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Abstract

The overall purpose of METIS is to develop a 5G system concept that fulfils the requirements of the beyond-2020 connected information society and to extend today's wireless communication systems for new usage cases. First, in this deliverable an updated view on the overall METIS 5G system concept is presented. Thereafter, simulation results for the most promising technology components supporting the METIS 5G system concept are reported. Finally, simulation results are presented for one relevant aspect of each Horizontal Topic: Direct Device-to-Device Communication, Massive Machine Communication, Moving Networks, Ultra-Dense Networks, and Ultra-Reliable Communication.

Keywords

System Concept, System-level simulations, Simulation results, Horizontal Topics, Direct Device-to-Device Communication, D2D, Massive Machine Communication, MMC, Moving Networks, MN, Ultra-Dense Networks, UDN, Ultra-Reliable Communication, URC, Architecture, Technology Components, TeC.

Executive summary

This deliverable reports on the intermediate results of analytical and simulation-based system evaluations including feasibility studies with respect to the requirements put forth in the project. Moreover, it reports on the possible system concepts identified up to this point. In this framework, and with the aim of integrating the different technologies studied in the consortium into a unified METIS system concept, this deliverable has a threefold objective.

- Firstly, this deliverable provides an updated view of the METIS system concept. In this sense, Horizontal Topics (HTs) are combined into a set of fundamental services that are described in the document. Besides, we give a consolidated view on the air interface alternatives and the preferences expressed in the project. Finally, this deliverable also updates on the architecture work. It is worth noting that this concept description is important to understand the set of assumption made in the simulation assessment.
- Secondly, this deliverable also collects the most promising Technology Components (TeCs) from all the work packages in METIS. Together with a detailed analysis of all of them, which is based on performed link and system simulations, this deliverable starts the process of tying different proposals together to define finally the METIS solutions for each one of the test cases defined in deliverable D1.1 [MET13-D11].
- Finally, this deliverable summarizes the evaluation, following the guidelines described in deliverable D6.1 [MET13-D61], of the impact of the different HTs on the METIS goals. Results permit 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 SIMO mode, to keep the needs of bandwidth within the margin of 10 times the available spectrum. Moreover D2D communications are definitively a key pillar for the evolution towards 5G to reduce latency. We have demonstrated that it is unfeasible to reach the objectives of latency without a significant change in the system architecture.

This deliverable represents the starting point of the evaluation of the METIS concept. Deliverable D6.5 "Report on simulation results and evaluations" is the final report on simulations and will go an step further, providing the system solution and its performance for the twelve test cases defined in the project [MET13-D11].

Among the main findings of this deliverable, we provide numbers on the impact of the HTs in the METIS goals and also show how the most promising TeCs contribute to these goals and interact with the HTs.

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List of Abbreviations

3GPP	Third Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
AAA	Authentication, Authorization and Accounting
AI	Air Interface
AMC	Adaptive Modulation and Coding
AP	Access Point
ARCH	ARCHitecture
BAD	Bursty Application Driven traffic
BB	Building Block
BBE	BaseBand Element
BLER	BLock Error Rate
BS	Base Station
BSOS	Border Switch Off Scheme
BUD	Bursty User Driven traffic
C-ITS	Cooperative Intelligent Traffic Systems
C-plane	Control plane
C-RAN	Cloud Radio Access Network
C/I	Carrier-to-Interference
CapEx	Capital Expenditure
CDF	Cumulative Distribution Function
CDN	Content Delivery Network
CN	Core Network
CNE	Core Network Element
CoMP	Coordinated Multi-Point
CP	Cyclic Prefix
CP-OFDM	Cyclic Prefix Orthogonal Frequency-Division Multiplexing
CQI	Channel Quality Indicator
CRC	Cyclic Redundancy Check
CSG	Closed Subscriber Group
CSI	Channel State Information
D	Deliverable
D2D	direct Device-to-Device
D2D-B	direct Device-to-Device Backhaul
D2D-C	direct Device-to-Device Critical
D2D-M	direct Device-to-Device Machine
D2D-N	direct Device-to-Device Non-critical
DCMR	Dynamic Clustering with Multi-antenna Receivers
DFT	Discrete Fourier Transform
DFT-S-OFDM	Discrete Fourier Transform-Spread Orthogonal Frequency Division Multiplexing
DFT-SM	Discrete Fourier Transform based Spatial Multiplexing
DFT-SM-MRT	Discrete Fourier Transform based Spatial Multiplexing Maximum Ratio Transmission
DL	DownLink
DMRS	DeModulation Reference Symbols

E2E	End-to-End
eNodeB	evolved universal terrestrial radio access NodeB
EESM	Exponential Effective SINR Mapping
eICIC	enhanced Inter-Cell Interference Coordination
EIRP	Equivalent Isotropically Radiated Power
ETSI	European Telecommunications Standards Institute
FBMC	Filter-Bank based Multi-Carrier
FDD	Frequency Division Duplex
FDMA	Frequency-Division Multiple Access
FeICIC	Further enhanced Inter-Cell Interference Coordination
FFT	Fast Fourier Transform
GP	Guard Period
GPON	Gigabit Passive Optical Network
HARQ	Hybrid Automatic Repeat reQuest
HetNet	Heterogeneous Network
HO	Hand-Over
HT	Horizontal Topic
HW	HardWare
IaaS	Infrastructure as a Service
IC	Interference Cancellation
ICI	Inter-Cell Interference
ICIC	Inter-Cell Interference Coordination
ICT	Information and Communications Technology
IEEE	Institute of Electrical and Electronics Engineers
IMT	International Mobile Telecommunications
IoT	Internet of Things
IP	Internet Protocol
IS	Interference Suppression
ISD	Inter-Site Distance
ISG	Industry Specification Group
ISM	Industrial, Scientific and Medical
JT	Joint Transmission
KPI	Key Performance Indicator
LOS	Line Of Sight
LSA	Licensed Shared Access
LTE	Long Term Evolution
LTE-A	Long Term Evolution-Advanced
M-MIMO	Massive Multiple-Input Multiple-Output
M-MTC	Massive Machine-Type Communications
M2M	Machine-to-Machine
MAC	Medium Access Control
MBB	Mobile BroadBand
METIS	Mobile and wireless

	communications Enablers for the Twenty-twenty Information Society
MIMO	Multiple-Input Multiple-Output
MISO	Multiple-Input Single-Output
MMC	Massive Machine Communication
MMC-A	Massive Machine Communication Accumulation
MMC-D	Massive Machine Communication Direct access
MMC-M	Massive Machine Communication Machine
mmW	millimetre Waves
MN	Moving Networks
MN-M	Moving Networks Mobility
MN-N	Moving Networks Nomadic
MN-V	Moving Networks Vehicle
MNGMT	MaNaGMenT
MNO	Mobile Network Operator
MS	Mobile Station
MTC	Machine-Type Communication
MU	Multi-User
MU-SCMA	Multi-User Sparse Coded Multiple Access
NA	Network Assistance
NE	Network Element
NFV	Network Function Virtualization
NN	Nomadic Node
NOMA	Non-Orthogonal Multiple Access
NRT	Non Real Time
NSPS	National Security and Public Safety
NW	NetWork
OAM	Operation, Accounting and Maintenance
OFDM	Orthogonal Frequency-Division Multiplexing
OFDMA	Orthogonal Frequency-Division Multiple Access
OpEx	Operational Expenditure
OQAM	Offset Quadrature Amplitude Modulation
OTT	Over-The-Top
PaaS	Platform as a Service
PAPR	Peak to Average Power Ratio
PF	Proportional Fair
PHY	PHYsical layer
PI	Polynomial Interpolation
PU	PUblic
QoE	Quality of Experience
QoS	Quality of Service
RA	Random Access
RAN	Radio Access Network
RANaaS	Radio Access Network as a Service
RAT	Radio Access Technology
RB	Resource Block
Rel	Release

RF	Radio Frequency
RFV	Radio Function Virtualization
RLA	ReLiability Aspect
RLC	Radio Link protoCol
RNFV	Radio Network Function Virtualization
RR	Round Robin
RRM	Radio Resource Management
RS	Reference System
RSOS	Random Switch Of Scheme
RSRP	Reference Signal Received Power
RSS	Remote Subscriber Stage
RT	Real Time
RZF	Regularized Zero-Forcing
SC	Small Cell
SC-FDM	Single Carrier Frequency Division Multiplexing
SC-FDMA	Single-Carrier Frequency-Division Multiple Access
SCMA	Sparse Coded Multiple Access
SDMA	Space-Division Multiple Access
SDN	Software Defined Network
SIC	Successive Interference Cancelation
SIMO	Single-Input Multiple-Output
SINR	Signal to Interference-plus-Noise Ratio
SISO	Single-Input Single-Output
SNR	Signal to Noise Ratio
SON	Self-Organizing Network
SRTA	Separate Receive and Training Antenna
SU-SCMA	Single-User Sparse Coded Multiple Access
SVD	Singular Value Decomposition
T	Task
TC	Test Case
TCP-IP	Transmission Control Protocol Internet Protocol
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TeC	Technology Component
TeCC	Technology Component Cluster
TRX	Transceiver
TTI	Transmission Time Interval
TV	TeleVision
TX	Transmitter
U-MTC	Ultra-reliable Machine-Type Communications
U-plane	Use plane
UDN	Ultra-Dense Networks
UDN-C	Ultra-Dense Networks Core
UDN-E	Ultra-Dense Networks Exteneded
UE	User Equipment
UFMC	Universal Filtered Multi-Carrier
UHD	Ultra-High Definition
UL	UpLink

UM	Unacknowledged Mode
URC	Ultra-Reliable Communication
URC-E	Ultra-Reliable Communication Emergency
URC-L	Ultra-Reliable Communication Long-term
URC-S	Ultra-Reliable Communication Short-term
UT	User Terminal
V2P	Vehicle-to-Pedestrian
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-anything
VFD-BR	Virtual Full-Duplex Buffer-aided Relaying

VN	Virtual Network
VNF	Virtual Network Function
VoIP	Voice-over-Internet Protocol
VRU	Vulnerable Road Users
VT	Video Traffic
WCDMA	Wide Code Division Multiple Access
WP	Work Package
WSDN	Wireless Software Defined Network
xMBB	extreme/advanced/flexible Mobile BroadBand
ZF	Zero-Forcing

1 Introduction

The overall purpose of METIS is to develop a system concept that meets the requirements of the beyond-2020 connected information society and extend today's wireless communication systems to support new usage scenarios. To this end, METIS is investigating new paradigms and technology components. The most promising technology components will be integrated into the METIS 5G concept. The proposed concept should achieve the METIS technical objectives [MET13-D11]:

- 1000 times higher mobile data volume per area,
- 10 to 100 times higher typical user data rate,
- 10 to 100 times higher number of connected devices,
- 10 times longer battery life for low power devices,
- 5 times reduced End-to-End (E2E) latency.

In the process towards the assessment of the METIS system, a specific concept was developed for each of the METIS Horizontal Topics (HTs): Direct Device-to-Device Communication (D2D), Massive Machine Communication (MMC), Moving Networks (MN), Ultra-Dense Networks (UDN), and Ultra-Reliable Communication (UDN). Then, the overall concept shall be developed through integration of the HT-specific concepts. A first version of the concepts associated with each HT and the overall METIS 5G concept was reported in [MET14-D62].

1.1 Objective of the document

The purpose of this document is to provide an updated view of the METIS 5G concept and report intermediate simulation results on the most promising Technology Components (TeCs) supporting the concept.

Intermediate evaluations, in terms of both system and link simulations provided by the Work Packages (WPs), of selected technology components are presented. The TeC evaluations focus on the promising components in terms of an overall METIS 5G system perspective, taking the METIS goals, horizontal topics and architectural aspects into consideration. It should be noted that many additional technology components are investigated by METIS. These are not yet mature enough to be included in the METIS 5G concept but still considered as potential parts of the 5G system. These technology components are thoroughly reported in the work package specific final deliverables.

Intermediate system evaluations of some relevant aspects for each of the horizontal topics are also presented. These evaluations are conducted on the "Dense urban information society" Test Case (TC2) as defined in [MET13-D11] according to the guidelines set forth in [MET13-D61] and path-loss values obtained through ray tracing (available at [MET14-Web]). Given the transversal nature of the horizontal topics, it was requested a complete evaluation of their performance to compare their impact and therefore their interest for the consortium. The simulation comparison is made for TC2 since this is the more generic scenario in which all HT can play an important role. The evaluation of test cases is out of the scope of this deliverable, since this task will be reported in Deliverable D6.5 "Report on simulation results and evaluations".

1.2 Overall research organization of METIS

This section presents in a short manner the organization of METIS. This is made to ease the reader understand the organization of this deliverable, since all results from the project are summarized here and are presented in the format of the METIS structure.

METIS has a matrix organisation that combines system-level design and evaluation through Horizontal Topics (HTs) with the comprehensive technical research in Work Packages (WPs).

The Horizontal Topics ensure that the global challenges and system aspects are addressed appropriately and also ensure interaction and coordination across WPs for system-level functionality. Work packages perform research in relevant areas and develop the technology components. The HTs go across all work packages, to tie together key technology components into a system concept and solutions that adequately address the different use-cases of future wireless systems.

On the other hand, the METIS work plan is structured into eight WPs, six of technical nature, one for dissemination of project results, and one for project management. The research work in the six technical work packages is selected to highlight the flow from user needs (WP1), to research on specific topics (WPs 2–5), to system-level synthesis and evaluation (WP6). WP2 Radio Link Concepts, WP3 Multi-node/Multi-antenna Transmissions, WP4 Multi-layer/Multi-RAT Networks and WP5 Spectrum perform research and develop the technology components. These WPs maintain close coordination through inter-WP alignment. WP6 System Design and Performance uses the horizontal topics to integrate the most promising technology components developed in WPs 2–5 and develop an overall system concept.

1.3 Structure of the document

The rest of the document is organised as follows:

- Section 2 describes the revised 5G system concept.
- Section 3 provides intermediate system evaluation results on the impact of the horizontal topics on the METIS goals.
- Section 4 contains conclusions of the evaluation and attained results.

In addition, this document has three Annexes:

- Annex A provides the details of the intermediate system evaluation results of the horizontal topics given in Section 3.
- Annex B captures the intermediate evaluations of the technology components that are part of Section 2.
- Annex C describes the intermediate system architecture that is part of Section 2.

2 Revised 5G system concept overview

With the aim of developing one 5G system concept that meets the requirements of the 2020 connected information society, METIS has established as key design principles efficiency, versatility and scalability to serve diverse use-cases and scenarios [MET14-D62].

The societal development will lead to an avalanche of mobile and wireless traffic volume. Even though we cannot predict the next “killer application” it is predicted that the traffic volume will increase a thousand-fold over the next decade.

Extreme Mobile Broadband (xMBB) provides the traffic volume and data rates required by new applications as virtual reality and augmented reality, extreme-resolutions 3-dimensional TV. Improved user Quality of Experience (QoE) and smart content delivery will also be necessary and provided by xMBB.

New use-cases include the wide range of applications related to Machine-Type Communication (MTC). The traffic characteristics and requirements of MTC often deviate substantially from those of human-centric communication.

Massive MTC concerns massive deployments of e.g. low-cost battery-powered sensors and actuators, remote-controlled and remote-read utility meters. 5G systems must provide up- and down-scaling connectivity solutions for tens of billions of network-enabled devices since it is expected that there will be 10-100 more connected devices per one human user of communications systems (for human interaction, connected machines owned by the user and devices owned e.g. by the city the user lives in).

Ultra-reliable MTC relates to the capability to provide a given service level with very high probability. Ultra-reliable MTC also includes applications where low delay is a critical factor, such as remote driving, industrial control, and haptic communication enabling remote work in e.g. hazardous environments or remote surgery. The various kinds of MTC will enable the wireless Internet of Things (IoT) encompassing tens of billions connected devices.

The coexistence of human-centric and machine-type applications, as illustrated in Figure 2.1, will lead to a large diversity of communication characteristics imposing very different requirements on 5G systems. A good example of these new communication paradigms are the V2X applications, by which cars are going to communicate among them, with the network and with the driver and passengers. Considering also other not yet identified application areas and use-cases poses a strong requirement on system flexibility.

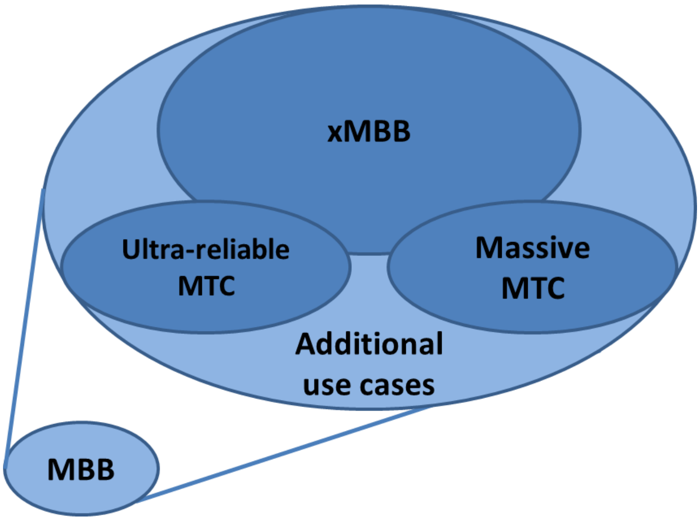


Figure 2.1: Development from today's MBB services to the beyond-2020 mix of xMBB, Ultra-reliable and Massive MTC. Additional use-cases enabled by 5G systems are to be expected.

2.1 The METIS horizontal topics

METIS uses Horizontal Topics (HTs) to facilitate the concept development process namely Massive Machine Communication (MMC), Ultra-Dense Networks (UDN), Moving Networks (MN), Ultra-Reliable Communication (URC) and Direct Device-to-Device Communication (D2D). HTs MMC and URC are more service-oriented, whereas HTs D2D and UDN are more oriented towards technical solutions. HT MN is a combination of both. However, each HT addresses a new key challenge and identifies new functionalities. The METIS 5G system concept is achieved by first developing specific HT concepts built on the relevant Technology Components (TeCs), and then integrating them, plus complementary technology components, into an overall system concept that meets the METIS goals.

Descriptions of the HT-specific concepts and a first view on the METIS 5G system concept are given in [MET14-D62]. The integration of research results through the HTs into the METIS 5G system concept is illustrated in Figure 2.2.

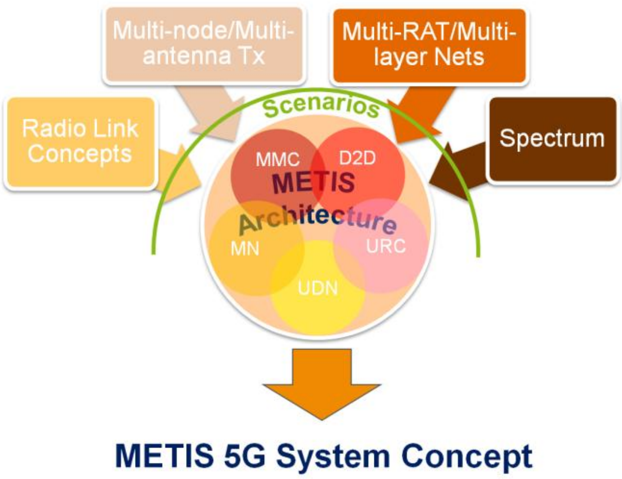


Figure 2.2: Illustration of how results developed in the different WPs are integrated through the HTs into the METIS 5G system concept.

In [MET14-D62] different "sub-topics" of each HT were identified. In the following we give a brief overview of each HT and corresponding sub-topics. We will then describe the identified commonalities based on these sub-topics. A more complete description of each HT is available in [MET14-D62].

2.1.1 HT Massive Machine Communication (MMC)

To achieve the METIS goals related to MMC, three different types of radio access is envisioned:

- **MMC-D**: The *Direct access*, in which devices transmit directly to the access node.
- **MMC-A**: The *Accumulation/Aggregation point type of access*, in which traffic from the devices in the proximity is accumulated in a local node before being sent to the access node. The accumulation point can either be a relay, a service dedicated gateway, a smart phone connecting personal electronic devices, or a dynamically selected device acting temporarily as the group/cluster head.
- **MMC-M**: The *direct Machine-to-Machine* (M2M) *communication* between devices, which is D2D communication applied to MMC devices. Though similar to HT D2D, the focus is on high protocol efficiency (i.e. very low signalling overhead), long device battery life, and low bit-rate and delay-tolerant traffic.

2.1.2 HT Ultra-Dense Networks (UDN)

Ultra-Dense Networks (UDN) refers to densification – reduction of Inter-Site Distance (ISD) – far beyond today's networks, and is one of the main enablers to address the predicted traffic demands and expected high data rates described in the METIS objectives. In the work on UDN, METIS has identified two main concepts:

- **UDN-C**: The *UDN Core concept* addresses the goals on traffic volume and data rate by providing solutions for increased network densification and related enablers. The core concept addresses three aspects; 1) Radio access technology, 2) Small cell integration and interaction, and 3) Wireless backhauling.
- **UDN-E**: The *UDN Extended concept* provides solutions for coexistence of a UDN layer with other wide area layers or other RATs in the form of a heterogeneous multi-RAT/multi-layer deployment. A closer collaboration between macro and UDN nodes than in today's systems is foreseen.

