be showcased in main events. The consortium includes large industry leaders, (infrastructure providers, semiconductor manufacturers and network operators), leading research institutions and academia, and active SMEs. This highly specialized consortium will bring disruptive HW/SW results that will impact and pave the way for the future 5G networks. Flex5Gware will also collaborate in the definition of 5G wireless systems together with the other 5G-PPP projects, by providing the HW/SW implementation standpoint.

F.3 mmMAGIC

A new radio interface concept will be developed in mmMAGIC and assessed using the developed channel models. More specifically, mmMAGIC as part of its WP4 will investigate, evaluate and compare new wave form(s) (such as FBMC, UFMC, GFDM) and currently used 4G wave forms (such as OFDM, SC-FDMA) regarding their applicability for mmW communication systems and will select and develop proper waveform candidates to fulfil the agreed KPIs. In order to substantiate the conceptual work and simulations on the design of the mmW radio interface (including PHY and MAC techniques), hardware in the loop transmission experiments will be performed. The most promising access schemes will then also be selected for performance evaluations at link and system-level.

F.4 SPEED5G

The project SPEED5G focuses on the use of extended dynamic spectrum access (eDSA), which is resource management with three degrees of freedom: densification, rationalized traffic allocation over heterogeneous wireless technologies, and better load balancing across available spectrum. With special emphasis in small cell scenarios, SPEED5G sees FBMC as the radio interface that will allow for such dynamic and heterogeneous use of narrowband chunks of the spectrum. Concerning simulations, two levels are envisioned. On link level simulations, the focus is on FBMC performance, for which a BS prototype fully based on this radio access technology will be used. On system level simulations, the SPEED5G intention is to use the METIS models, or the alternatives proposed by METIS-II for the 5G-PPP evaluation of new radio access technologies.

The main use cases of SPEED5G are ultra-dense deployments of small cells, Broadband access everywhere and support of massive IoT, which is mapped to different test environments or scenarios. Initially, SPEED5G will consider 4 realistic scenarios (TC1, 2 & 3 from METIS [MET13-D61]) and a new one called extended suburban depicted in Figure F-4. There are other synthetic test environments based on [3GPP13-36872], [3GPP13-36932], [3GPP15-36889] from 3GPP. The channel models will be PS#1, PS#2, PS#3, PS#4 & PS#7 from METIS [MET13-D61] and IMT-A channel models. Mobility and traffic models are still not defined, but will be aligned with the ones defined at METIS [MET13-D61] for the realistic scenarios in order to have a proper evaluation framework. FBMC techniques and the MAC layer for 5G developed in SPEED5G will be evaluated in these scenarios.

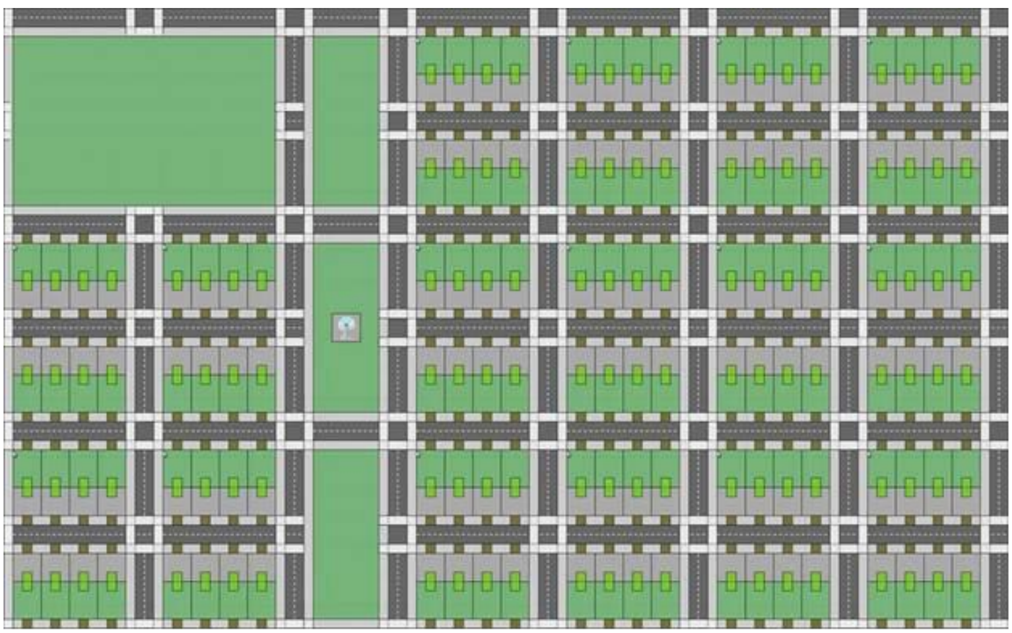


Figure F-4: Extended Suburban Layout.