2.1.3 HT Moving Networks (MN)

Moving Networks (MN) refers to integration of moving and nomadic nodes into a dynamic RAN of the proposed system concept to provide improved coverage, capacity and safety. MN focuses on improving the mobility management and connectivity of moving terminals and moving/nomadic network nodes, e.g. connected cars. The MN concept has three sub-topics:

- **MN-M** for *Mobility-robust high-data rate communication links* to enable broadband as well as real-time services in mobile terminals and moving relays.

- **MN-N** for *Nomadic network nodes* to enable a flexible and demand-driven network node deployment for example in conjunction with large events in temporary venues.
- **MN-V** for *V2X communications* to enable reliable and low-latency services such as road safety and traffic efficiency.

2.1.4 HT Ultra-Reliable Communication (URC)

Ultra-Reliable Communication (URC) refers to solutions that will enable high degrees of reliability and availability, and aims at providing scalable and cost-efficient solutions to support network services with very high requirements on availability and reliability, not met by today's systems. Three different cases of URC are identified:

- **URC-L**: *Long-term URC* concerns how to guarantee (provide with high probability) certain rates to multiple users over longer periods. URC-L targets moderate-to-high data rates for providing an ordinary, rather than emergency connectivity.
- **URC-S**: *Short-term URC* concerns provisioning of moderate data rates with low latency with very high probability, e.g. latency less than 2 ms with 99.999 % guarantee, for a limited number of devices.
- **URC-E**: *URC for Emergency* is related to providing communications when the infrastructure becomes partially damaged or non-functional. The most important parameters are the time to establish a connection at a certain data rate, and the probability that a device will be able to send a message of a given size within a certain time-frame.

2.1.5 HT Direct Device-to-Device Communication (D2D)

Direct Device-to-Device Communication (D2D) refers in METIS to network-controlled direct communication between devices without user plane traffic going through any network infrastructure; the network controls radio resource usage of the direct links and the resulting interference effects. D2D is an enabler for the 5G system and other HTs. We have identified the following sub-topics:

- **D2D-N** for *Non-critical applications*, e.g. traffic offloading in MBB-type use-cases.
- **D2D-C** for *Critical/ultra-reliable applications*, e.g. V2X communication, where fast establishment of the links and ultra-reliable communication of low to moderate amounts of data with very low latency are the dimensioning factors.
- **D2D-M** for *direct M2M communication* in MMC-M applications. Here, the protocol overhead is more important than latency, and the established links can be valid for longer time.
- **D2D-B** for *Backhaul* applications to provide in-band self-backhaul in multi-hop mesh networks in UDN deployments.

2.2 Interim METIS 5G system concept

As illustrated in Figure 2.1, we have identified main fundamental services and key supporting functions, based on the HT sub-topics described above. Each fundamental service and enabler in turn consists of several technology components. The identified main fundamental services are:

- **Extreme/advanced/flexible Mobile BroadBand (xMBB):** provides high data rates and low-latency communications and improves Quality of Experience (QoE) through a more uniform experience over the coverage area, and graceful degradation of rate and increase of latency as the number of users increases. It is foreseen that xMBB can also be used for reliable communication in emergency situations.
- **Massive Machine-Type Communications (M-MTC):** provides up- and down-scalable connectivity solutions for tens of billions of network-enabled devices. Scalable connectivity, wide area coverage and deep penetration are important, and compared to xMBB, we trade rate for coverage.
- **Ultra-reliable/Critical MTC (U-MTC):** provides ultra-reliable low-latency communication links for network services with extreme requirements on availability, latency and reliability, e.g. V2X communication and industrial control applications.

It should be noted that the latter two main fundamental services are not identical to the HTs MMC and URC. The fundamental services M-MTC and U-MTC are substantially based on HTs MMC and URC, but solutions from other HTs are also included in M-MTC and U-MTC.

The key supporting enablers include:

- **Dynamic RAN** providing a new generation of dynamic Radio Access Networks (RANs). In dynamic RAN the wireless device exhibits a duality, being able to act both as a terminal and as an infrastructure node. Dynamic RAN incorporates UDN and MN-N access nodes (mobile relaying does not exist up to now in 3GPP networks), and supports D2D communication both for local traffic (off-loading) and backhaul. In some cases, e.g. in [MET14-D62], we have also used the term RAN 2.0 referring to this flexibility of the RAN.
- **The spectrum toolbox** contains a set of enablers (tools) to allow 5G systems to operate under different regulatory and spectrum sharing scenarios. The toolbox is divided into three layers called “spectrum regulatory framework”, “spectrum usage scenarios”, and “enabler domain”, where the latter contains the different tools needed in a given spectrum scenario.
- New **lean signalling/control information** is necessary to guarantee latency and reliability, support spectrum flexibility, allow separation of data and control information, support large variety of devices with very different capabilities and ensure energy efficiency.
- **Localized contents/traffic flows** allows offloading, aggregation and distribution of real-time and cached content. Localization reduces the load on the backhaul and provides aggregation of e.g. sensor information.

The fundamental services are built on contributions from the different HTs. The mapping from the HT sub-topics to the main fundamental services is illustrated in Figure 2.3. The following sections contain elaborations on the main fundamental services and enablers and explain how different HT sub-topics contribute to the main fundamental services and enablers, and mention some key aspects. It is worth noting that we have intentionally left aside the discussion on the air interfaces. The air interface discussion is made in Section 2.3, explicit TeCs are described in Section 2.4, and architecture in Section 2.5.

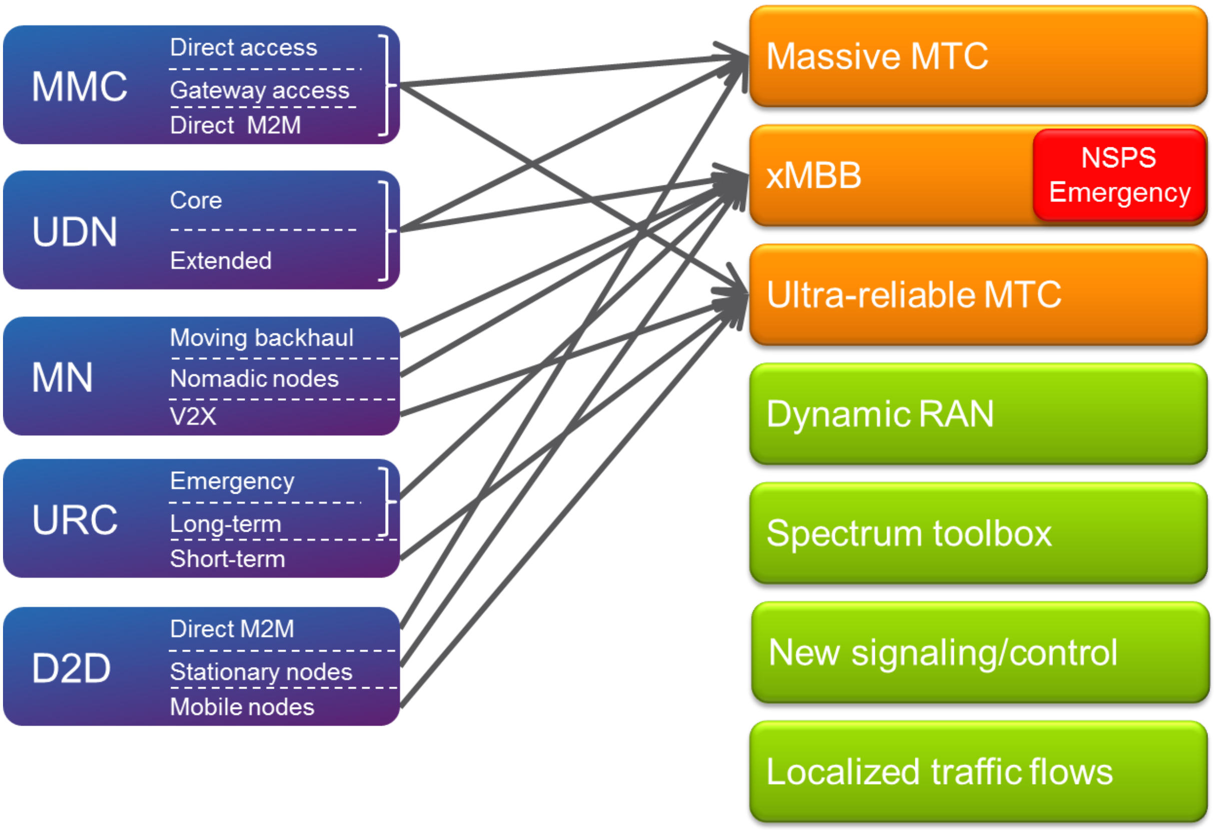


Figure 2.3: Showing how the different horizontal topics contribute to the main fundamental services. The supporting enablers support all main fundamental services (mappings omitted for clarity).

2.2.1 Extreme/advanced/flexible Mobile BroadBand (xMBB)

The xMBB service provides both increased data rates, and equally important, improved QoE for the users. Together with dynamic RAN, xMBB supports the increased traffic volumes foreseen in 5G systems.

xMBB builds on the spectrum-flexible air interface for UDN-C to meet the demands for increased achievable user data rates, which are important for the end-user to support high-demand applications such as virtual or augmented reality. From a network perspective, the increased rates contribute to support the increasing traffic volume. xMBB will utilize multi-layer and multi-connectivity, the spectrum toolbox and new signalling procedures to achieve spectrum flexibility.

From an end-user experience perspective, reliable provisioning of moderate rates is at least as important as maximizing the peak rates. This is often expressed as providing a certain minimum data rate “everywhere”. URC-L provides mechanisms for providing moderate data rates (50-100 Mbps) with very high reliability. Also, the reliable service composition leads to graceful degradation of rate and increase of latency, instead of dropped connections, as the number of users increases.

The reliable support for moderate rates is fundamentally different than extrapolating today's air interfaces to higher data rates. The xMBB need to strike a good balance.

UDN-C and MN-N provides tools for dense and flexible network node deployments, which yield a more uniform user experience over the area serviced by the system. D2D-N allows for further QoE improvements through offloading. UDN-E also provides a more uniform user experience.

xMBB together with MN-N can be used to establish reliable communication in National Security and Public Safety (NSPS) emergency situations. xMBB can also be used for machine-initiated emergency communication, e.g. automatic messages after accidents. Though this is MTC, it does not require the special features of Massive MTC or Ultra-reliable MTC described in the following.

2.2.2 Massive MTC (M-MTC)

Massive MTC (M-MTC) provides connectivity for a large number of cost and energy-constrained devices. Sensor and actuator deployments can be both wide-area for surveillance and area-covering measurements, and co-located with human users as in the case of body-area networks.

In general, the M-MTC air interface solution should be the same for all three connection modes described in Section 2.1.1 to minimize costs. Most solutions come from HT MMC, but M-MTC also utilizes work done for D2D-M and UDN.

For wide-area deployment of sensors and actuators, the access method will be MMC-D. Here coverage improvements for low complexity devices are critical, and Massive MIMO on the access node side is one enabler of enhanced coverage.

For human collocation, MMC-A and MMC-M can also be used. For the MMC-M mode, M-MTC uses the technical solutions from D2D-M. A key feature is very high protocol efficiency (i.e. very low signalling overhead) and the requirement for long device battery life. However, the user traffic is usually of lower data rates and comparably delay-tolerant. M-MTC can also piggy-back and benefit from UDN deployment [MET14-D62].

Licensed IMT spectrum access is preferred for MMC to provide area-coverage and service quality. However, unlicensed ISM spectrum access can be considered on economical and global harmonization merits.

Both connectionless and always-connected approaches should be supported. This poses requirements on the dynamic RAN, since in the connectionless approach, there is no user context stored on the network side and all required control plane data, whereas in the always-connected approach user context is stored on the network side.

2.2.3 Ultra-reliable MTC (U-MTC)

This service addresses the needs for ultra-reliable, time-critical services. It builds on the solutions developed in MN-V, URC-S and D2D-C.

V2X applications require fast discovery and communication establishment and reliable communication. MN-V has identified a number of relevant TeCs related to implementation of an air interface for M-MTC, e.g. reduced synchronization and robustness to high Doppler shifts and channel estimation errors. Additional TeCs related to supporting RAN functionalities have also been identified.

In industrial control applications, the discovery and communication establishment requirements may be less stringent but the reliability must still be large.

Dedicated spectrum for U-MTC applications is preferable to guarantee sufficient QoS. The specific spectrum band(s) to utilize depends on desired range and propagation characteristics.

Multi-operator support is crucial for discovery and communication, in particular for V2X communication applications. For traffic safety applications vehicles/user need to be able to communicate with each other regardless of which operator a vehicle/user has.

2.2.4 Dynamic RAN

METIS foresees a new generation of Dynamic Radio Access Network (RAN). This is a new paradigm of wireless networking which integrates UDN and MN-N nodes and D2D communication in a dynamic manner for multi-RAT environments. UDN and MN-N nodes exhibits strong similarities; UDN nodes are densely deployed at fixed locations, but are turned off when not serving users for energy performance purposes. MN-N nodes offer their services as temporary access nodes at non-predictable locations at non-predictable times. Both are utilizing activation/deactivation mechanisms to select which nodes should be activated at which times and locations. A user device exhibits a duality, being able to act both as a terminal and as an infrastructure node by temporarily taking over the role of access nodes for other users, e.g. to guarantee the ubiquity of high quality services. This leads to security issues that should be addressed with the support of the network infrastructure.

Interference will occur not only from users but also from time-varying access nodes. TeCs addressing improved interference management will mitigate this issue.

Wireless multi-hop self-backhaul from D2D-B will be utilized to establish backhaul links from UDN and MN-N nodes. D2D-N communication providing local traffic offloading utilizing localized traffic flows.

Dynamic RAN implies a flat architecture from service point of view resulting in low latency, supporting also the requirements of URC-S and MN-V. It is also accompanied by an agile infrastructure support since ad-hoc and smart coordinated setup of networks is expected under this service/user-centric model. Dynamic RAN also entails a different distribution of functions over network nodes depending on the service at hand and the hardware and software capabilities of the network nodes.

For MMC operations, Dynamic RAN will provide, as compared with current systems, more device centric processing for mobility in order to minimize frequent measurement reports and signalling overhead. Further, both connection-less and always-connected operations need to be supported.

2.2.5 Spectrum toolbox

The spectrum toolbox enables flexible use of available frequency resources aiming at best serving the user by increasing the efficiency in the use of spectrum. This is a fundamental enabler of multi-service operations and spectrum-flexible air interfaces. At a regulatory level, the toolbox supports different regulatory and licensing schemes, and multi-operator operations. The toolbox provides tools to:

- Consider different regulatory rules for different services, e.g. certain spectrum may only be used for certain services.

- Operate in widely distributed spectrum at both high and low frequencies, considering the suitability of different spectrum bands for different applications, e.g. lower frequencies are preferred for wide-area coverage for M-MTC and control information in a multi-connectivity system.
- Operate using small as well as large bandwidths, which enables spectrum-flexible air interfaces supporting higher data rates.
- Improve spectrum utilization through different sharing mechanisms supporting increased traffic volume. Also to operate in fragmented spectrum, with different duplex arrangements.

The spectrum toolbox is applicable to all foreseen 5G use-cases and services [MET14-D53].

2.2.6 New signalling/control information

The control information/signalling needs to be fundamentally readdressed in 5G systems to accommodate the different needs of different services.

In order to facilitate the spectrum-flexible multi-layer connectivity for xMBB services, a separation of control and data plane can be used. One example is mmW communication, where the control channel can be established at lower frequencies. Another example is network-controlled communication of content via D2D connection, offloading the cellular network.

M-MTC, on the other hand, benefits from a closer coupling between the control and data plane, even integration of the control and data planes. MMC also requires optimized sleep mode solutions for battery operated devices, and mobility procedures with a minimum of signalling and measurements.

U-MTC requires guaranteed latency and reliability. Here it should be noted that the successful reception of control information is a prerequisite for communication of the data part. For very reliable, low-latency V2X connection the device discovery can be assisted by the wide-area network. The increasing number of network nodes requires lean signalling for energy performance boost.

Another aspect that requires further attention is the security in D2D communications. The wide-area system shall provide security parameters to both communications links based on the internal credentials of the users. This network-assisted security establishment is a challenging issue in the development of D2D communications.

2.2.7 Localized contents and traffic flows

One of the main goals of METIS is to reduce current latency performance by a factor of five. However, the delay budget analysis of legacy technologies reveals that most of the delay comes from the Internet and the core network parts of the E2E link. Therefore, localized traffic flows, including data traffic offloading, aggregation, caching and local routing contribute to meeting this target [San12].

In the context of D2D traffic offloading, the control and data planes can be separated. The control plane is managed by the network and the data plane is transmitted over the D2D link. The network operator improves the user experience by providing e.g. authentication and security features while reducing the load on the data transport. In this framework context information and network assistance for D2D discovery are of paramount importance to enable such direct communication.

In MMC, the use of concentrators acting as local gateways could allow direct communication among sensors located in a local area without the need to reach the core network gateway. For MMC the localized traffic flows allow low-power access to the network. The network edge nodes can provide aggregation and information fusion of sensor data reducing the transport load and provide local added information value. Further, the necessary context information for MMC operations can be stored locally.

For delay-sensitive services, e.g. MN-V, it is necessary to turn-around the traffic flow and perform critical computations close to the user to meet the latency constraints.

Moreover, the concept of caching could be shifted to the network edges, reaching access nodes or even the own devices that could act as proxies in case of having the requested content in the memory.

2.3 Possible air interfaces

The waveform design has been the main driver in the evolutionary path we know today as cellular generations. They have motivated intense research and industrial disputes. From FDMA/TDMA until OFDMA, passing through WCDMA, different generations have been characterized by the choice of a single radio interface solution. In light of this history track, it is natural to consider that the main differentiator for 5G could be another major change in the signaling and multiple access formats we use today. However, METIS foresees not a single radio interface, but several of them coexisting in the same technology and being selected as a function of the scenario and the specific needs of transmitter and receivers. This section presents a summary of the current point of view of METIS concerning the air interface design. More information and details on the new air interfaces described in this section can be found in [MET14-D23].

2.3.1 OFDM

Orthogonal Frequency-Division Multiplexing (OFDM)-based waveforms (including e.g. SC-FDMA also known as DFT spread OFDM) are still considered promising for application in future wireless systems, especially for xMBB, due to the following reasons:

- Good time-localization of OFDM waveform enables low latency. This is an important aspect in TDD systems with demand on frequent link direction switching.
- Fulfilling requirements of low complexity, since efficient implementations based on FFT are available.
- The capability of OFDM to convert the fading channel to multiple flat channels allows straightforward extension to MIMO and beamforming solutions. Very large MIMO and high gain beamforming are perceived as the crucial technical components for 5G xMBB access going towards much higher data rate, much larger bandwidth and new and higher frequency bands up to mmW.

There is still room for improvement of OFDM:

- Since rectangular pulses are used in time domain, OFDM based systems exhibit high out-of-band radiation. When accessing fragmented spectrum while sharing spectrum with another service, the out of band radiation will impose strong interference on the coexisting systems in adjacent channels and vice versa, degrading the performance of both systems. However, it is not known if sharing will be an important part of the future 5G system. Especially for the millimeter wave region, sharing is not needed due to high amount of available bandwidth.

- On the uplink it is necessary to achieve tight synchronization with the sub-carriers. Otherwise it would not be possible for a narrow-band device with narrow-band RF, as typical for MMC, to access only a fraction of the signal bandwidth without generating inter-carrier interference. However, guard subcarriers can be used with only small overhead.
- In a multi-user / multi-service scenario, the subcarrier spacing, number of subcarriers and Cyclic Prefix (CP) length have to be selected as a “best compromise”, matching the requirements of the services / users as best as possible. The more diverse the requirements of the services are, the worse this compromise will be, resulting eventually in an inefficient use of resources.
- Overhead through CP and guard bands at the band edges can be adjusted dynamically according to the situation.

In UDN, the advantages of the OFDM are much more significant and the main classical drawbacks of OFDM become less critical in dense deployment environment.

- The out-of-band emission problem of asynchronous OFDM becomes negligible in dense deployment environment due to the usage of low power levels and utilization of higher carrier frequencies with very wide channel bandwidths.
- In UDN, synchronization can be established very fast since distance in the transmission link is shorter and time differences are minimized.
- In small cells and with current OFDM symbol duration, UL synchronization is not needed since with high probability only a single user is active at any given time.
- Co-channel interference needs to be taken into account in the air interface design instead of interference due to adjacent channels and can be managed by locally coordinated networks, high gain beamforming etc., which are natural solutions for UDN and not requiring large efforts.
- The overhead due to CP, enabling easy localization the OFDM waveform at the receiver, decreases in dense deployment due to small cell sizes with smaller delay spreads, provided the same OFDM symbol duration.

2.3.2 Filtered multi-carrier systems as alternative to OFDM

Multi-carrier schemes that apply additional filtering can solve some of the drawbacks of OFDM (adjacent channel emissions and tight synchronization requirements). The use of filters with steep power roll-off in frequency domain strictly confines the signal power distribution to a pre-defined frequency band. In a multi-service scenario, this allows for a partitioning of the spectrum into independent sub-bands, which can be individually configured according to the particular needs of a selected radio service. Due to the inherent spectral containment, only a very coarse synchronization between the signals used in adjacent sub-bands is required to ensure interference-free operation of the system, so that even independent and unsynchronized frame structures can be used as individual configurations in the adjacent sub-bands. A prominent example is the coexistence of M-MTC in a frequency band shared with mobile broadband data service. A loosely synchronized narrow-band MTC-link can coexist next to a tightly synchronized mobile broad-band service without any mutual interference. Moreover, the M-MTC device needs to synchronize to its dedicated (narrow-band) sub-band only and not to the entire signal band covered by all coexisting services, as it would be the case in OFDM, allowing for low-cost RF realizations of the M-MTC device.

Other configuration parameters to be adapted per sub-band are the subcarrier spacing, which could be adapted in highly mobile environments to reduce the distortions caused by the Doppler effects, as well as the shape of the applied filter, which can be designed to meet desired requirements of a particular service. Along with these plain advantages comes a high robustness of the signal to misalignments in frequency and time. This significantly relaxes one of the core problems of OFDM in macro-cell environments: The problem of time mismatches caused by propagation delays, which used to be solved by a timing advance in OFDM at the cost of some signalling overhead. Hence, with filtered multi-carrier systems, open-loop synchronization is enabled and the use of cheap oscillators can be well supported, rendering these systems a key enabler for low-cost applications like MMC also in macro-cell scenarios or for CoMP schemes in non-perfectly synchronized multi-cell environments.

The well-localized signal energy in frequency domain of the multi-carrier signal also allows for efficient access to fragmented spectrum and efficient spectrum sharing, as a minimum amount of guard bands are needed for the signal separation in frequency. Multi-carrier systems with filtering can use up to 10 % more spectrum compared to LTE-A by reducing the guard bands needed at the band edges

The filtering does not introduce an additional overhead compared to classic OFDM, as the length of the tails generated by the filters can be limited to the length of the cyclic prefix used in OFDM, or maybe even shorter (depending on the type of filtered multi-carrier scheme used). Thus, the spectral efficiency can be improved even further in this respect, in particular if long symbol bursts are being transmitted.

There exist two different alternatives of filtered multi-carrier systems, which are investigated in METIS:

1. Filter-Bank based Multi-Carrier (FBMC),
2. Universal Filtered Multi-Carrier (UFMC).

The following gives a brief overview on the main properties of both these schemes.

FBMC

- Filtering is done per subcarrier signal.
- The pulse shaping filter can be freely designed without constraints in temporal length. This implies maximum degree of freedom for the system design.
- Signals overlap in time domain, but due to the fully separable orthogonal design this yields less temporal containment as in OFDM.

- OQAM signaling: Full orthogonality can only be achieved for real valued symbols (no complex valued symbols allowed). Requires some adaptations of TRX schemes compared to OFDM. However, all existing schemes can be transferred.
- No CP required for successive FBMC symbols, but filter tail at the end of the burst generates overhead.
- Filter tail can be wrapped into time-constrained burst by using circular convolution and block based processing (developed in METIS). This way, FBMC can be matched to any frame structure at small overhead cost (an additional CP is necessary at the edges of the burst).

UFMC

- Filtering is done per sub-band or resource block. The width of sub-band depends on the desired filter tail length. If filter tail length equals the length of CP in LTE, then sub-band width is equal to a Resource Block (RB) in LTE (twelve subcarriers occupy 180 kHz).
- There is a trade-off to be done between filter tail length (overhead) and filter power roll-off in frequency domain (spectral containment).
- Spectral and temporal behavior is adaptable per sub-band. This enables the system to be highly flexible for meeting the diverse needs of the multitude of service and device characteristics.
- The OFDM signal structure can be fully maintained, thus matches any frame structure that is defined based on classic OFDM symbols.
- Complex field signaling as in OFDM: All TRX schemes used in OFDM can be applied without any modification required.

However, there are some issues worth mentioning:

- For short bursts, tails are needed, which means overhead (typically about the same as CP in OFDM).
- Higher base band transceiver complexity, but in the same order of magnitude as OFDM.

2.3.3 Main air interface candidates

The four identified main candidates from METIS are OFDM / SC-FDMA, zero-tail DFT spread OFDM, FBMC, and UFMC. The research and discussion on these main candidates are still ongoing at the writing of this document.

2.4 Technology components addressing concept needs

This section is dedicated to the analysis of the most promising Technology Components (TeCs) investigated in METIS so far. Note that this analysis is preliminary, since there is lots of research activities not completed yet, but it at least provides a good glimpse of the overall picture in METIS.

The description is made following the different layers in the radio protocol stack. Therefore, we will start with the physical aspects going up until the network management and the spectrum usage.

2.4.1 Air interface

The unified air interface design cluster (WP2-TeCC1, see Section B.2.1) goes into the direction of TDD mode and dynamicity of the system including UL/DL ratios and also the configuration of the OFDM including the possibility of making some changes for the continuous phase modulation to reduce the PAPR and device battery consumption. In this sense, METIS foresees for the 5G timeframe coexistence of FDD and TDD modes, although TDD may gain momentum due to its higher flexibility and the fact that the traffic is still highly asymmetrical with higher data volume (five times) in the downlink.

METIS has also dedicated significant effort towards the integration of the MN concept into the system. Concerning the radio interface, solutions on how to estimate the channel status and on increasing the reliability are on track, unless further research on the integration of MN into the frame structure is needed.

Concerning the integration of new waveform and multiplexing schemes (WP2-TeCC8, see Section B.2.2), and to sum up the analysis made in Section 2.3.2, UFMC reduces the need for a priory synchronization and is built up from a conventional OFDM signal. This fact makes this solution easily adaptable to LTE and has huge potential for M-MTC. Therefore, although FBMC has other benefits, we believe that the main focus among the two should be placed on UFMC. Moreover, we need to stress that OFDM could be well adapted to different requirements in the different scenarios by adapting some of its parameters (CP length and subcarrier spacing). A dynamic OFDM configuration is also a good candidate for the evolution of the air interface.

Finally the Non-Orthogonal Multiple Access (NOMA) concept is also playing an important role in the METIS research on the radio interface (WP2-TeCC11.1 and T3.2-TeC8, see Section B.2.3 and Section B.3.9, respectively). NOMA uses the concept of Successive Interference Cancellation (SIC) and superposition coding for the multiplexing of users. METIS research has demonstrated a 30 % efficiency gain that makes the most of the different radio conditions in a cell. In this sense, it seems that these kinds of techniques are more adequate for big cells in which the user diversity is more significant.

2.4.2 Massive MIMO

In massive MIMO we see a very large antenna array at each base station and in general an order of magnitude more antenna elements as compared with conventional systems. Massive MIMO can be used for a more efficient backhaul wireless link or even for the access link, in which a large number of users are served simultaneously. Here, massive MIMO is interpreted as multiuser MIMO with lots of base station antennas.

Concerning the usage of massive MIMO for the backhaul link, METIS has proposed a simplified precoding scheme (T3.1-TeC1b, see Section B.3.1) for mm-waves especially suited for UDN. This low complexity system called Discrete Fourier Transform based Spatial Multiplexing (DFT-SM) with Maximum Ratio Transmission (DFT-SM-MRT) allows that the data streams are either mapped onto different angles of departures in the case of aligned linear arrays, or mapped onto different orbital angular momentums in the case of aligned circular arrays. Maximum ratio transmission pre-equalizes the channel and compensates for arrays misalignments. This proposal has demonstrated a spectral efficiency 166 higher than mm-wave SISO.

On the other hand an energy-efficient beamforming scheme in TDD mode to provide backhauling to moving nodes is also of huge interest (T3.1-TeC6, see Section B.3.2). The idea of this new scheme, called Polynomial Interpolation (PI), is that an array of aligned predictor antennas, placed upon the roof of the vehicle periodically sends pilots to the BS, to provide a very dense pattern of channel measurements in space. The BS interpolates the measurements to predict the channel between the BS and the receive antenna, accurately. With this solution the amount of power radiated by the base station decreases and boosts robustness to speeds from 0 to 300 km/h.

Concerning the use of massive MIMO for the access link, two contributions brought out, T3.1-TeC7: Massive MIMO transmission using higher frequency bands based on measured channels with CSI error and hardware impairments (see Section B.3.3) and T3.1-TeC11: Heterogeneous multi-cell, MU Massive-MIMO, massive SDMA (see Section B.3.4). T3.1-TeC7 proposes novel precoding and compensation methods so as to satisfy the requirements for massive MIMO using higher frequency bands. On the other hand, T3.1-TeC11 proposes to include in the system the feedback of the information about the interference situation experienced by users. Then Regularized Zero-Forcing (RZF) precoding can be used where the idea is that inter-stream interference is only reduced to the same level as the already existing inter-cell interference. To keep the additional feedback overhead low we propose to use a wideband power value per user. A seven times gain compared to the LTE-A baseline scenario regarding the median value of the sum spectral efficiency is observed by utilizing this proposal, that is only feasible for the TDD mode. Again, this transmission mode outperforms FDD mode due to its capability to better estimate channel state.

2.4.3 Advanced inter-node coordination

Advanced inter-node coordination tends to joint processing concept in which distributed antennas in both transmit and receive side are used to get rid of interference. Backhaul constraints and system overheads are the main challenges to make the most of this concept. Advanced inter-node coordination is a fundamental part of the METIS research.

Joint processing is part of a broader concept, Coordinated Multi-Point transmission and reception (CoMP), which is already incorporated into 4G, but its operation is restricted to transmitters in a single site. In this sense, METIS extends existing concepts to transmitters in multiple locations, mostly thanks to the advances in wireless backhauling and fibre intensive deployment. Of course, for this clustering is a must, and some good proposals in METIS try to give an answer to the optimum configuration of these clusters (T3.2-TeC7, see Section B.3.5).

Concerning the performance of network MIMO, METIS is working towards improving performance thanks to interference capabilities of UEs assisted by the network that provides interference information or transmission points coordination (T3.2-TeC12, see Section B.3.6).

Architectures must evolve towards the support of network MIMO-like coordination with the final target of a cloud radio access network that allows for a flexible configuration of both ends in the communication link.

The integration of network MIMO with massive MIMO is also in the scope of METIS, since both ideas could be combined in an efficient manner to enhance interference mitigation and ensure improved overall performance. (T3.2-TeC13, see Section B.3.7).

2.4.4 Multi-hop communications

Multi-hop relaying in cellular networks, with the direct intervention of the infrastructure, is an intrinsic part of the METIS vision of 5G. Multi-hop communications are to change the way connections are established, combining the traditional centralized schemes of connectivity with D2D communications.

According to METIS studies, multi-hop communications increase spectrum efficiency, fairness, and reduce transmit power. Moreover, METIS foresees that, in order to further enhance spectrum efficiency, the wireless backhaul and wireless access might share the same spectrum. T3.3-TeC2 (see Section B.3.10) investigates low complexity sub-optimal algorithms for sharing and coordinating the resources among the backhaul and the access network. In particular, solutions are proposed to route data from simultaneous users through the mesh to one or several access gateway, reaching an increase by a factor of ten in the spectrum efficiency by enabling usage of available spectrum in the 60 GHz area and an unprecedented densification of wirelessly connected access nodes.

On the other hand, buffering could be applied in the relay nodes, allowing a virtual full duplex communication in a network where two relays allow for concurrent transmissions with inter-relay interference cancellation (T3.3-TeC3, see Section B.3.11).

Finally, it is worth highlighting that METIS is investigating how to integrate wireless network coding in conventional cellular systems. At this stage, some practical multiple access schemes used in conjunction with wireless network coding are proposed to create a NOMA effect (T3.3-TeC5). Considering that this TeC is in an early research phase, it is hard to ensure its future integration in the METIS system evaluation phase.

2.4.5 System aspects

D2D is a main component and integration with the system is thoroughly investigated in METIS. Indeed, D2D communication is a great means to reduce latency and increase throughput with the use of opportunistic caching. Thanks to the higher availability of nodes, link distance is hugely reduced which entails better performance and lower power consumption. In this sense several TeC are proposed to switch the transmission mode (from D2D, to cellular-based) in a distributed manner (T4.1-TeC3-A1, see Section B.4.1) or to allocate resources for its usage in the D2D link (T4.1-TeC4-A1, see Section B.4.2).

Another main challenge of the METIS concept is the densification of the network. In this framework, UDN also requires coordination between transmitters. In this sense, the concept of supercells (T4.1-TeC10, see Section B.4.6) and dynamic clustering (T4.1-TeC9, see Section B.4.5) aims at providing better performance (increase in average throughput by a factor of approximately two with dense networks consuming the same amount of power).

Another aspect of interest in METIS is context awareness understood as the capability of the network and the UEs to know where the UEs are, other users in the vicinity, and what resources are nearby. Context awareness in METIS is applied to mobility management (T4.2-TeC2 and T4.2-TeC5-A1, see Sections B.4.7 and B.4.8, respectively) to scheduling (T4.2-TeC9-A2, see Section B.4.9) and to the optimum management of an increased number of machines (T4.2-TeC12, see Section B.4.10).

Finally, moving network integration in the system (T4.3-TeC3-A2, see Section B.4.12) and energy efficiency using dynamic switching off of base stations (T4.3-TeC5, see Section B.4.13) are also of interest in the research related to the system design.

2.4.6 Spectrum usage

It is envisaged in the future that a complex landscape of spectrum availability and access will emerge where multiple frequency bands, subject to different regulations including various forms of shared spectrum, are expected to be available to wireless communication systems. In METIS, relevant future spectrum access modes and sharing scenarios are identified, described and analysed with regard to the technical requirements for 5G system design. Additional spectrum is expected both below and above 6 GHz, although most of the spectrum will be in the mmW bands. A number of technology components for spectrum access are introduced, enabling the needed flexibility and efficiency in making the best out of available spectral resources. Of special relevance is the research dealing with spectrum sharing with D2D communications (WP5-TeC14, see Section B.5.2) where up to 4.5x gain in spectral efficiency is expected.

One key concept in this future spectrum landscape is the spectrum sharing toolbox and the corresponding components which are detailed in [MET14-D52].

2.5 Preliminary conclusions of architectural analysis

To get an overview of the architecture big picture, the HTs have been broken down into well-defined Building Blocks (BBs). With respect to the methodology description in Section C.1, this top-down BB analysis is half completed. Different display formats of the HT concepts as elaborated in [MET14-D62] have been harmonized. Looking to the HT specific BB depictions from overarching point of view the high level view shown in Figure 2.4 can be drawn.

From functional point of view the METIS system can be decomposed into:

- *Network Management* where all blocks that cover network overarching functionalities are arranged;
- *Radio Node Management* containing the BBs that provide radio functionalities that affect more than one node;
- *Air Interface* that includes all the functions that are directly related to air interface functionalities of radio nodes and devices;
- *URC Reliable Service Decomposition* as well as *Ultra Dense Network Extension* belongs to horizontal specific overarching BBs.

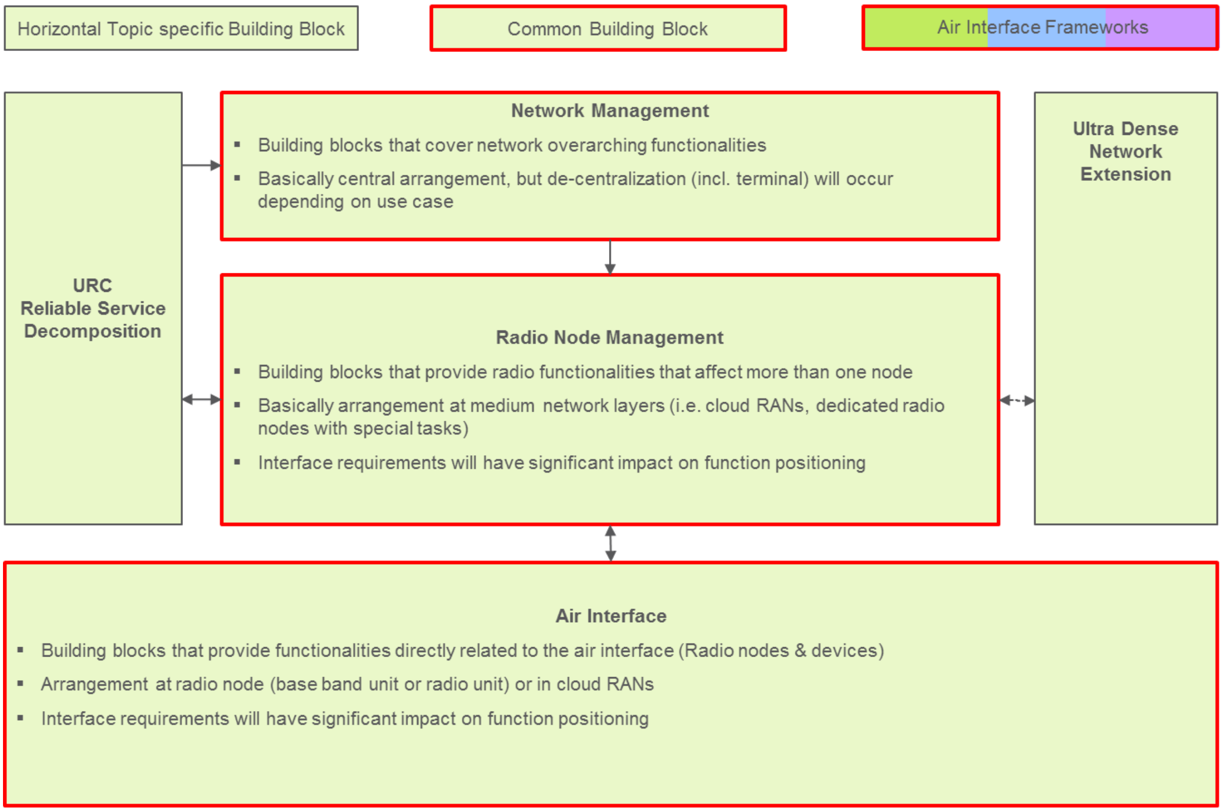


Figure 2.4: Overall functional architecture at high level.

A first estimate of the arrangement of functionalities within the Radio Access Network (RAN) can already be done by assuming that:

- Network Management functions will be usually centrally positioned. But depending on certain use cases de-centralization of functions may happen.
- Radio Node Management functions will be arranged at medium network layers, e.g. at location of Cloud-RANs (C-RANs) [NGMA13] or dedicated radio nodes with special tasks. Especially in this case the performance of the network will heavily depend on the properties (throughput and latency) of the interfaces. Hence in this case careful investigation of the interface requirements is needed.
- Air Interface functionalities are located at radio nodes or in C-RANs. An in-depth investigation of interface requirements is needed here as well.

Figure C.2 to Figure C.6 can be assembled to Figure 2.5. Air Interface (AI) frameworks for MN, URC and M2M have been identified. If the assignment of TeCs to the different main BBs is completed some more frameworks may become visible.

There are several common BBs, building blocks, that appear mainly in *Network Management* and *Radio Node Management*. Most HT specific BBs emerge in the *Air Interface*.

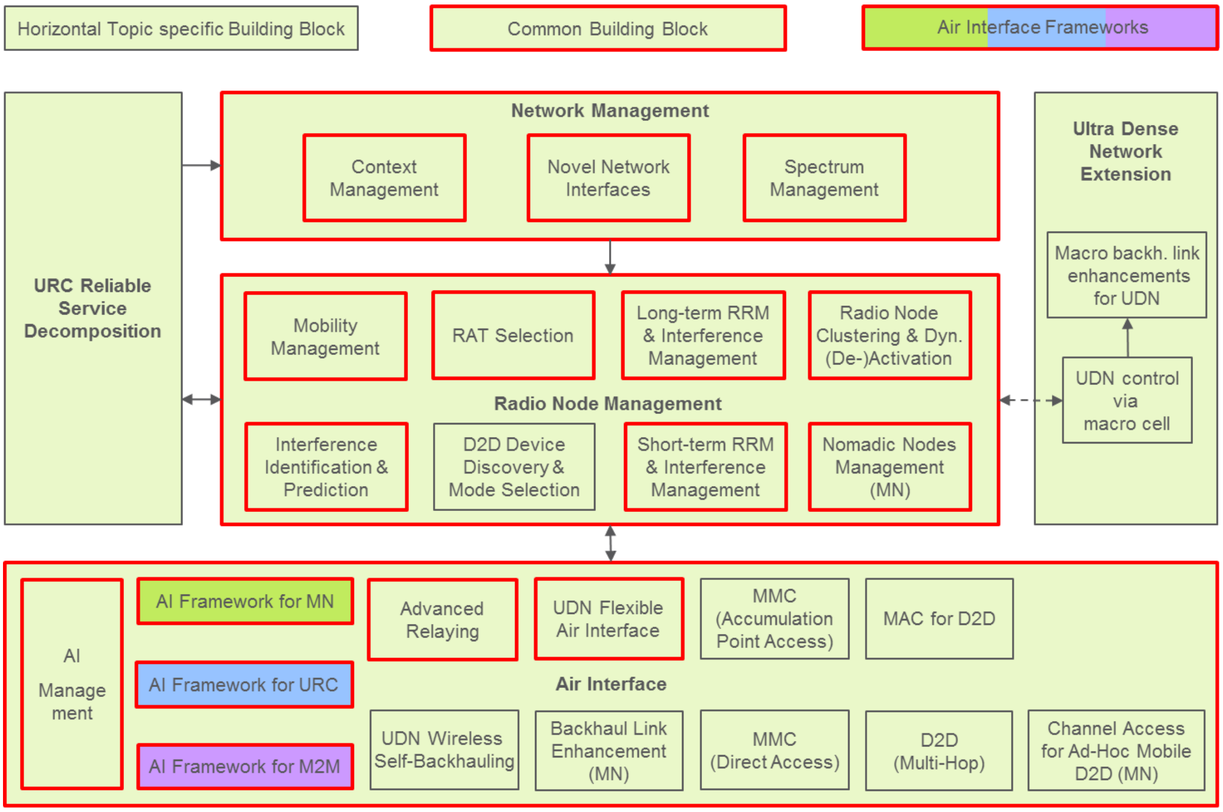


Figure 2.5: Preliminary view on overall building blocks.