The most relevant KPIs evaluated in the project are throughput CDF, SINR vs. BER and signalling overhead. However, real hardware demonstrators will be also used for evaluating some outputs of the project. Results are expected by Q1 2017. In particular, SPEED5G interest area is providing to the other 5G-PPP projects FBMC look-up tables, or to cross-check the validity of other approaches against the ones proposed in the project.

F.5 5G Crosshaul

The project Xhaul mainly focuses on developing an adaptive, sharable, cost-efficient 5G transport network solution by integrating both the fronthaul and backhaul sections of the network. It is also intended to develop novel infrastructures and switch architectures for this transport network to flexibly interconnect the 5G RAN and core network functions.

Validation and proof of concept shall integrate the advanced Xhaul technology components developed in other WPs into a multi-technology and multi-functional 5G testbed in Berlin in order to demonstrate the Xhaul use cases. In particular, fixed and wireless fronthaul and backhaul transmission schemes including the distributed transport network will be tested in a real-world, relatively large-scale deployment in order to provide a flexible, scalable data proliferation to wireless access points in the field, fulfilling 5G-relevant KPIs towards throughput, latency and energy efficiency. In particular the various fixed and wireless Xhaul technologies will be evaluated with regards to various 5G-relevant KPIs. Specific interest is towards advanced Xhaul network features like meshing, load balancing, energy efficiency, mobility, adaptive capacity scaling, real-time status availability of Xhaul connectivity, etc.

The performance evaluation framework definition is not yet started. Input from RAN models defining latencies, jitter, end to end delays and other performance metrics will be used as input to define the transport network design and simulation models. Simulation techniques can be different according to different interfaces used (mmW, copper or fibre). Popular tools available today shall be used to model packet networks. These tools might need to be adapted based on RAN requirements to develop a framing protocol and transport network architecture for the defined scenario. For the final demo, a well-defined specific use case shall be used to show the performance quantitatively.

F.6 5G-Xhaul

5G-XHaul designs a flexible backhaul/fronthaul network, utilizing integrated optical and wireless (sub 6 GHz and mmWave) technologies, through a converged software-based control plane. The project will provide a self-consistent transport network design able to operate in a RAN agnostic way. Additionally, 5G-XHaul will make interfaces available to future 5G RAN technologies.

The use cases to be analysed will be representative of potential new 5G services that may benefit from the technological solutions developed in the project. Potential examples to consider (but not limited to):

- Massive communications in large venues like stadiums, airports, train stations, etc., which can take advantage of the dynamic re-routing of backhaul capacity and traffic offloading solutions
- Spontaneous hotspots like traffic jams, mobs, etc., that can be better handled thanks to the capabilities provided by the Scalable Cognitive Control plane
- Support of ultra-low latency applications, like tactile Internet or the support of augmented reality, which can take advantage of localization in nomadic environments.
- Blocks of flats, where the management of home fixed/cellular network can be useful.