3 Contributions of the horizontal topics to the METIS goals

This section presents a first set of simulations conducted in METIS for the evaluation of the impact of the different horizontal topics on the METIS goals. Each HT is evaluated in a separated manner. Cross effects are at this stage not evaluated. This will come in the final evaluation of the METIS system concept in D6.5.

3.1 Direct Device-to-Device (D2D)

Direct Device-to-Device communication is one of the key enablers for the 5G system concept. It addresses the goals of 1000x data volume, 10-100x user data rate, 5x reduced E2E latency and energy efficiency.

METIS goals addressed by D2D	
✓ (green)	1000x data volume
✓ (green)	10-100x user data rate
	10-100x number of devices
	10x longer battery life
✓ (green)	5x reduced E2E latency
✓ (green)	Energy efficiency and cost

Intermediate system level evaluation has been performed for D2D-N type of use case (traffic offloading for non-critical user data) in METIS Test Case 2 (TC2) [MET13-D11]. 50 % of the users are assumed to be D2D users and 50 % cellular users. Users forming a D2D pair must be within 50 meters from each other.

The content of the D2D transmission is assumed to be local, i.e. either generated locally in the UE or cached opportunistically earlier. When transmission opportunity occurs, content is always assumed to be available (full buffer traffic).

The technical component “Further enhanced Inter-Cell Interference Coordination (ICIC) in D2D enabled HetNets” (T4.1-TeC15 [MET14-D42]) is applied and tuned for the 5G deployment setting. The motivation is that in TC2 there is lot of potential inter-cell interference which can be greatly reduced by time and frequency domain ICIC techniques, especially by coordinated muting (e.g. blank or almost blank subframes). This on the other hand creates new transmission opportunities for local D2D communication both with and without opportunistic caching. In the evaluated technique, UEs of a D2D pair do measurements during muted subframes of controlling macro BS. If a Small Cell (SC) is not detected nearby, the D2D pair can be allocated resources within those muted resources for their communications, otherwise unmuted resources are used.

A quasi-static TDD system simulator is used. Both downlink and uplink directions are simulated at the same time during one simulation run. In the reference case, D2D is able to use macro cell UL resources only, and we compare that to the case where D2D is able to use also micro cell UL or DL resources with and without Reference Signal Received Power (RSRP) restriction (RSRP to nearest small cell). A more detailed description of the simulation setup is presented in Section A.1.

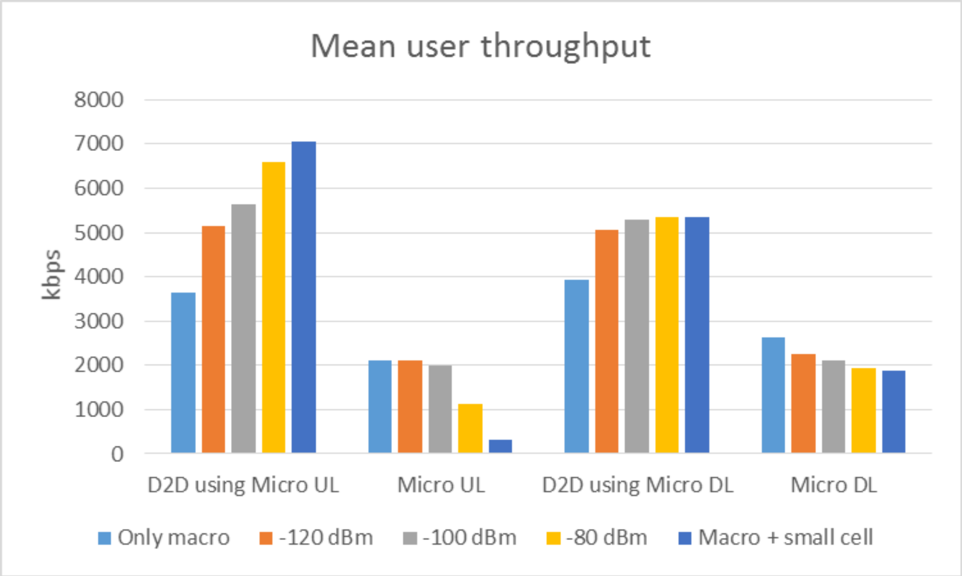


Figure 3.1: Mean user throughput for different allocation configurations and RSRP thresholds.

In Figure 3.1 mean D2D and cellular throughput in micro-cells is shown for different configurations. Figure 3.2 shows the gain on mean D2D UE throughput versus the corresponding loss in mean cellular UE throughput in small cells (due to the increased interference from D2D users).

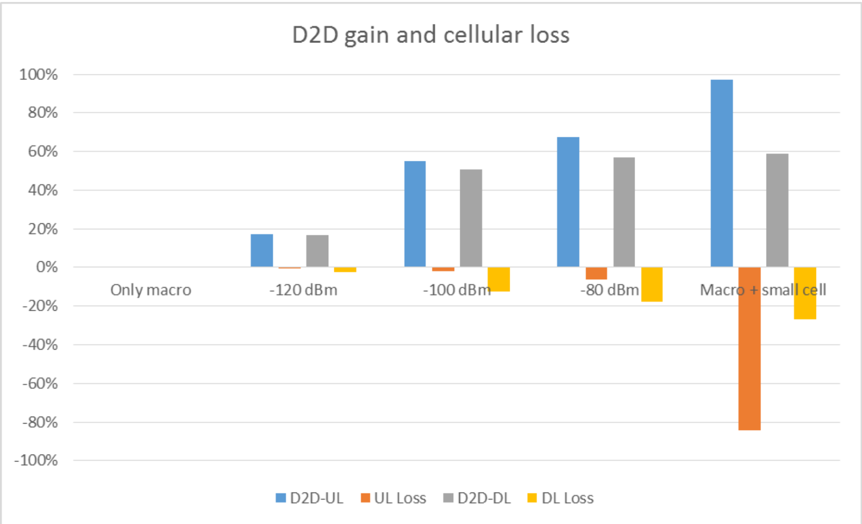


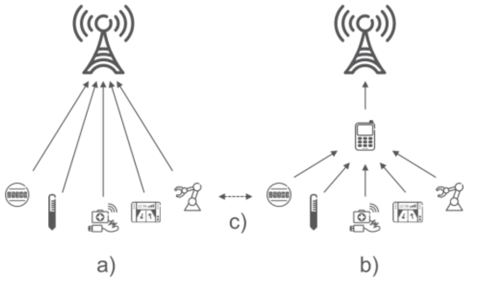
Figure 3.2: Gains and losses when using D2D with UL resources (D2D-UL) or with DL resources (D2D-DL).

From the results it can be observed that taking into use the resources reserved for small cell can lead to substantial throughput/capacity gain for D2D UEs. With properly selected safety distance, this can be done with negligible impact on small cell throughput. The exact gains depend on the scenario (in particular the density and coverage of the small cells). For downlink, the gains are much smaller. It is seen that the best overall gains are achieved with quite tight RSRP restrictions for D2D communication – around -80 dBm. These results can be used to balance the trade-off between cellular and D2D performance.

3.2 Massive Machine Communication (MMC)

The Massive Machine Communication, MMC, addresses the expected massive increase in number of machine devices and to improve the battery life for these machine devices at similar cost and energy efficiency. These addressed METIS goals are highlighted in green to the right. The envisioned MMC radio accesses are:

METIS goals addressed by MMC	
	1000x data volume
	10-100x user data rate
	10-100x number of devices
	10x longer battery life
	5x reduced E2E latency
	Energy efficiency and cost

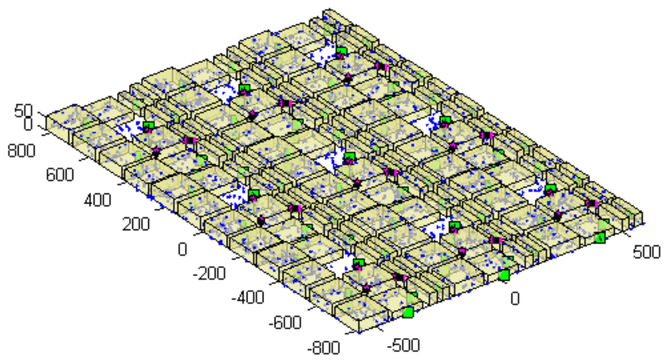


a) Direct access;
b) Accumulation point access; and
c) M2M access.

These MMC radio accesses are illustrated to the left and are also described in Section 2.1.1.

An intermediate MMC system evaluation has been performed where the direct access, MMC-D, and the accumulation point access, MMC-A, was considered. The evaluated technique is to enable regular sensors to also serve as relays. A careful selection of sensors to serve as sensor-relays by the system should enable more devices to communicate. It should also enable longer battery life for sensors with bad coverage, as they no longer need to use the same amount of power to communicate. The simulation methodology and results are presented below. Note that each user in the simulations represents several sensors. In Section A.2 a more detailed intermediate system evaluation of MMC is given.

The evaluation has been conducted in both downlink and uplink, on either 20 MHz or 500 MHz bandwidth for each macro, micro and sensor-relay station using full buffer traffic. The area of interest, illustrated to the left, is dense urban with buildings (yellow), streets and parks (white), macros (pink), micros (green) and sensors/users (blue). The network decides which sensors that are allowed to act as sensor-relays based on their current path loss values and if they are able to provide coverage for another sensor. The 20 MHz bandwidth simulation results are presented below, as those are similar to the baseline given in [MET13-D61], while the 500 MHz results are presented in Section A.2.3.2.



In Figure 3.3 the experienced user throughput at various loads are presented for the legacy system and the sensor-relay system in both downlink and uplink at 20 MHz bandwidth. As parts of the uplink results in Figure 3.3 are hidden by the legend these results are also given in Figure A.13, in Section A.2.3.1, without the legend.

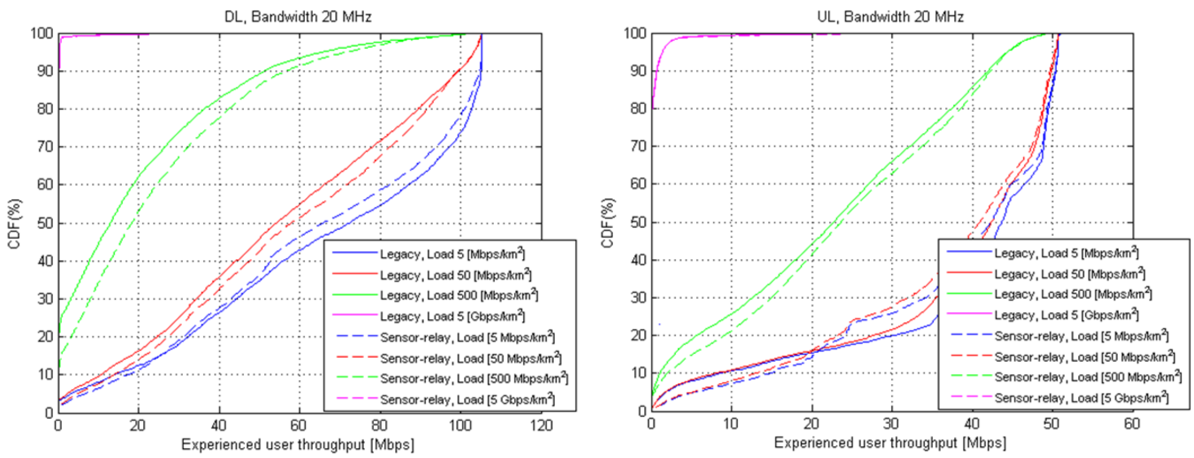


Figure 3.3: Experienced user throughput in downlink (left figure) and uplink (right figure) of the legacy system (solid lines) and the sensor-relay system (dashed lines) at 20 MHz bandwidth and various loads.

Figure 3.4 shows the 5th percentile experienced user throughput as a function of the total served traffic in the legacy system and the sensor-relay system in both downlink and uplink at 20 MHz bandwidth.

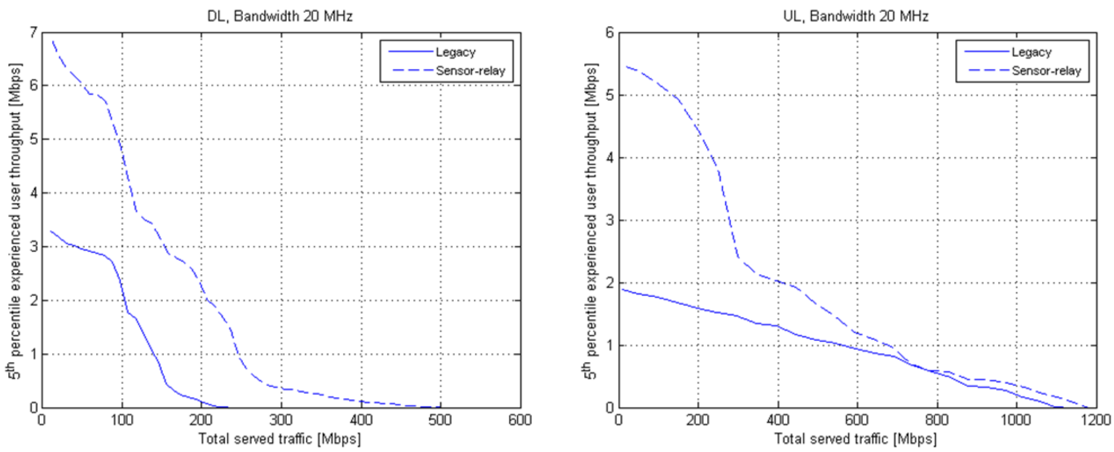


Figure 3.4: The 5th percentile experienced user throughput, as a function of the total served traffic, in downlink (left figure) and uplink (right figure) of the legacy system (solid line) and the sensor-relay system (dashed line) at 20 MHz bandwidth.

In the sensor-relay system higher experienced user throughputs are attained, both in downlink and uplink, at the lower percentiles, compared to the legacy system, see Figure 3.3. At higher percentiles other devices may experience reduced performance.

The sensor-relay capability improves the 5th percentile experienced user throughput. The improvement factor is somewhere between two and three at lower total served traffic, see Figure 3.4. At higher total served traffic the factor increases in downlink while it decreases in uplink.

It is essential for the system to select sensor-relays wisely in order to avoid significant performance degradation. If the system is able to do so, it then can make good use of all available sensors by selecting the ones that currently are in the best positions to serve as sensor-relays, e.g. those that both can provide good coverage and have access to electricity. Some additional intermediate system evaluation of MMC conclusions are provided in Section A.2.4.

3.3 Moving Networks (MN)

The horizontal topic on Moving Networks, MN, focuses on enhancing existing solutions as well as developing novel technology components in order to improve the mobility management and connectivity of moving terminals and moving/nomadic networks. The overall METIS technical goals addressed by this HT are:

- 1000 times higher mobile data volume per area,
- 10 to 100 times higher typical user data rate,
- 5 times reduced E2E latency.

METIS goals addressed by MN	
✔ (addressed)	1000x data volume
✔ (addressed)	10-100x user data rate
✔ (addressed)	10-100x number of devices
	10x longer battery life
✔ (addressed)	5x reduced E2E latency
	Energy efficiency and cost

The main challenge of this HT lies in the fact that the HT addresses a broad and very diverse range of applications and requirements. In this context, the HT MN organized the research activities with respect to moving/nomadic networks into three main clusters and four mobility aspects [MET14-D62]. More specifically, the three clusters are:

- ***Cluster #1:*** Mobility-robust high-data rate communication links for mobile terminals and moving relays to enable broadband as well as real-time services.
- ***Cluster #2:*** Flexible and demand-driven network deployment based on nomadic network nodes.
- ***Cluster #3:*** V2X communications to enable reliable and low-latency services such as traffic safety and traffic efficiency.

Whereas, the four mobility aspects are:

- ***Mobility Aspect 1:*** Link level performance in mobile channels.
- ***Mobility Aspect 2:*** Handover and cell reselection.
- ***Mobility Aspect 3:*** Management of nomadic and moving cells.
- ***Mobility Aspect 4:*** Enablers of mobile D2D.

This section aims at presenting a summary of the intermediate system evaluation of the MN concept made so far in METIS. In order to isolate other effects, here the link level performance is of maximum simplicity, and all the focus is on two main techniques that envelops the three main concepts: mobile relaying for the increase of robustness (cluster #1), and opportunistic caching based on V2X communications for the flexible and on-demand support of the overlay network (clusters #2 and #3). The evaluation is conducted through system level simulations in the TC2 deployment.

For opportunistic caching, we assume that popular contents can be cached offline by cars. During normal operation of the vehicle, cached contents are forwarded to the car passengers or to other pedestrians. The communication between the vehicle and the final destination of the content will happen via direct V2X communications in a separate band (5 GHz band), without passing through the network that will only assist the final destination in the identification of the most appropriate caching point. The performance of the V2X link is the same as LTE-A.

Cars can also operate in relaying mode only for their passengers, similarly to the Closed Subscriber Group (CSG) concept. Thanks to relaying, vehicle penetration losses are avoided and the reception chain increases, due to the better characteristics of the antenna and the receptor in the vehicle. Within the car, a small cell forwards the data to the final destination. The mobile relay operates in a separate band in full duplex mode, that is, is totally transparent for the network point of view that treats the vehicle small cell like a regular user.

Figure 3.5 shows a conceptual illustration of the two mechanisms that the MN concept brings to the METIS system. Mobile relaying is represented in the upper part where a relay placed in a car serves multiple users inside the car, and has a link to a base station. In the lower part, a pedestrian user receives contents cached in the car through connection to a D2D transmitter placed in the car.

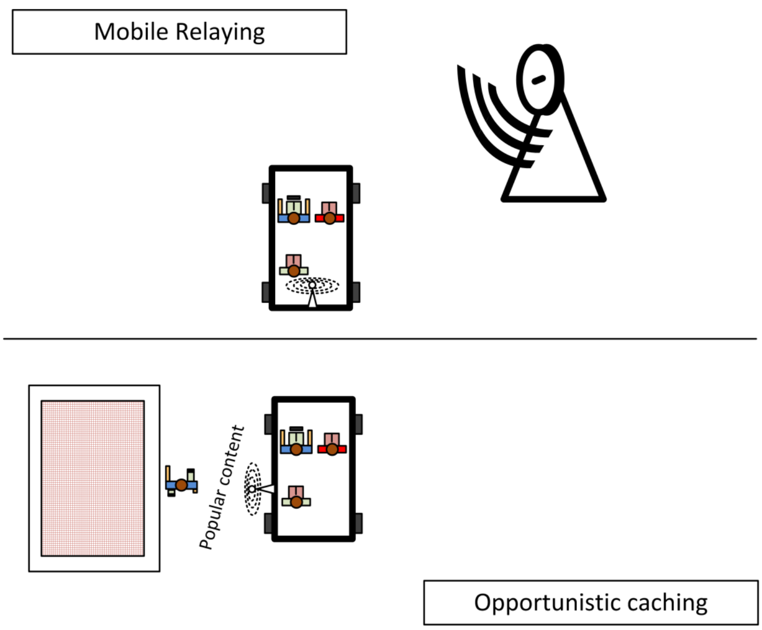


Figure 3.5: Concepts involved in the Moving Network horizontal topic. Mobile relaying is represented in the upper part and opportunistic caching in the lower part.

The number of users and traffic load considered in the simulations of the legacy system have been calculated based on the requirements for beyond 2020 system in Table 9.6 of [MET13-D61] and the METIS goals for beyond 2020 system, that are relative to legacy system performance. In Table 9.6 of [MET13-D61] it is indicated the number of users in TC2 scenario, together with the packet size and reading time for each type of traffic (Bursty User Driven (BUD), Video Traffic (VT), Bursty Application Driven (BAD) Real Time (RT) or BAD Non Real Time (NRT)) and different location (car, park, sidewalk, traffic light or bus stop). Specifically, the number of outdoor users in TC2 is 13000. Packet sizes are 20 Mega Bytes (MB) for BUD, 0.125 MB for BAD RT, 2 MB for BAD NRT and VT presents different sizes depending on the location of the user.

The METIS goals for beyond 2020 systems that we consider in this study are: 10 times more users, 100 times more traffic load and 5 times less latency compared to the legacy system.

Therefore, in the legacy system we simulate 1300 outdoor users (13000/10) with packet sizes 100 times lower than those in in Table 9.6 of [MET13-D61]. That is, 200 kB for BUD, 1.25 kB for BAD RT and 20 kB for BAD NRT.

To evaluate the performance of the legacy system, it has been considered 20 MHz bandwidth for macro-cells and 80 MHz for micocells.

Simulations have proven two positive effects of caching. First, caching reduces E2E latencies of cached users. This reduction increases with smaller packets, that is, when the non-radio-transmission delay is more relevant over the whole E2E latency. With just 20 MHz allocated to caching, users experience a latency for BAD RT packets in the order of that experienced in the legacy system (with packets 100 times smaller).

The second positive effect of caching, as proposed in this assessment, is the offloading of traffic. About one fourth of the users are offloaded from the macro and micro layers. With the traffic type distribution and caching probabilities of each traffic type, about one half of the traffic load is offloaded.

Results show that, with the expected increase in the traffic load, the cellular system should increase its allocated bandwidth up to 4 GHz. As compared with the legacy situation, with 100 MHz allocated, that means an increase of 40 times in the available bandwidth. Although this increase seems (and is) huge, we should take into account that the amount of traffic has increased 1000 times and the reduction from a 1000 to 40 factor is due to the benefit of caching and mobile relaying together with the fact that the legacy solution could support additional traffic before getting congested.

3.4 Ultra-Dense Networks (UDN)

METIS goals addressed by UDN	
	1000x data volume
	10-100x user data rate
	10-100x number of devices
	10x longer battery life
	5x reduced E2E latency
	Energy efficiency and cost

The horizontal topic Ultra-Dense Networks, UDN, focuses on access node densification far beyond today's networks. Actually the investigated components should enable unlimited density of nodes in very sophisticated three dimensional deployments. The UDN is the main METIS horizontal topic capable to accommodate future traffic increase coming from the human centric services and one of the enablers for future frequent usage of new cloud services. The massive traffic uptake foreseen for 2020 and beyond comes also from increased expectations related with experienced data rates independent from the user location. HT UDN is going to provide solutions for network densification up to the level of sufficient network capacity envisioned for 5G systems. The overall METIS technical goals addressed by HT UDN with highest priority are:

- 1000 times higher mobile data volume per area,
- 10 to 100 times higher typical user data rate,

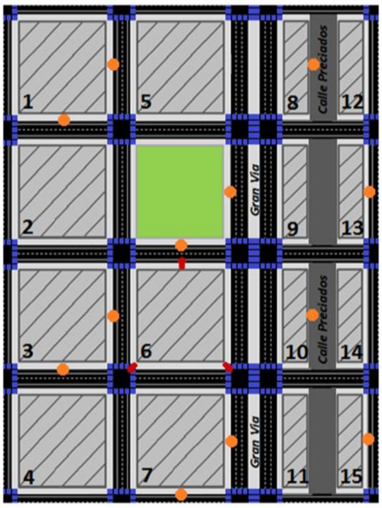
Additional goals for HT UDN are addressed indirectly as:

- 5 times reduced E2E latency; a requirement for achieving high data rates from e.g. TCP-IP internet protocol.
- Energy efficiency and cost; a key KPI for evaluation of UDN components and driver for UDN related functionalities such as dynamic networks clustering and (de-)activation or wireless backhaul mechanisms for flexible UDN deployments.
- On top of these main objectives, HT UDN has identified additional goal related with enabling a better exploitation of under-utilized spectrum.
- The analysis of technical components investigated by METIS partners and METIS test case analysis result in following UDN concept proposal.

UDN-Core concept described in [MET14-D62] is a stand-alone system optimized for dense deployments and features such as:

- Scalable frame structure for cm and mmW (3.5 to 90 GHz) based on flexible UL/DL slot allocation in TDD mode optimized for short ISD between nodes.
- Different approaches for waveforms based mainly on OFDM modifications like CP-OFDM, UFMC, etc.
- Efficient mechanisms for small cells automated clustering and initial network setup, combined with components offering fast and dynamic node (de-)activation dependent on local traffic volume.
- Short and long term radio resource and interference management, supported by interference identification techniques, novel approaches for user mobility and network discovery in ultra-dense deployments
- Efficient self-backhauling/relaying techniques offering high resource reuse ratio for simplified and rapid deployments.

The final concept is a stand-alone system suitable for indoor and outdoor UDN deployments with limited ISDs up to few hundred meters. Its key functionality besides enabling highly spectrum efficient and resource flexible PHY is the ability to create self-configurable networks that are fully aware of closest dynamic environment. Additional enablers for new spectrum management are necessary to provide sufficient bandwidth dedicated to particular UDN network. Used technology components have also high importance for D2D, MMC and URC-L concepts and relate directly to top two METIS goals addressed by HT UDN.



The keystone component for UDN Core, UDN-C, and concept is a WP2 *TeCC#1 Unified Air Interface* and for this purpose it is taken for further system level evaluation. The work in WP2 is mainly conducted by link level analysis and it requires additional work to perform system level evaluation. For this purpose we define a UDN scenario based on TC2.

From HT UDN perspective the biggest challenge is related to the indoor environment where most of the traffic is generated. The HT UDN evaluation is conducted for an exemplary building defined in TC2. KPI's evaluation process assumes two aspects to be verified.

The first aspect is related directly with network densification where for this purpose number of nodes in the simulation scenario is gradually increased by factor of two and four, reaching one node per room on average. The second aspect of the study is related with verification of the WP2 TeCC#1 and its ability to fulfill METIS goals jointly with the same density factors as in part one. The key elements improving overall UDN network performance in this evaluation are related to flexible UL/DL resource allocation dependent on the local traffic, reduced TTI length to 0.25 ms and capability of using wide spectrum bands.

Achieved results imply, that with expected traffic growth the nodes densification and air interface based on new TDD frame structure is capable to directly meet TC2 required KPIs for experienced user data rate (300 Mbps for DL and 60 Mbps for UL with 95 % availability). Provided results indicate significant decrease of packet delay when the new air interface is introduced. Additional spectrum, 40 MHz in TDD mode in total, is needed to achieve TC2 KPIs, although evaluation results suggest that by careful adjustment of scheduler settings lower value may be sufficient.

3.5 Ultra-Reliable Communication (URC)

The overall METIS technical goals addressed by HT URC are:

- 10 to 100 times higher number of connected devices: URC through the reliable service decomposition can provide mechanisms for graceful degradation of rate and increase of latency, instead of dropped connections, as the number of users increase.
- 10 times longer battery life for low power devices: URC can provide beneficial for low power devices in disaster applications.
- 5 times reduced E2E latency: URC can provide reduced end to end latency in real-time applications.

METIS goals addressed by URC	
	1000x data volume
	10-100x user data rate
✓ (addressed)	10-100x number of devices
✓ (addressed)	10x longer battery life
✓ (addressed)	5x reduced E2E latency
	Energy efficiency and cost

Based on the different requirements of reliability and availability, the problems dealt with in URC can be segmented into three cases as introduced in Section 2.1.4: URC over a Long term (URC-L); URC in a Short term (URC-S); and URC for Emergency (URC-E).

In this work, an evaluation of LTE network performance with respect to V2V and V2P communications is carried out in Section A.5, which shows the performance of legacy network when URC-S type of services is required. The system evaluation result indicates inefficiency of exploiting LTE network to enable URC-S type of services. Important factors related with system performance of exploiting LTE FDD for V2V and V2P communications are highlighted here. These factors demonstrate challenges of legacy network under the umbrella of URC-S type of services.

- Large number of users in downlink: since one packet generated at transmitter should be received by multiple receivers in the proximity of the transmitter, this number of receivers is quite large when a big radius of target communication area is under inspection. Above corresponding packet transmission procedure involves one packet transmission in uplink and multiple packet transmission in downlink. This huge traffic load in downlink introduces heavy traffic. Therefore, due to the traffic congestion in downlink, even though one packet can be transmitted in uplink to the serving eNodeB of transmitters, this packet may not be always successfully delivered to receivers in downlink. By exploiting some technology enablers, e.g. flexible Uplink/Downlink spectrum allocation and deploying UDN and MN, the severe situation in downlink can be mitigated.

- Coding and modulation scheme: the coding and modulation scheme is critical since it determines BLock Error Rate (BLER) of packet transmission with respect to a specified Signal to Interference-plus-Noise Ratio (SINR) value. In LTE, coding and modulation scheme is adapted to reach a target BLER value below 10 % which means the BLER of a specific link should be in the range between 0 % to 10 % and unsuccessful received packets need to be retransmitted with a HARQ scheme. In LTE FDD mode, the minimum delay between the end of a packet and the start of its retransmission is 7 ms. This delay component cannot be neglected due to the large value. Thus, in order to guarantee a required value of packet end to end latency, the number of packet retransmissions is required to be below a certain level. Therefore, using more robust coding and modulation scheme can help to decrease the number of retransmissions.
- Frame structure: taking into account of all delay components and the minimum retransmission delay of 7 ms, packets which are not successfully received by the first transmission attempt will have a larger value of latency. And these latency values cannot fulfill the strict E2E latency requirement of 5 ms for V2V and V2P communications. Thus, a flexible frame structure is necessary in order to decrease the minimum delay for packet retransmission.
- Scheduling algorithms: in current LTE network, scheduling algorithms aim at serving users with the consideration of cell capacity. However, instead of cell capacity, a high successful packet transmission ratio with tight latency requirement is the main challenge for URC-S type of services. Therefore, latency dependent scheduling algorithms should be inspected and developed in order to fulfill the small latency value and meanwhile offer a high successful packet transmission rate.
- Transmission technology: the transmission technology design is highly relevant for spectrum efficiency since it determines the number of resource blocks in both time and frequency domain required for one packet transmission. Therefore, transmission technology design with higher spectrum efficiency can offer URC-S type of service to a larger number of devices.
- Unicast transmission through eNodeB: since V2V and V2P communications require local information exchange between one transmitter and multiple receivers in the proximity, unicast transmission of packets through eNodeB is not as efficient as D2D transmission mode which only involves the transmitter and receivers in U-plane. Therefore, a D2D transmission mode offering a lower U-plane latency to V2V and V2P communications is considered as a key technology enabler for this special service. Note that D2D mode only benefits for this special service since transmitter and receiver locate in the proximity of each other. For other URC-S services without this character, e.g. transmitter and receiver are geographically separated, D2D mode may be not beneficial.

Above description shows the bottleneck of deploying LTE network to enable URC-S type of services and can be well illustrated and reflected by the simulation result in Section A.5. The main outcome of the simulations is that a LTE system, where packet transmission routed through network infrastructure, cannot satisfy the requirement of emerging V2X service. As a proposal, network controlled D2D communication is considered as a promising solution since the data transmission in user plane does not need to go through network infrastructure and therefore contributes to decreased end to end latency in user plane.

Even though above analysis is directly derived from evaluation of URC-S cluster, it also reflects key technologies used for enabling URC-L and URC-E type of services, especially services with strict requirement on low latency and high successful packet transmission rate.

4 Conclusions and future work

To achieve the goals of the METIS project this deliverable, D6.3, elaborates a revised system concept and intermediate system evaluation results.

The refinement of the METIS 5G system concept based on the grouping of the horizontal topics into three fundamental services: the extreme mobile broadband xMBB, massive machine-type communication, M-MTC, and ultra-reliable MTC, U-MTC, have been identified as fundamental services. These major services are provided through key enablers such as dynamic RAN, the spectrum toolbox, new lean signaling and control information, localized contents and traffic flows. The intermediate system architecture is structuring enablers into Building Blocks (BBs), horizontal topic specific BB structure, and finally an overarching high level view of the BBs as well as a high level overall functional architecture.

Promising technology components, TeCs, of an overall METIS 5G system concept have been identified. Note that this analysis is preliminary. For the radio interface the unified air interface design, new waveform and multiplexing schemes and non-orthogonal multiple access concept have been brought forward. Massive MIMO is a proposal that can be used to achieve efficient backhaul wireless links and for the access links. Advanced inter-node coordination can be used in both transmit and receive side to get rid of interference. Multi-hop communications enable connectivity with D2D communications in addition to the traditional centralized schemes. Other system aspects, such as densification via supercells and dynamic clustering, context awareness of the UEs positions, energy efficiency and moving network integration in the system are also investigated.

The horizontal topics have been evaluated in a dense urban setting where intermediate system evaluations have been conducted, each HT has been evaluated separately. D2D enables connectivity, reduced latency and improved spectral efficiency. The simulation results are addressing traffic offloading of regular user data, D2D-N, where throughput/capacity gains are obtained. The MMC evaluation has investigated the impact of enabling sensor-relays. The technique improves the coverage and can avoid draining the battery of such sensors. MN simulations are considering mobile relaying and opportunistic caching. As it turns out the mobile relaying is not useful in the studied dense urban setting as it is interference-limited. The opportunistic caching on the other hand reduces end-to-end latency of the cached users and also offloads the macro and micro stations which lead to reduced latency for their connected users as well. For core UDN concept a flexible UL/DL TDD air interface design has been investigated to show benefits from flexible resource allocation under conditions of increased network density and higher amount of available spectrum compared with legacy solution. The results regarding URC are addressing URC-S, and demonstrate the challenge and bottlenecks of deploying legacy network to provide URC-S type of services. In order to fulfill the requirement on strict E2E latency and high successful packet transmission rate for V2X communications, a network controlled D2D communication can be exploited. Taking into account of the fact that receivers locate in the proximity of transmitter, a D2D mode can provide beneficial here since user data transmission does not go through network infrastructure. Evaluation work also reflects that the URC goals cannot be achieved by simply changing a parameter in a system design, but to develop a crafted architecture taking all technologies into account from physical layer to other relevant higher layers.

In the future work we will for each test case, TC, select a set of TeCs, together with a deployment and functional architecture that allow reaching the KPIs defined in D1.1 [MET13-D11]. Extensive simulations of each TC will be made and compiled into the METIS final solution and performance evaluation in D6.5. This document, together with the final report on architecture, D6.4, and the final report on the METIS 5G system concept, D6.6, contains the output of the METIS 5G system concept and architecture development and evaluation.

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Annex A

A. Intermediate system evaluation of the horizontal topics

In Annex A the intermediate system evaluation of the horizontal topics within the METIS project is presented. The system evaluation is conducted on the Dense urban information society, TC2, that was defined in [MET13-D11]. Note that the aim of this deliverable is not to assess the twelve test cases described in METIS, [MET13-D11], but rather to compare the performance of the different HTs and to present a common view of the impact of the most relevant technology components presented in METIS so far. All test cases will be evaluated in D6.5 "Report on simulation results and evaluations". Concerning the choice of TC2, it was motivated by the fact that this test case has room for the operation of the five HTs and is also the most general test case used in the project. In TC2, the deployment is the 387 m x 552 m Madrid grid, illustrated in Figure A.1, which was defined in [MET13-D61]. In addition to the specified requirements and simulations guidelines in [MET13-D11; MET13-D61], path loss values for this setting have been obtained through ray-tracing and are available at [MET14-Web].

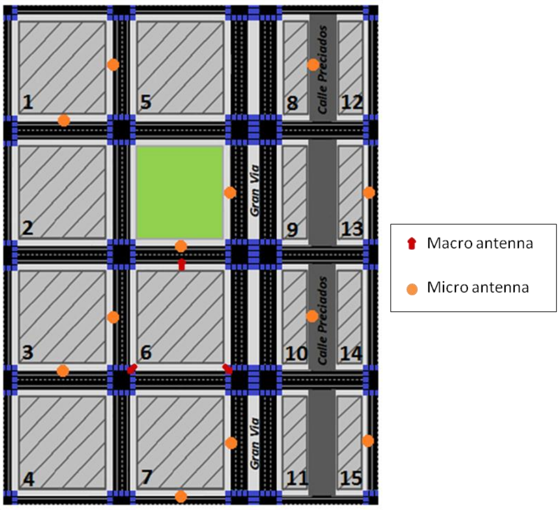

Figure A.1: The Madrid grid of the dense urban information society, TC2.

The intermediate system evaluation is presented in one section per horizontal topic. The horizontal topics are:

- Direct device-to-device, D2D,
- Massive machine communication, MMC,
- Moving networks, MN,
- Ultra-dense networks, UDN,
- Ultra-reliable communication, URC.

A.1 Intermediate system evaluation of D2D

This chapter evaluates one technical component for the horizontal topic D2D. This TeC contributes to the METIS objective of 10-100x higher data rates. D2D in general can shorten the E2E latency between the UEs as well as to act as enabler for new services.

A.1.1 Evaluated techniques

Interference control techniques similar to Further enhanced Inter-Cell Interference Coordination (FeICIC) in LTE Rel-11 will very probably be one of the essential elements also in 5G system. Here, we evaluate *Further enhanced ICIC in D2D enabled HetNets* (see T4.1-TeC15 in [MET14-D42]) applied and tuned for the Dense urban information society, TC2.

The motivation is that in TC2 there is lot of potential inter-cell interference which can be greatly reduced by time and frequency domain ICIC techniques, especially by coordinated muting (e.g. blank or almost blank subframes). This, on the other hand, creates new transmission opportunities for local D2D communication both with and without opportunistic caching.

In the evaluated technique, UEs of a D2D pair do measurements during muted subframes of controlling macro BS. If a Small Cell (SC) is not detected nearby, the D2D pair can be allocated resources within those muted resources (in addition to unmuted resources) for their communications, otherwise only unmuted resources are used.

A.1.2 Simulation methodology and assumptions

A quasi-static TDD system simulator is used. Both downlink and uplink directions are simulated at the same time during one simulation run.

METIS TC2 is used with Full Buffer traffic in both directions. 50 % of the UEs are assumed to be D2D users and 50 % use cellular communication. Users forming a D2D pair must be within 50 meters from each other. The content of the D2D transmission is assumed to be local, i.e. either generated locally in the UE or cached opportunistically earlier.

Four micro-cells from the original TC2 are considered. Specifically, those placed in the park limits (see yellow, orange, pink and brown markers in Figure A.2). The three Macro-cells in TC2 are simulated. Sixty users (devices) are considered in the simulations. See in Figure A.2 the distribution of cells and an example of the distribution of users over the simulated area.

It is important to point out that in this assessment the simulated area shown in Figure A.2 is assumed to be isolated, and there is no interference coming from outer cells.

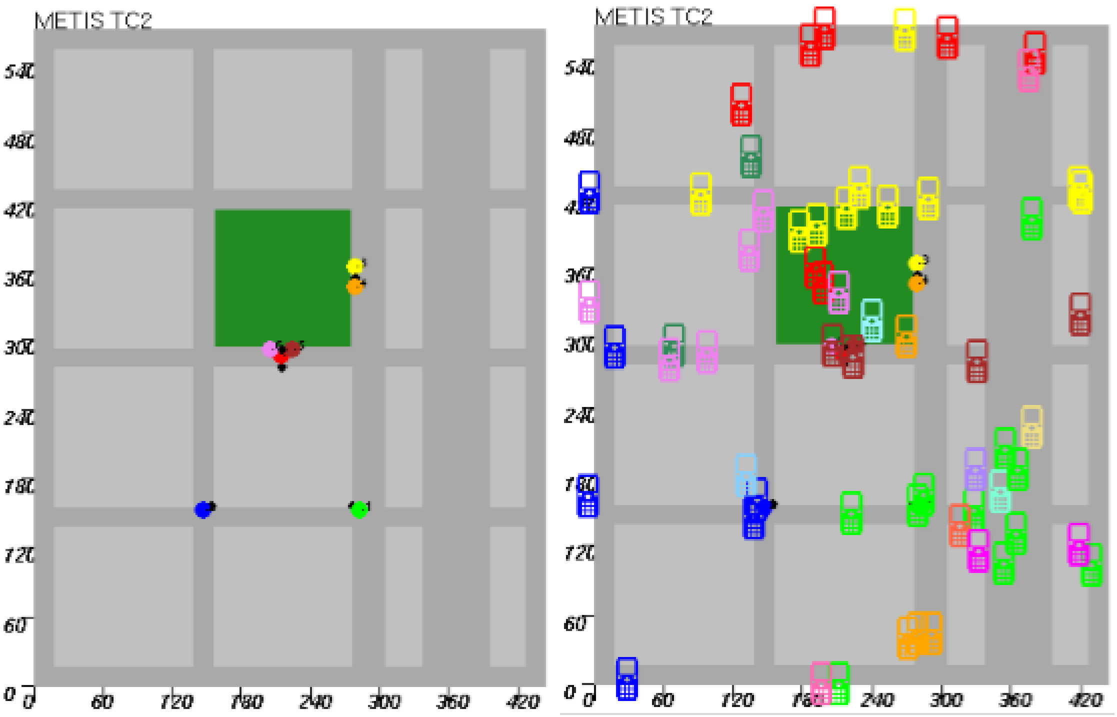

Figure A.2: Macro- and micro-cells with UEs (right figure) attached (colour of the UE shows the cell it is attached to).

Macro cell, small cell and UE transmit powers are 43 dBm, 30 dBm and 21 dBm, respectively. No power control is applied for the UE.

Macro and micro resources are separated in time as shown in Table A.1.

Table A.1: The separation of macro and micro resources.

Macro	D	U	D	U	-	-	-	-
Micro	-	-	-	-	D	U	D	U

The D2D can use three different resource configurations specified in Table A.2.

Table A.2: The specified D2D resource configuration.