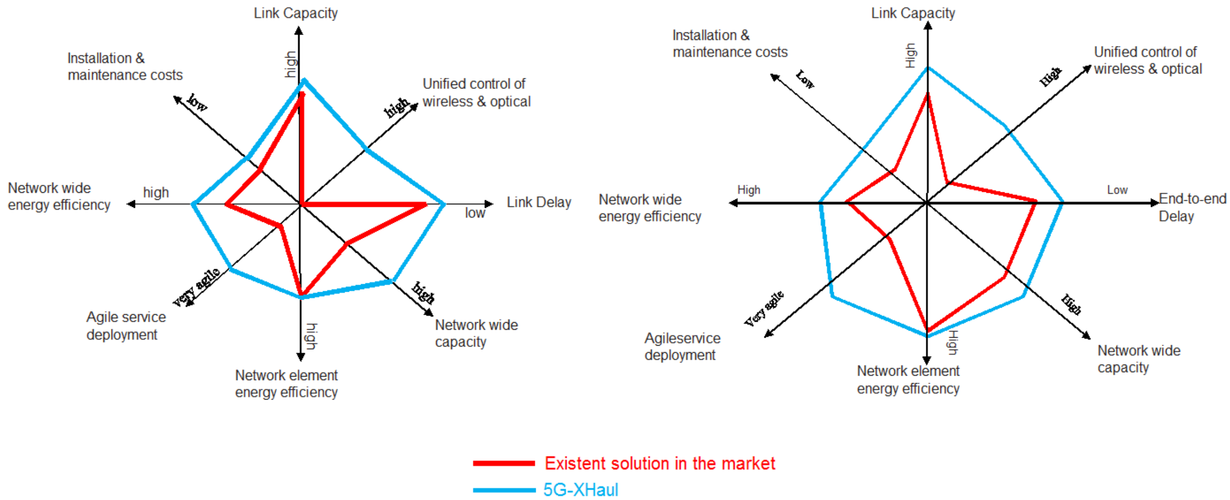


Figure F-5: Comparative analysis (a) Wireless X-Haul, (b) Optical X-Haul.

Two testbed facilities will be used to assess the achievement of KPIs and to evaluate the performance of the proposed paradigm: UTH's testbed (NITOS) and the testbed of UNIVBRIS. NITOS features a variety of commodity wireless access technologies, including LTE, WiMAX and WiFi. Its nodes are connected to programmable OpenFlow switches. Experiments involving spatial SDN, high level functions of Medium Transparent MAC (MT-MAC) and all OSI layer 2 (and above) systems, except for the low level optical and wireless control functions, will be performed at NITOS. Moreover experiments related to the scalability and elasticity of 5G-XHaul orchestrator controller will be tested on NITOS cloud. The testbed of UNIVBRIS features a multitude of OpenFlow-enabled devices and network domains, such as Ethernet switches, optical WDM and fibre switching equipment. It also features general purpose servers and network-attached storage. mmW solutions will be deployed and integrated in the testbed of

UNIVBRIS, creating a flexible converged optical-wireless infrastructure for testing backhaul/fronthaul architectural solutions. Experiments involving all systems developed within programmable optical and wireless backhaul and fronthaul as well as low level control functions will be performed in this testbed.

The first deliverable related to requirements and KPIs will be issued in February 2016 ("D2.1 Requirements Specification and KPIs Document"), where a first description of potential use cases, and the associated requirements and KPIs will be provided.

F.7 5G NORMA

The key objective of 5G NORMA is to develop a conceptually novel, adaptive and future-proof 5G mobile network architecture. The architecture is enabling unprecedented levels of network customisability, ensuring stringent performance, security, cost and energy requirements to be met; as well as providing an API-driven architectural openness, fuelling economic growth through over-the-top innovation.

Relevant to strands "Radio network architecture and technologies" and "Convergence beyond last mile", the 5G NORMA architecture will provide the necessary adaptability able to efficiently handle the diverse requirements and traffic demand fluctuations resulting from heterogeneous and hanging service portfolios. Not following the 'one system fits all services' paradigm of current architectures, 5G NORMA will allow for adapting the mechanisms executed for a given service to the specific service requirements, resulting in a novel service- and context-dependent adaptation of network functions paradigm. The technical approach is based on the innovative concept of adaptive (de)composition and allocation of mobile network functions, which flexibly decomposes the mobile network functions and places the resulting functions in the most appropriate location. By doing so, access and core functions no longer (necessarily) reside in different locations, which is exploited to jointly optimize their operation when possible. The adaptability of the architecture is further strengthened by the innovative software-defined mobile network control and mobile multi-tenancy concepts, and underpinned by corroborating demonstrations.

5G NORMA will ensure economic sustainability of network operation and open opportunities for new players, while leveraging the efficiency of the architecture to do so in a cost- and energy-effective way.

Whenever possible, it is expected to quantify which are the measurable contributions of 5G NORMA to each of the KPIs.

- ***Wireless area capacity***: According to 5G-PPP, one of the contractual KPIs is to provide "*1000 times higher wireless area capacity and more varied service capabilities*". It is known that such a gain can only be achieved by an architecture where the wireless area capacity scales with an increasing number of base stations (densification) [DHL+11]. 5G

NORMA will provide a 5G architecture that enables a cost-efficient densification approach and guarantees an improved energy-efficiency. Adaptability and, in particular, mobile network multi-tenancy concepts will be the key concepts here. 5G NORMA will thus contribute to a large share of the overall 1000 times increase. That increase builds on the improved centralized control, mobile network multi-tenancy, multi-service mechanisms, and enabling ultra-dense networks

- ***Massive machine type traffic:*** Another KPI of 5-GPPP is to provide "*very dense deployments to connect over 7 trillion wireless devices serving over 7 billion people*". This KPI will be one of the key contributions of 5G NORMA as the architecture designed is specifically tailored to support heterogeneous deployments including very dense ones and immense scalability. In particular, 5G NORMA contributes to this KPI by enabling the adaptive allocation of network functions, enhanced control functions through centralized control, and by the efficient support of heterogeneous backhaul deployments in order to increase the network deployment flexibility.