D2D #1	-	X	-	X	-	-	-	-
D2D #2	-	X	-	X	-	X	-	X
D2D #3	-	X	-	X	X	-	X	-

The first configuration uses macro UL resources, the second one both macro and micro UL. Third configuration uses macro UL and micro DL. The configuration can be dynamically switched based on the RSRP measured by D2D terminals from the strongest micro cell with active links.

In the reference case macro UL resources were used for D2D communication. We compared this with using also small cell DL and UL resources for D2D when D2D UEs were further than a configured “safety distance” from nearest small cell. Distances ranging from -80 to -120 dBm (in terms of RSRP) were considered. Additionally, we used another reference case where the small cell resources were used without restriction for D2D UEs.

A.1.3 Benchmark plots

In this section, some basic plots are shown for verification and benchmarking purposes. Figure A.3 and Figure A.4 show the static RSRP plots the studied network area. Figure A.5 and Figure A.6 show the effective SINR, i.e. Exponential Effective SINR Mapping (EESM), and throughput CDFs for the cellular transmissions, respectively.

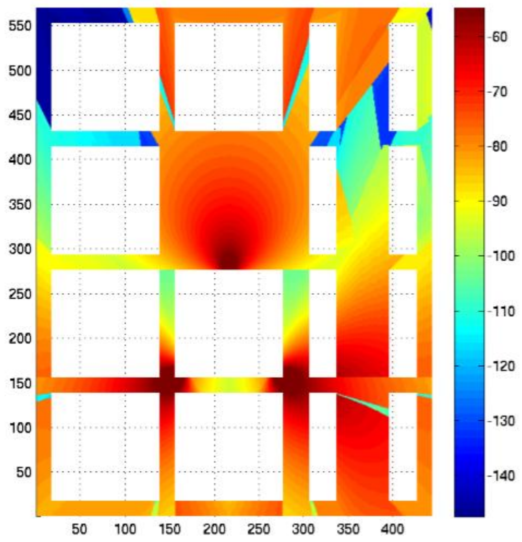

Figure A.3: Macro cell RSRP.

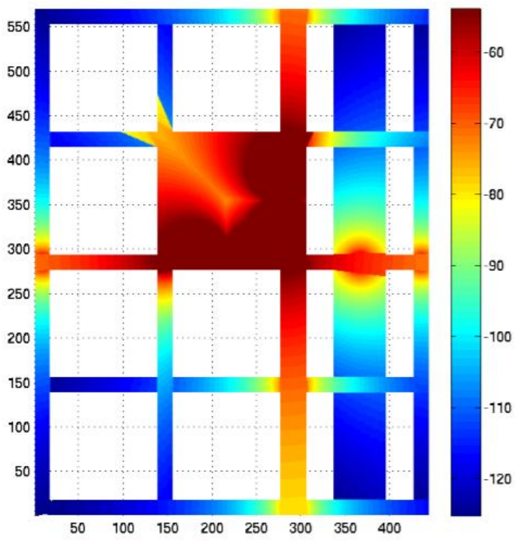

Figure A.4: Micro cell RSRP.

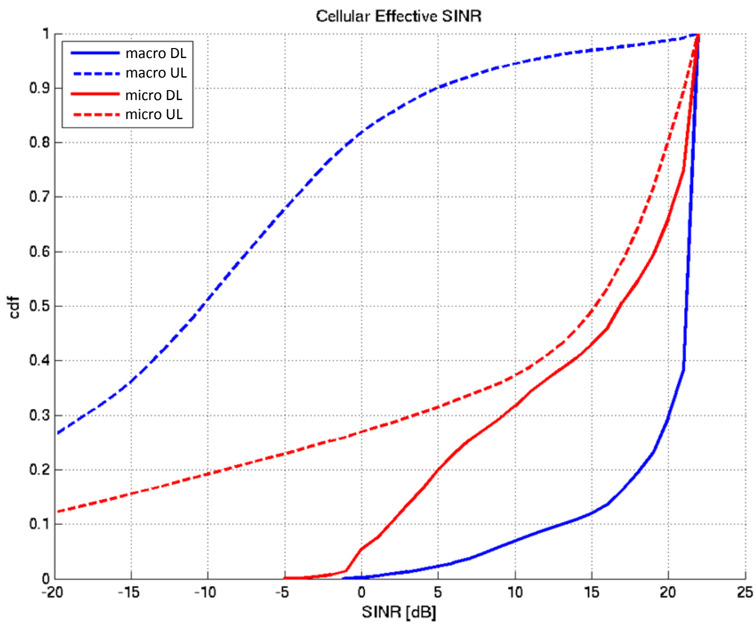

Figure A.5: Cellular exponential effective SINR mapping (EESM).

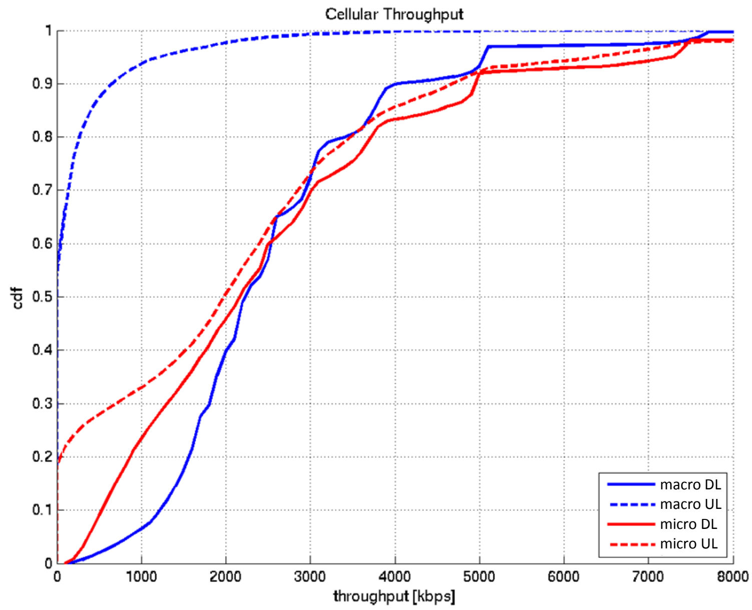

Figure A.6: Cellular throughput.

A.1.4 Results

Figure A.7 illustrates the gain on mean D2D UE throughput and the corresponding loss in mean cellular UE throughput in small cells (due to the increased interference from D2D users). In Figure A.7 we can observe that taking into use the resources reserved for small cells can lead to substantial throughput/capacity gain for D2D UEs. With properly selected safety distance, this can be done with negligible impact on small cell throughput. The exact gains depend on the scenario (in particular the density and coverage of the small cells). For downlink, the gains are much smaller.

Figure A.8 shows the relative gains and losses for all configurations. It is seen that the best overall gains are achieved with quite tight RSRP restrictions for D2D communication – around -80 dBm. These results can be used to balance the trade-off between cellular and D2D performance.

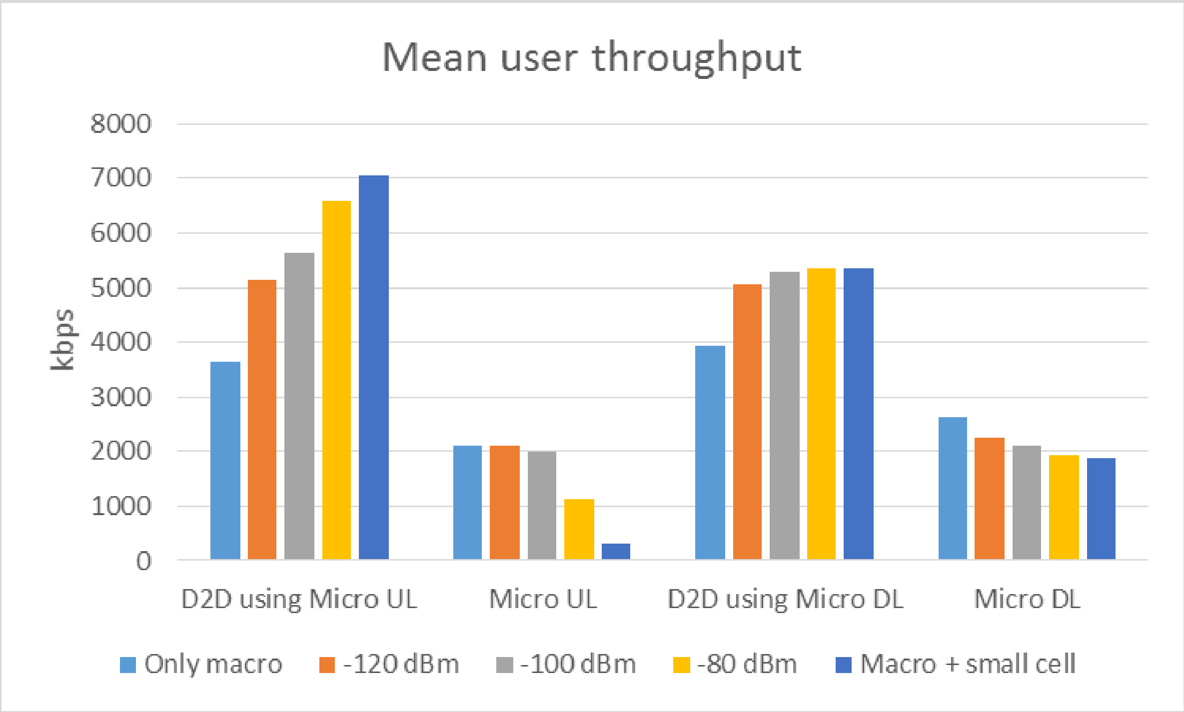

Figure A.7: Mean user throughput for different allocation configurations.

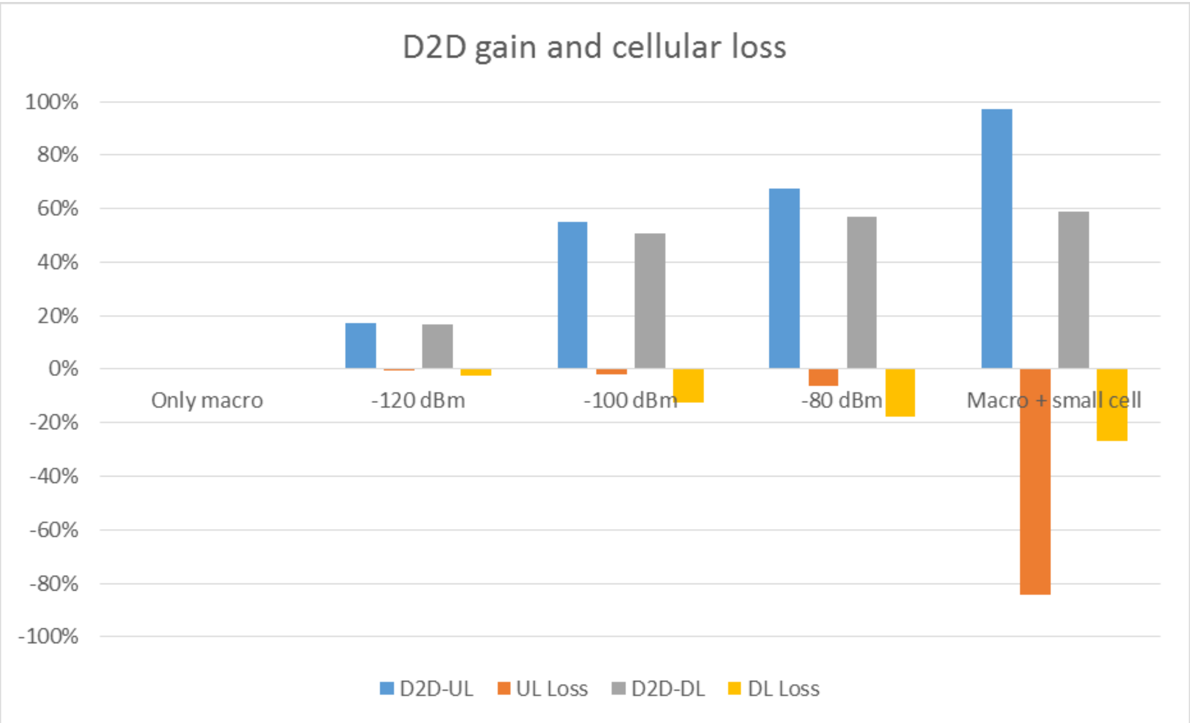

Figure A.8: Gains and losses when using D2D with UL resources (D2D-UL) or with DL resources (D2D-DL).

Table A.3 and Table A.4 show the overall system throughput and received data for cases with D2D on micro UL and DL, respectively. It should be noted that the numbers show combined results for DL and UL and for macro and micro and for cellular and D2D. For example, the received data is the data received by any node and system throughput is that amount of data divided by simulation time.

Table A.3: Total system throughputs for D2D on macro UL and micro UL case.

D2D resource	Received data [GB]	Throughput [Mbps]
Macro UL	29.22	233.7
Macro UL and micro UL	40.47	323.8
Macro UL and micro UL RSRP < -80 dBm	39.15	313.2
Macro UL and micro UL RSRP < -100 dBm	37.42	299.4
Macro UL and micro UL RSRP < -120 dBm	31.78	254.2

Table A.4: System throughputs for D2D on macro UL and micro DL case.

D2D resource	Received data [GB]	Throughput [Mbps]
Macro UL	29.22	233.7
Macro UL and micro DL	36.92	295.3
Macro UL and micro DL RSRP < -80 dBm	37.11	296.9
Macro UL and micro DL RSRP < -100 dBm	36.35	290.8
Macro UL and micro DL RSRP < -120 dBm	31.67	253.3

A.1.5 Conclusions

We showed results of system level performance evaluation for D2D-aware ICIC scheme in the METIS dense urban TC2 setting. Good gains were achieved especially on UL when micro UL resources where used with a strict RSRP safety margin. With proper dimensioning, there is only a minor loss in corresponding cellular throughput. Based on the results, the trade-off between cellular and D2D performance can be easily tuned. Further evaluation of the concept could e.g. include different Quality of Service criteria for different users, e.g. for VoIP users.

A.2 Intermediate system evaluation of MMC

The Horizontal Topic Massive Machine Communication, HT MMC, addresses the foreseen massive number of communicating machines, such as sensors, in a twenty-twenty information society. Figure A.9 illustrates the envisioned radio accesses that are: a) direct access, where there is direct transmission between the device and the access node; b) accumulation point access, where there is an accumulation point in between the device and the access node transmission; c) M2M access, where there is direct M2M communication.

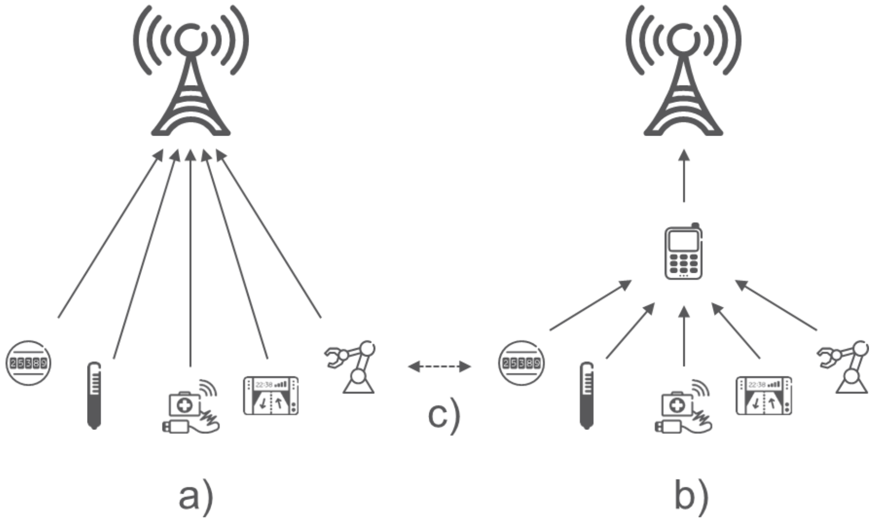

Figure A.9: HT MMC illustrated in the case of a) direct access, b) accumulation point access, and c) M2M access.

A.2.1 Evaluated technique

The evaluated technique is the ability for some of the sensors to, in addition to basic device capabilities, also convey relay capability enabling these relays to serve as the accumulation point access illustrated in Figure A.9 b) above. This technique, TeC improvement, is foremost targeting to improve coverage by assisting the devices that otherwise would have bad or non-existing possibilities to communicate.

The network needs to decide which sensors that should turn on their sensor-relay capability wisely, as whenever a new accumulation point is introduced this may reroute more traffic than merely the targeted sensor(s) with bad coverage. In addition, any selected sensor obviously must be in such a position that it serves as a suitable sensor-relay by having a sufficiently strong direct access as well as the ability to convey resources that improves coverage.

A sensor would like to use a sensor-relay (Re) if its current path gain to the access node is strictly less than the equivalent channel gain g_{eq}. The equivalent channel is defined in [SFM14] as

$$\frac{1}{g_{eq}} = \frac{1}{g_{TxRe}} + \frac{1}{g_{ReRx}}$$

where g_{TxRe} and g_{ReRx} denote the path gain between the transmitter (Tx) to sensor-relay and the sensor-relay to receiver (Rx), respectively.

An access node allows a sensor to become, i.e. serve as, a sensor-relay if it is able to provide coverage for another sensor that is not reached without this new sensor-relay. Note that a sensor that has activated its sensor-relay capability both serves the out-of-coverage devices as well as any other devices that benefit of using the sensor-relay.

A.2.2 Simulation methodology

The evaluation of the MMC horizontal topic legacy system has been made in a LTE-A system level simulator. The evaluated technique was studied in an improved system level simulator.

The analysis was conducted in TC2, i.e. the setting specified in Section 9.2 of [MET13-D61], on a wrap-around map given in Figure A.10, which is a 3x3 repetition of the map given in Figure A.1. In this map there exist 9 macro stations, each operating in 3 sectors via one directed-antenna per sector, and 108 micro stations, each operating via their single omni-antenna. The bandwidth is either 20 MHz or 500 MHz for each macro station and each micro station. The distribution assumption of the sensors is that 25 % are located outdoor and that 75 % are located indoor.

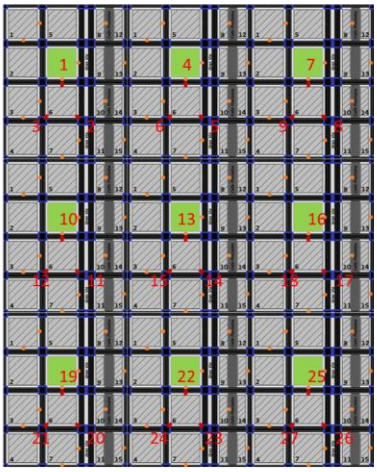

Figure A.10: TC2 and area of interest in the MMC analysis.

In this study the number of users is kept constant at 4000 (where each user represents several sensors in the simulations). The path loss values between devices are derived from the given path loss models in [MET13-D61], whereas the other path loss values are obtained at [MET14-Web]. The considered user positions within this MMC study is illustrated in Figure A.11.

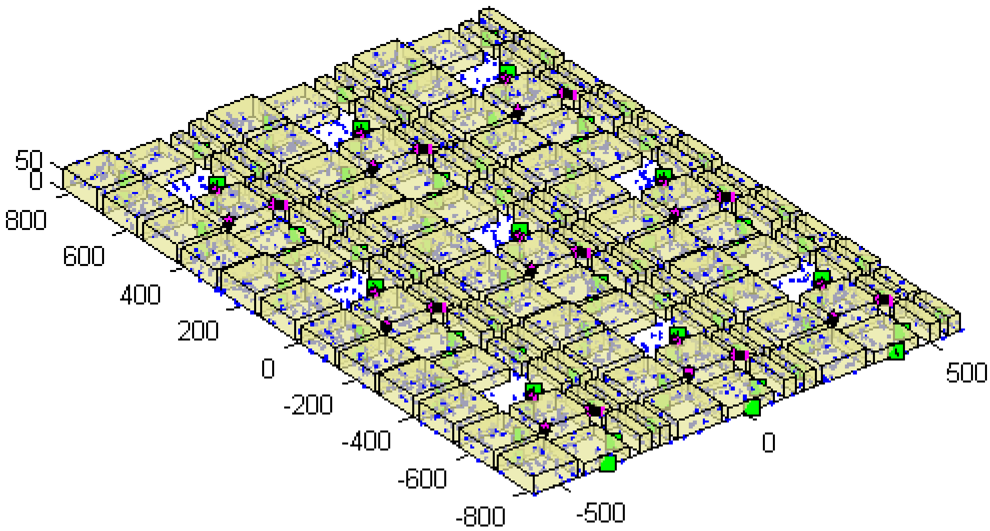

Figure A.11: The area of interest in 3D. The yellow boxes are the buildings and the white areas are on street level, i.e. streets and parks. The pink stars indicate the positions of the macro antennas while the green squares represent the positions of the micro stations. Each user position is illustrated as a blue dot (and it represents several sensors).

The relay-sensors are using the same amount of bandwidth as the macro and micro stations (i.e. a user admitted to serve as a relay are given the same amount of bandwidth as the macro and micro stations), at 2 GHz carrier frequency. A user admitted to serve as a relay has 23 dBm per 10 MHz as the maximum Tx power (compared to a macro station that has 43 dBm per 10 MHz and the micro station that has 30 dBm per 10 MHz as the maximum Tx power, see [MET13-D61]). Full buffer traffic is considered.

A.2.3 Results

The intermediate system evaluation of MMC is performed both in downlink and uplink, with the bandwidth on each station (macro, micro and user/sensor-relay) being either 20 MHz or 500 MHz. Experienced user throughputs, i.e. packet size divided by packet latency as defined in Section 4.2.2 of [MET13-D11], are presented as Cumulative Distribution Functions (CDFs). Coverage is shown by the 5th percentile experienced user throughput as a function of the total served traffic. In these simulations the offered rates are varied while the number of devices is kept constant at 4000 users (where each user represents several sensors).

A.2.3.1 Legacy system and evaluated technique comparison at 20 MHz

The legacy system and the evaluated technology component system, referred to as the sensor-relay system, are compared at various loads at 20 MHz bandwidth. The downlink and uplink experienced user throughput results are given in Figure A.12 and Figure A.13, respectively.

The downlink and uplink 5th percentile experienced user throughput as a function of the total served traffic are given in Figure A.14 and Figure A.15.

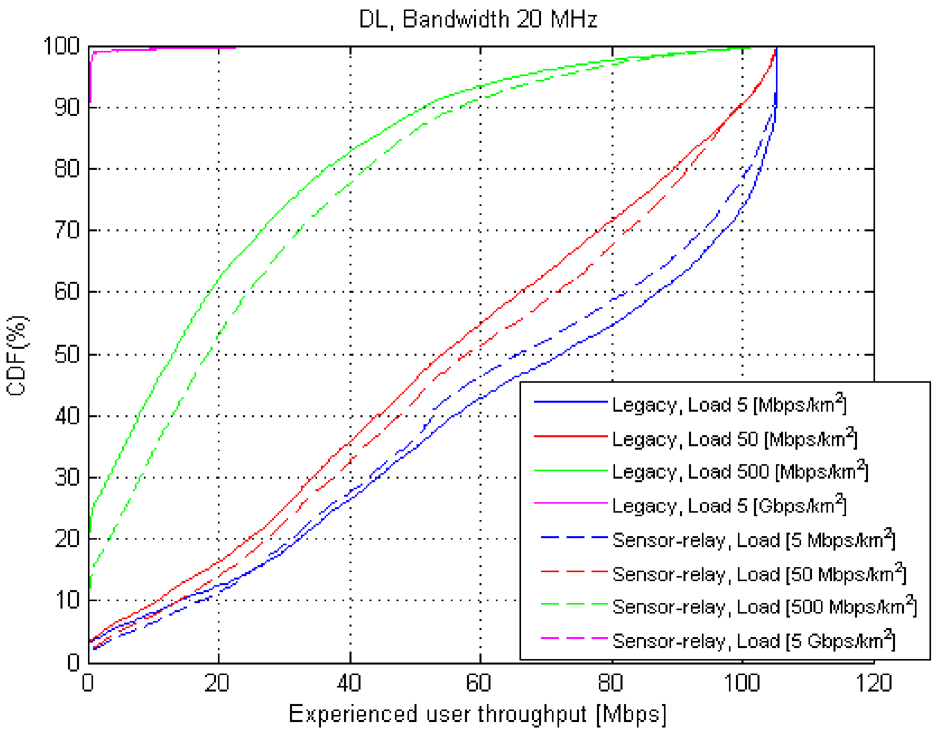

Figure A.12: Downlink experienced user throughput, 20 MHz bandwidth, of the legacy system (solid lines) and the sensor-relay system (dashed lines).

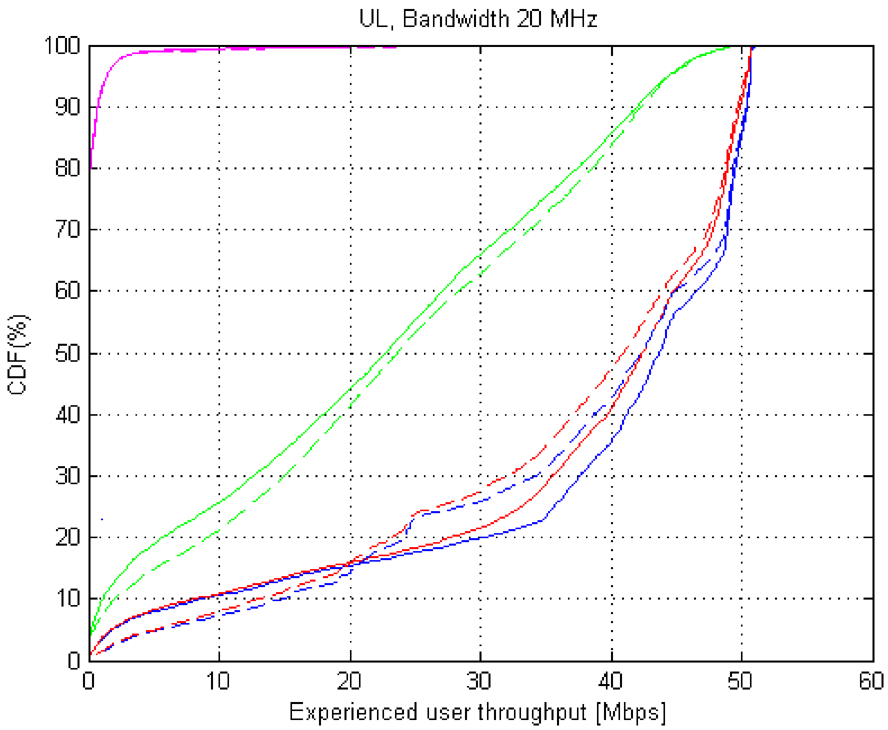

Figure A.13: Uplink experienced user throughput, 20 MHz bandwidth. This figure (Figure A.13) is the same figure as the right figure of Figure 3.3, but without the legend.

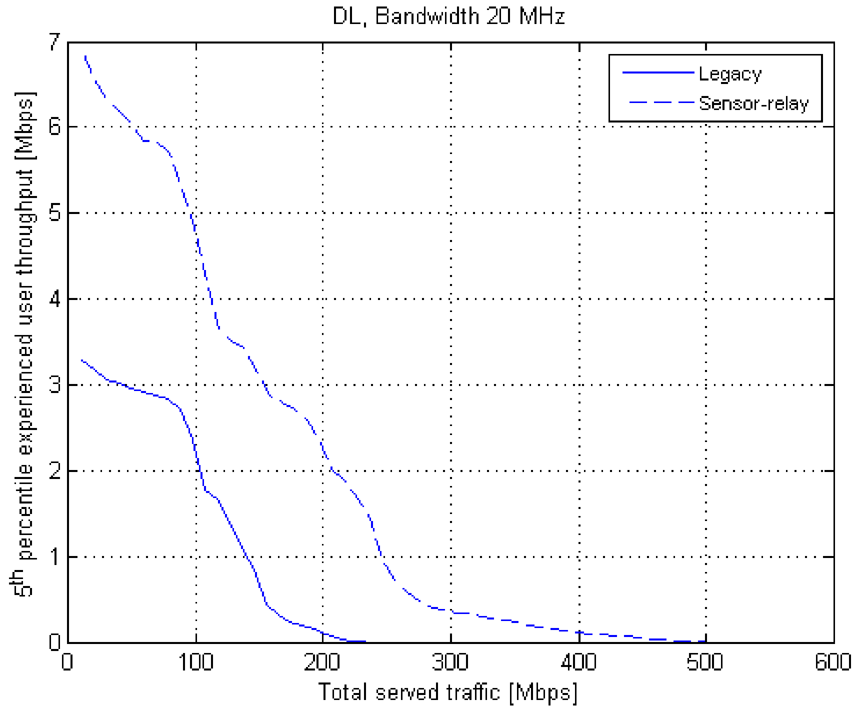

Figure A.14: The 5th percentile experienced user throughput in downlink, 20 MHz bandwidth, as a function of the total served traffic of the legacy system (solid line) and the sensor-relay system (dashed line).

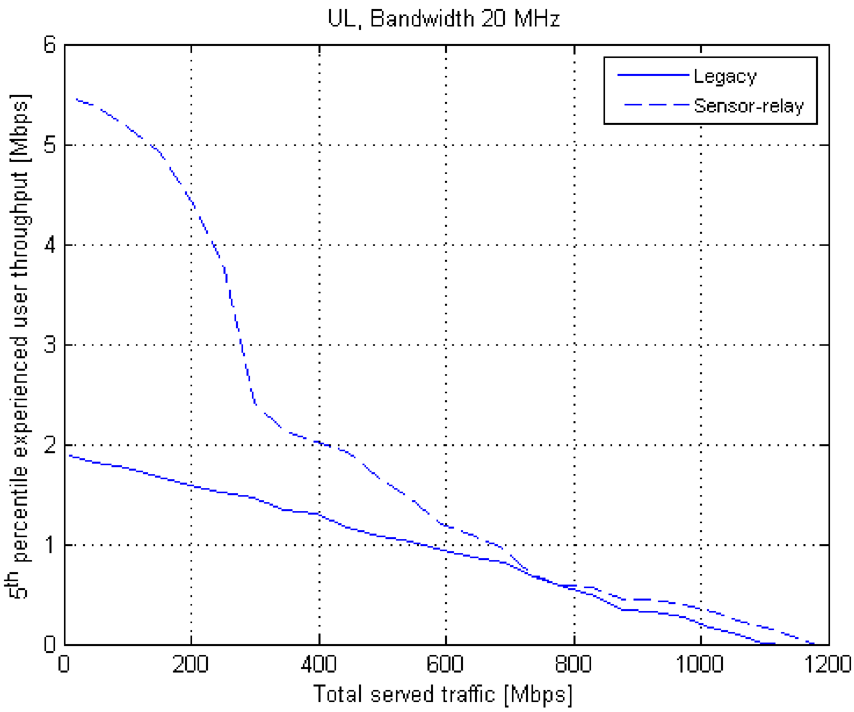

Figure A.15: The 5th percentile experienced user throughput in uplink, 20 MHz bandwidth, as a function of the total served traffic of the legacy system (solid line) and the sensor-relay system (dashed line).

A.2.3.2 Legacy system and evaluated technique comparison at 500 MHz

At 500 MHz the legacy system and the sensor-relay system are compared at various loads. The downlink and uplink experienced user throughput results are given in Figure A.16 and Figure A.17.

The downlink and uplink 5th percentile experienced user throughput as a function of the total served traffic are given in Figure A.18 and Figure A.19.

In downlink with bandwidth 500 MHz at the load 100 Mbps/km^2 the utilization of the macro stations and micro stations are given in Figure A.20 while their offered traffic and dropped traffic are given in Figure A.21.

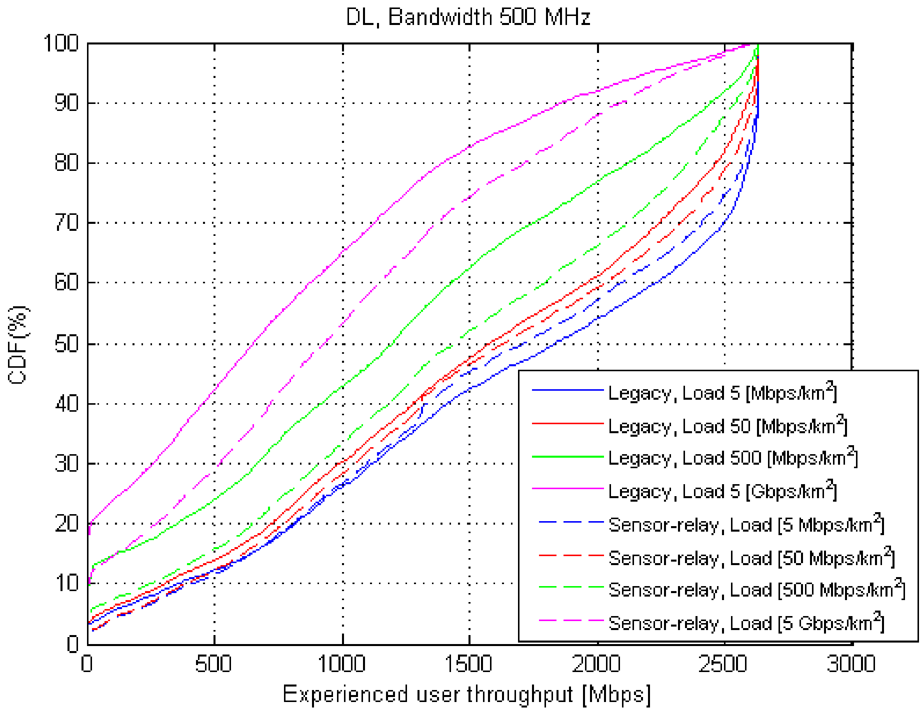

Figure A.16: Downlink experienced user throughput, 500 MHz bandwidth, of the legacy system (dashed lines) and the sensor-relay system (solid lines).

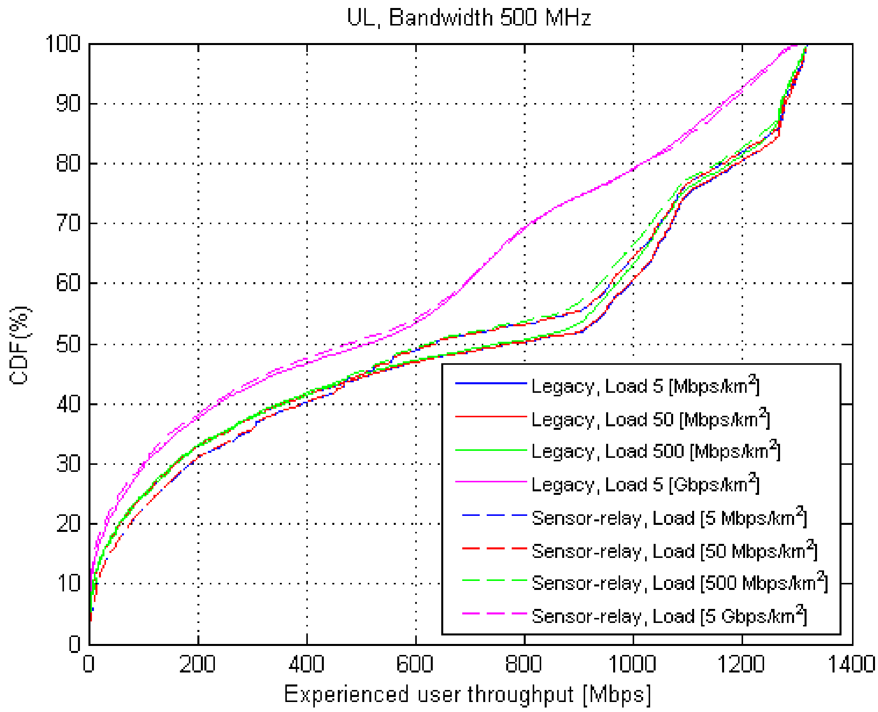

Figure A.17: Uplink experienced user throughput, 500 MHz bandwidth, of the legacy system (dashed lines) and the sensor-relay system (solid lines).

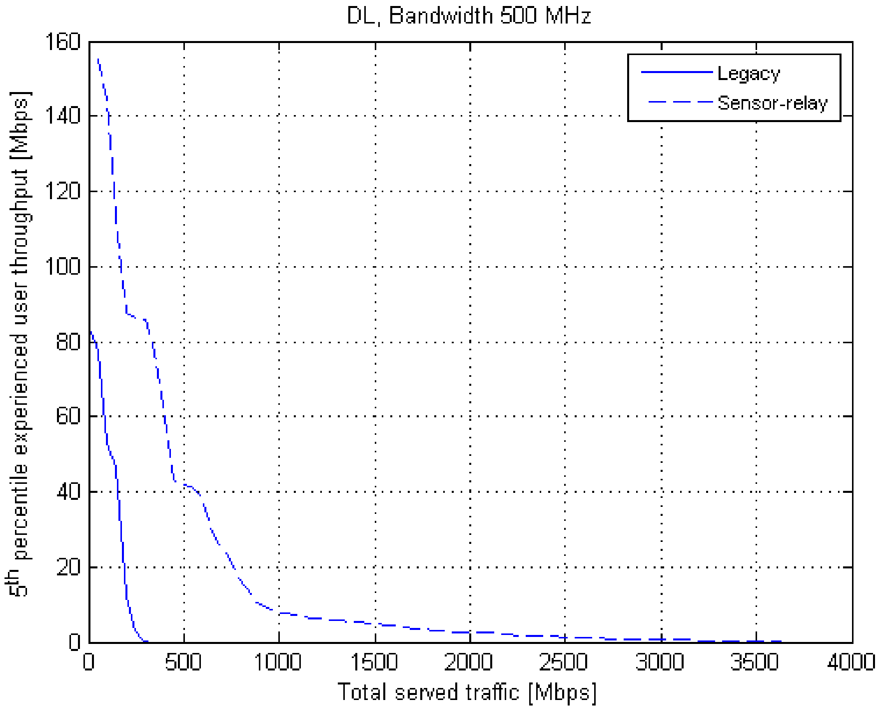

Figure A.18: The 5th percentile experienced user throughput in downlink, 500 MHz bandwidth, as a function of the total served traffic of the legacy system (solid line) and the sensor-relay system (dashed line).

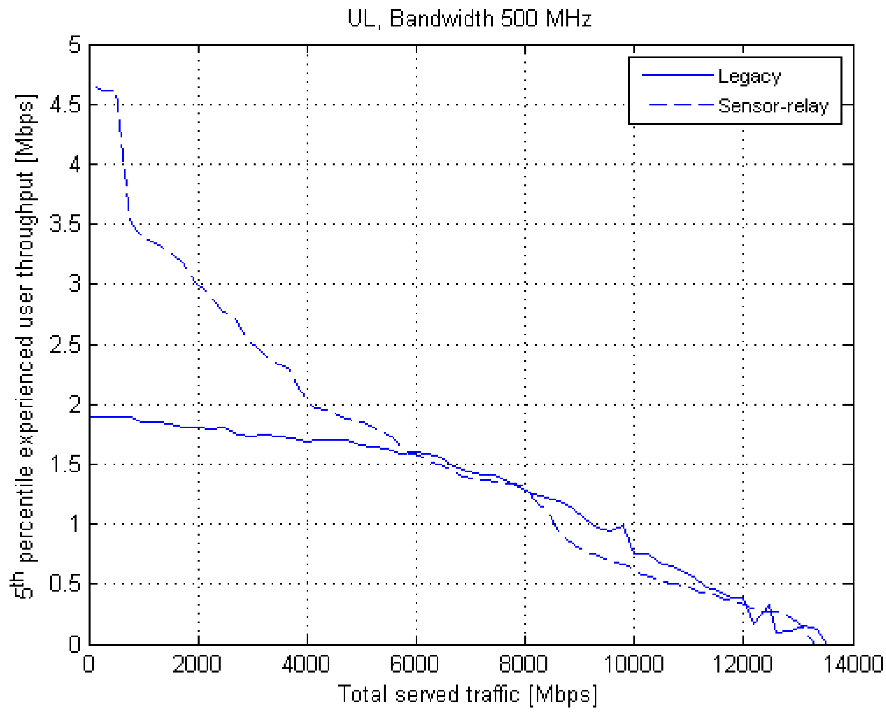

Figure A.19: The 5th percentile experienced user throughput in uplink, 500 MHz bandwidth, as a function of the total served traffic of the legacy system (solid line) and the sensor-relay system (dashed line).

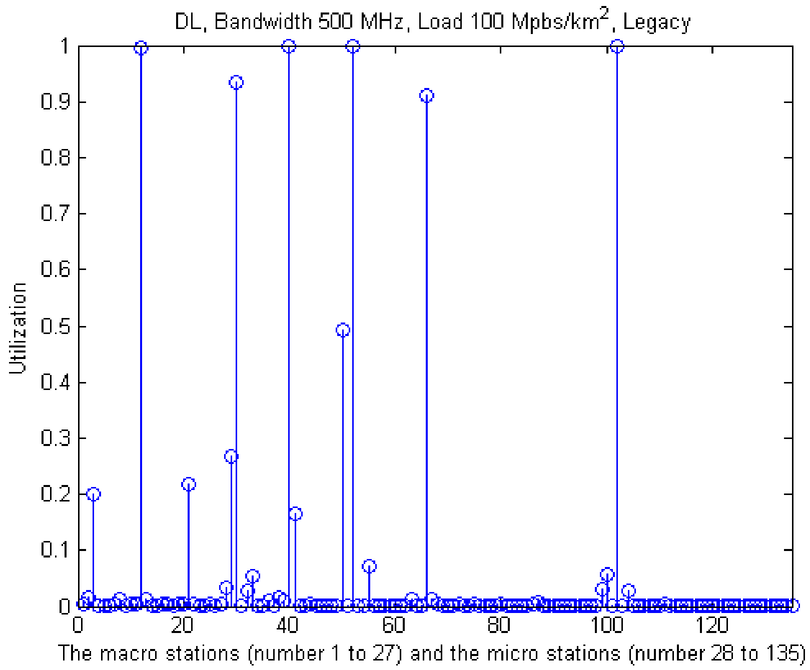

Figure A.20: The utilization of the legacy system in downlink at the load 100 Mbps/km^2 and bandwidth 500 MHz.