In addition to the KPIs identified by 5G-PPP, 5G NORMA also focuses on other KPIs that are not included in the 5G-PPP list but are very relevant for network performance.

- ***Latency***: Latency is critical for many applications. The project goal with respect to this KPI is to provide latencies that are sufficient to satisfy the requirements of vehicular applications (which means latencies below 5 ms) as well as those of tactile applications (which require latencies below 1 ms). These requirements will be satisfied through the adaptability to service requirements and the support of edge computing concepts defined in 5G NORMA, which can be tailored to a specific service and thus optimized on a per-service basis for a given metric.

- ***Cost efficiency***: Another KPI not included by the 5G-PPP that is very relevant and will be addressed by 5G NORMA is that of cost efficiency. Indeed, as exposed above, this KPI is essential in order to deploy a sustainable mobile network that provides the desired services and quality to end-users. The *entire architecture* design has been focused on providing the necessary flexibility and efficiency so that new services can be offered in a cost-effective manner. The ultimate goal is to provide such new services and additional capacity at a cost that is comparable to that of today's networks.

In addition to the above KPIs, 5G NORMA also contributes to other KPIs, which, though not within the main targets of the project, also benefit from the proposed architecture design:

- ***Service creation time***: An additional KPI of 5G-PPP is to reduce "*the average service creation time cycle from 90 hours to 90 minutes*". While 5G NORMA does not specifically focus on service creation, it does provide the technology enablers that allow for improving the efficiency of service creation. In particular, the *software-defined mobile network control* technology of 5G NORMA facilitates the flexible re-design of new functions based on software implementations only, which improves very substantially the flexibility and efficiency as compared to current closed solutions. The creation of services through these functions is greatly facilitated by the fact that these functions are more flexible and therefore better tailored to the services they support. This ability to accelerate and to open up **service creation enables a very wide range of innovative products & opportunities.**

- ***Security, reliability and dependability*****:** 5G-PPP also includes a KPI on "*secure, reliable and dependable Internet with a zero perceived downtime for services provision*". While 5G NORMA does not specifically focus on these, such aspects need to be built-in the architecture and cannot be plugged in as an add-on to an architecture design that has not taken them into account from the start. Therefore, 5G NORMA will allocate effort dedicated to these aspects and will ensure that all the solutions provided within the architecture are expressly designed to deliver security, reliability and dependability.
- ***Energy consumption***: As a societal KPI, 5G-PPP targets the "*reduction of energy consumption per service up to 90%*". Particularly for dense small cell deployments fast on/off switching of small cells will be essential for energy efficiency and is supported by the 5G NORMA architecture. Otherwise, energy consumption is more closely related to the node design and implementation rather than the architecture itself, and hence this is not a primary focus of 5G NORMA. However, as a side effect of the improved efficiency resulting from *multi-service mechanisms* and *centralized control*, it is expected expect that 5G NORMA will contribute to reducing energy consumption by a factor between two and four.
- ***Spectral Utilisation:*** Spectrum is a scarce resource and although technology is enabling us to use higher frequencies, better utilisation of the available frequencies should be emphasized. Technologies such as LTE-A have reached a limit of spectral-efficiency in a narrow sense of bps/Hz in a given channel – but we must take a broader definition. This is especially the case for lower frequencies with **wide area propagation characteristics.** 5G NORMA will enable more flexible use of spectrum, ensuring scarce resources are used to best ends. As such, spectrum allocation is dynamic and optimal, rather than being static and technology constrained.
- ***Coverage:*** A KPI of 5GPP is to reach "*7 trillion wireless devices serving over 7 billion people*". Today's cellular networks reach perhaps 80% of the population, and a much smaller portion of the earth's surface, and even in developed countries coverage is not universal. The desire to support MTC or IoT implies an even wider geographic reach than today's human-centric services. In order to reach the 5G-PPP objectives, the 5G NORMA architecture facilitates not just hyper-dense deployments for capacity limited scenarios, but also low-power, cost-effective deployment modes to extend wide area coverage.