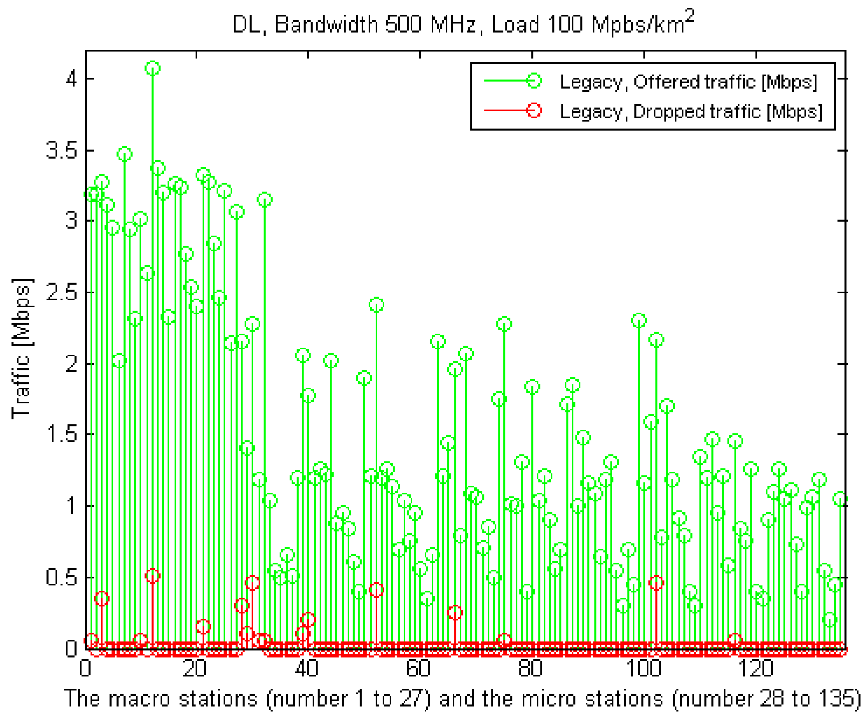

Figure A.21: The offered traffic and dropped traffic of the legacy system in downlink at the load 100 Mbps/km^2 and bandwidth 500 MHz.

A.2.4 Conclusions

In a system that carefully selects which sensors to allow serving as sensor-relays, improvements, i.e. higher experienced user throughputs, can be obtained in both downlink and uplink for the devices at the lowest percentiles. However, at the same time other devices may suffer of reduced performance.

The introduced sensor-relay capability is typically improving the coverage, in terms of increasing the 5th percentile experienced user throughput. At lower total served traffic the 5th percentile experienced user throughput improvements seem to be approximately a factor of two. At higher total served traffics this factor increases in downlink, while in uplink the factor decreases from slightly above two at lower total served traffic towards zero at higher total served traffic.

One can notice degradation of the 5th percentile experienced user throughput at lower total served traffic in uplink when increasing the bandwidth from 20 MHz to 500 MHz. At higher total served traffic the system with the larger bandwidth is also able to provide the higher 5th percentile experienced user throughput.

In downlink the total served traffic of the legacy system is not improved by much when increasing the bandwidth from 20 to 500 MHz. At the bandwidth 500 MHz and at the load 100 Mbps/km^2 a reason for this is illustrated in Figure A.20 and Figure A.21. Here a few stations are running at full utilization while other stations are barely being used, Figure A.20. The stations with full utilization also have rather high dropped traffic rates, Figure A.21. To improve the system performance these stations should be offloaded.

It is of high importance for the network to perform a careful selection of which sensors to appoint as sensor-relays in order not to lose significantly in terms of performance, e.g. due to unnecessary overhead. If some sensor-relays are being provided with electricity they can provide coverage to sensors in need of help, improving those sensors battery life, without draining their own energy levels. Another system performance improvement would be to enable full-duplex sensor-relays, instead of the considered half-duplex sensor-relays. However, the current working assumption for low cost sensor devices is the half-duplex operation.

A.3 Intermediate system evaluation of MN

In this section intermediate system evaluation of MN HT is presented. Performance of a legacy system in TC2 scenario is compared with that of a 5G system. In the 5G system two techniques are used in a moving network: opportunistic caching and mobile relaying. The evaluation is conducted through system level simulations.

A.3.1 Evaluated techniques

Concerning the specific mechanism that MN can bring in, we assume two main mechanisms, namely, opportunistic caching and mobile relaying.

For the former, we assume that popular contents can be cached offline by cars. This could happen during the night in the parking lot where the electric car will be wired to the data network. During normal operation of the vehicle, cached contents are forwarded to the car passengers or to other pedestrians provided that they are in good coverage (SNR greater than 20 dB). The communication between the vehicle and the final destination of the content will happen via direct V2X communications in a separate band (5 GHz band), without passing through the network that will only assist the final destination in the identification of the most appropriate caching point. The performance of the V2X link is the same as LTE-A. With respect to the amount of data that can be cached, we need to distinguish between video contents, which represents half of the amount of traffic [CIS14], and non-video traffic. For video traffic, that represents 50 % of total traffic, 60 % is popular content that can be cached [CIT14], whereas for regular contents, only 10 % can be cached [FMG+13]. We have translated these figures to METIS TC2 scenario, where we have assumed the caching probabilities for each traffic type shown in Table A.5.

Table A.5: Caching probability of each traffic type.

Traffic type	Caching probability
BUD	0.1
VT NRT	0.6
BAD RT	0.6
BAD NRT	0.1

Cars can also operate in relaying mode only for their passengers, similarly to the Closed Subscriber Group (CSG) concept. Thanks to relaying, vehicle penetration losses are avoided and the reception chain increases, due to the better characteristics of the antenna and the receptor in the vehicle. Within the car, a small cell forwards the data to the final destination. The mobile relay operates in a separate band in full duplex mode, that is, is totally transparent for the network point of view that treats the vehicle small cell like a regular user.

A.3.2 Simulation methodology

The evaluation of the MN horizontal topic has been made using a 5G system-level simulator that emulates the system at the packet level, which enables an accurate evaluation of many output variables that could be defined, including the final user perceived QoS through the implementation of advanced MN-related mechanisms. The radio interface specifications of this simulator is OFDMA-based similar to LTE-A with certain differences related to the extension to MN that do not hold 3GPP specifications. The use of this dynamic simulator, which works with a high time resolution (in the order of milliseconds), validates the capability of the simulation platform to dynamically and precisely evaluate the performance of the MN techniques. The platform has been developed following a modular and scalable design, in which packets traverse the different protocol layers, from the application layer, down to the physical layer. In this sense, the simulation is closer to an emulation of a real system rather than a simple simulation. The two proposed techniques (opportunistic caching and mobile relaying) have been evaluated through quasi-static simulations. Thus, the effect of long term movement, e.g. the effect of handovers, has not been considered.

The analysis was conducted in TC2, with the wrap-around effect being emulated with a replication of the scenario under study, red area in Figure A.22. Cells out of the red area are considered as interferers for the cells in the red area, and are assumed to be transmitting a continuous signal at full power level to consider a worst case scenario.

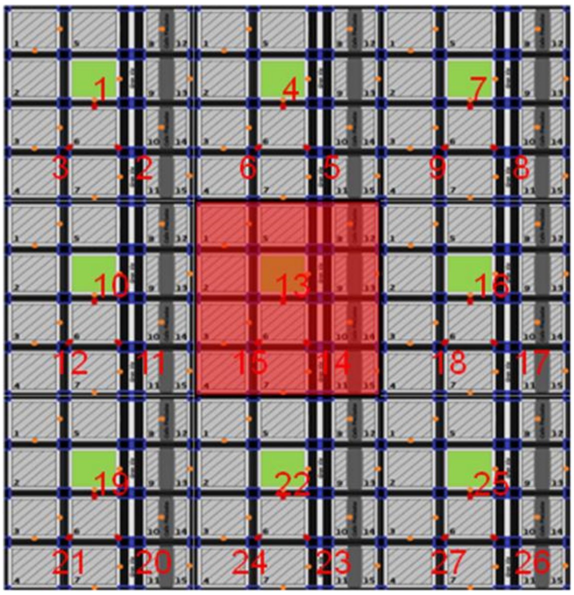

Figure A.22: TC2 and area of interest in the MN analysis.

The focus of the analysis is only on the outdoor case, since the impact of MN on indoor users is considered negligible.

Users are dropped over the simulation scenario following the user distribution in Table 9.6 of [MET13-D61]. A traffic type is allocated to each user according to traffic type distribution in Table 9.6 [MET13-D61]. To be more specific, users are dropped not only within the red area, but also in the replicas. However, only users connected to cells located in the red area are simulated.

In order to determine the serving cell for each user, the next procedure is followed user-by-user in a random order:

- User measures power spectral density received from each cell.
- Cells are ranked by its received power spectral density plus cell range expansion
- User requests connection to the highest ranked cell that applies an admission control procedure consisting on accepting all users up to a maximum load.
- If a cell denies connection, connection is requested to the next ranked cell until user connects to any cell.

Table A.6: Connection related parameters.

Parameter	Macro-cells	Micro-cells
Cell range expansion	0 dB	5 dB
Maximum load (beyond 2020 system) [number of active users]	70	210

In simulation with caching, it is assumed that the car has two independent interfaces: one to communicate with out-of-car users (pedestrians) and another one to communicate with in-car users. The next procedure is followed user-by-user in a random order to determine if the traffic of a user is cached:

- Get the probability of having its traffic cached (caching probability) from Table A.5, depending on the traffic type of the user.
- Randomly determine if user traffic can be cached, based on caching probability.
- If user traffic can be cached:
    - if user is inside a car, this car will be the moving transmitter,
    - else (user is pedestrian), the user will find the nearest car not doing caching to any pedestrian user, in a range of up to 85 m. If no cars are found fulfilling these conditions, no caching is done for this user.

In other words, if caching applies to a pedestrian user, the user is served by the closest car within a range of 85 m that is currently not transmitting to another user. This distance is calculated assuming PS#1, a target SNR of 20 dB and 20 dBm EIRP in the car.

While opportunistic caching could be used to any user, mobile relaying is only applicable to the car passengers. In the simulations, if caching is used, first it is determined if in-car users have their traffic cached. If any in-car user is not being cached it connects to the mobile relay. When caching is not used, all in-car users connect to the mobile relay.

One of the key performance indicators of this study is E2E latency. Some components of this latency and their values have been summarized in Table A.7.

Table A.7: E2E latency components.

Component	Value
Content server to base station delay	15 ms
Base station processing time	2 ms
Buffering time (until next scheduling)	0.5 ms
Base station to user equipment transmission time	1 ms
User equipment processing time	2 ms

The content-server-to-base-station delay has been obtained as half the mean round trip time reported by ATT for its America network in [ATT14-Web] in June 2014. A transmission time interval of 1 ms has been assumed, as in LTE. Therefore, mean buffering time, defined as the mean time a packet waits in layer 2-3 buffers until being considered for scheduling, is half the transmission time interval. Base station and user equipment processing times of 2 ms are values commonly used in literature.

Our analysis has several limitations that should be pointed out when analysing the results:

- For the sake of simplicity, simulations focus on downlink since this is the limiting link with the foreseen traffic profile.
- The transmission mode is SIMO 1x2. Using MIMO less bandwidth could be necessary in the beyond 2020 system to achieve METIS goals. However, we have decided to limit the transmission capabilities of the transmitters to isolate the impact of MN.

- Only RLC UM has been used on top of MAC layer. Therefore, latency has been prioritized over packet losses.
- No fast fading emulation has been considered.
- Round Robin scheduler has been used to allocate resources to the users. Neither user nor traffic prioritization has been applied. Again, the aim is to isolate the MN impact on the simplest legacy system.
- For the sake of simplicity, V2X links do not interfere with each other.

In the simulations done in this assessment, in addition to what [MET13-D61] includes for TC2, the following assumptions apply:

- The in-car transmission does not interfere others outside the car and there is not interference within the car.
- Antenna gain of the vehicles is 6 dBi.
- The noise figure of the vehicle receivers is 5 dB.
- Pathgain for the V2X follows a simplified version of PS#1 [MET13-D61] (where path loss depends only on the distance between transmitter and receiver) whereas pathgain for the macro and small cells are taken from the ray-tracing files provided for TC2 [MET14-Web].
- The azimuth for each microcell is such that in each site a cell points to one opposite direction of the street where it is located, with an angle of 20º with respect to the closes wall (as in the calibration case 3 of [MET13-D61]).
- Antenna pattern for micro-cells is the one used in the calibration case 3 of [MET13-D61].

A.3.3 Results

Results on both the legacy system and the beyond 2020 system are presented below.

A.3.3.1 Scenario calibration

In Figure A.23 we represent the wideband SINR distribution for the different type of user locations in the area under study.

A.3.3.2 Legacy system

The number of users and traffic load considered in the simulations of the legacy system have been calculated based on the requirements for beyond 2020 system in Table 9.6 of [MET13-D61] and the METIS goals for beyond 2020 system, that are relative to legacy system performance. In Table 9.6 of [MET13-D61] it is indicated the number of users in TC2 scenario, together with the packet size and reading time for each type of traffic (BUD, VT, BAD RT or BAD NRT) and different location (car, park, sidewalk, traffic light or bus stop). Specifically, the number of outdoor users in TC2 is 13000. Packet sizes are 20 MB for BUD, 0.125 MB for BAD RT, 2 MB for BAD NRT and VT presents different sizes depending on the location of the user.

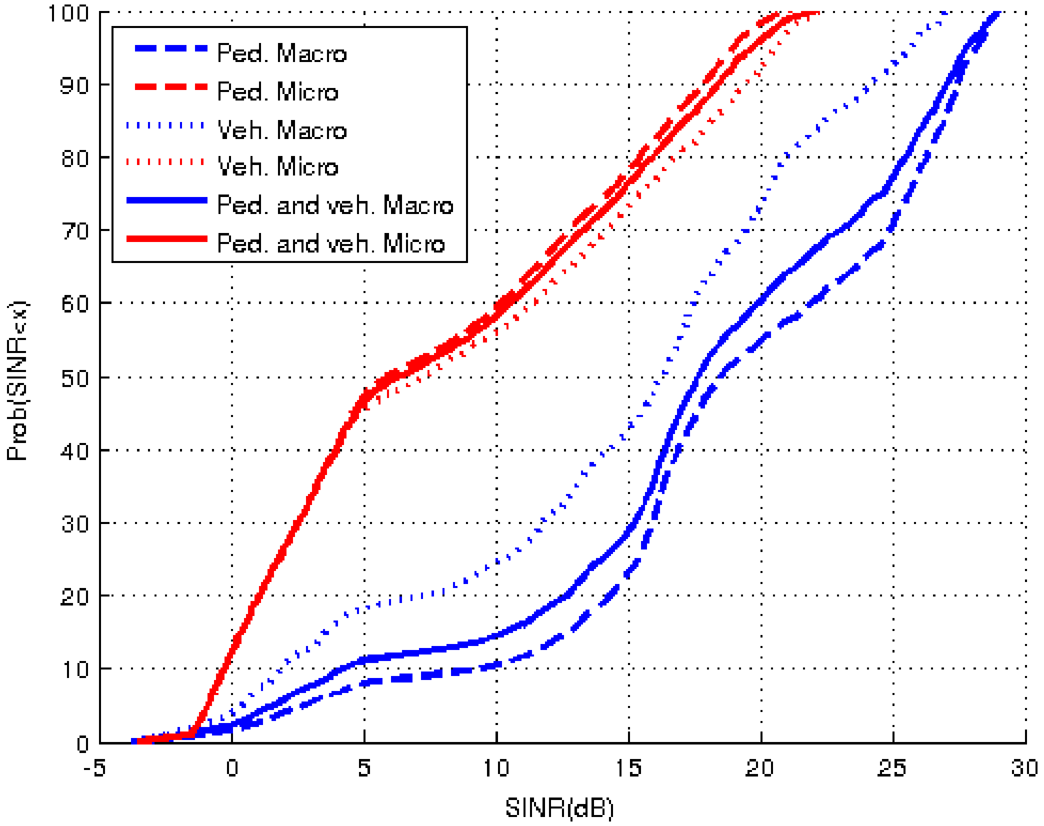

Figure A.23: Wideband SINR CDF in dB for the area under study.

The METIS goals for beyond 2020 systems that we consider in this study are: 10 times more users, 100 times more traffic load and 5 times less latency compared to the legacy system.

Therefore, in the legacy system we simulate 1300 outdoor users (13000/10) with packet sizes 100 times lower than those in Table 9.6 of [MET13-D61]. That is, 200 kB for BUD, 1.25 kB for BAD RT and 20 kB for BAD NRT.

To evaluate the performance of the legacy system, it has been considered 20 MHz bandwidth for macro-cells and 80 MHz for micro-cells.

Before simulations with real traffic, we conduct a full-buffer evaluation, where it is assumed that an infinite amount of bits is pending to be transmitted to each user anytime. An average system throughput of 3900.0 Mbps and a mean user throughput of 3 Mbps are obtained. In the macro-cells a mean throughput of 55.7 Mbps is achieved, while micro-cell mean throughput is 155.5 Mbps.

With the cell selection mechanism used, without admission control, the number of users connected to each cell is very unbalanced. One of the macro-cells is heavily loaded, and also two micro-cells are much more loaded than the others, as shown in Figure A.24.

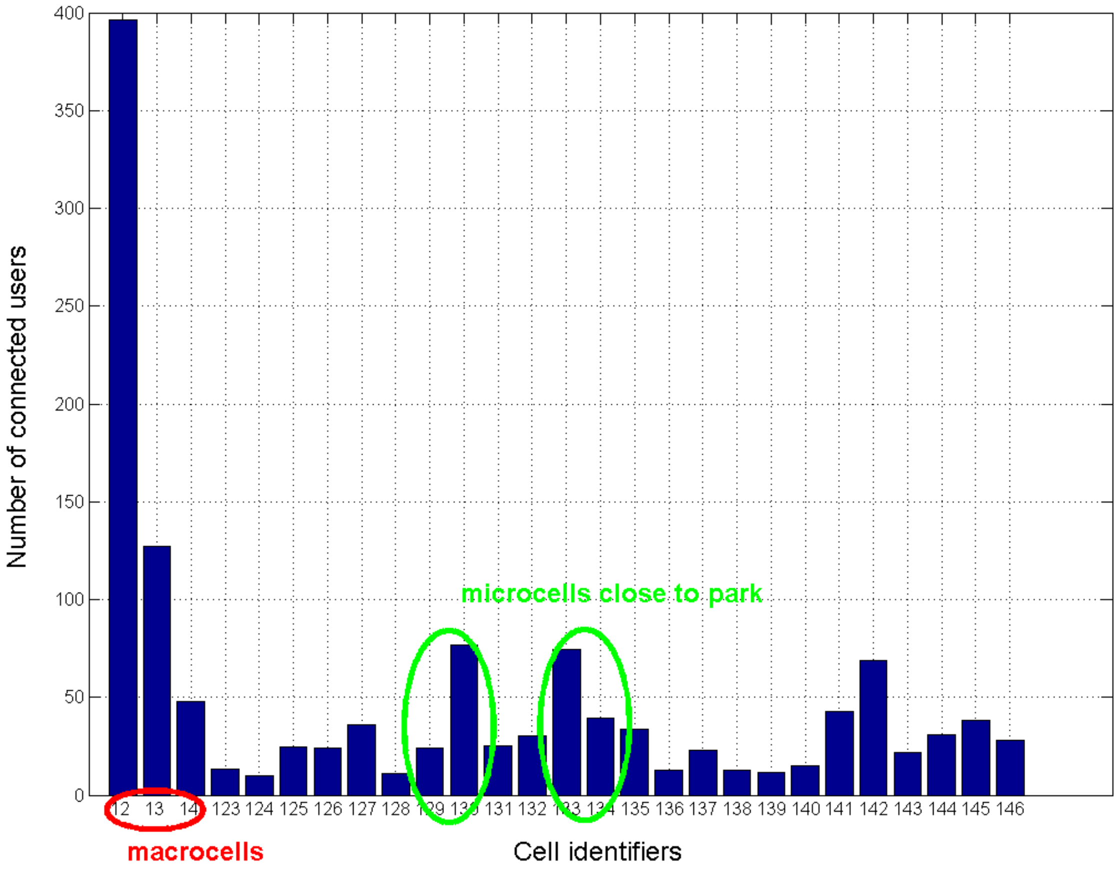

Figure A.24: Mean number of users connected per cell.

The traffic load in Table 9.6 of [MET13-D61] is such that the mean data rate is around 2.5 Mbps for outdoor users. Thus, with our numbers for the legacy system, the mean offered data rate per user is 25 kbps. Taking into account this mean data rate, the mean throughput for each type of cell and the mean number of users connected to each cell, it turns out that the offered load is easily supported by the legacy system. This explains the good latency results shown in Table A.8 and Figure A.25. Results for VT NRT traffic are not shown because this traffic does not have a fixed packet size, but it changes depending on the location of the user, therefore it is not interesting to obtain mean latency values for this kind of traffic.

Table A.8: Median of mean user E2E latency in legacy system.

Traffic type	Radio transmission delay [s]	E2E latency [s]
BUD	0.0304	0.0499
BAD RT	0.0010	0.0205
BAD NRT	0.0033	0.0228

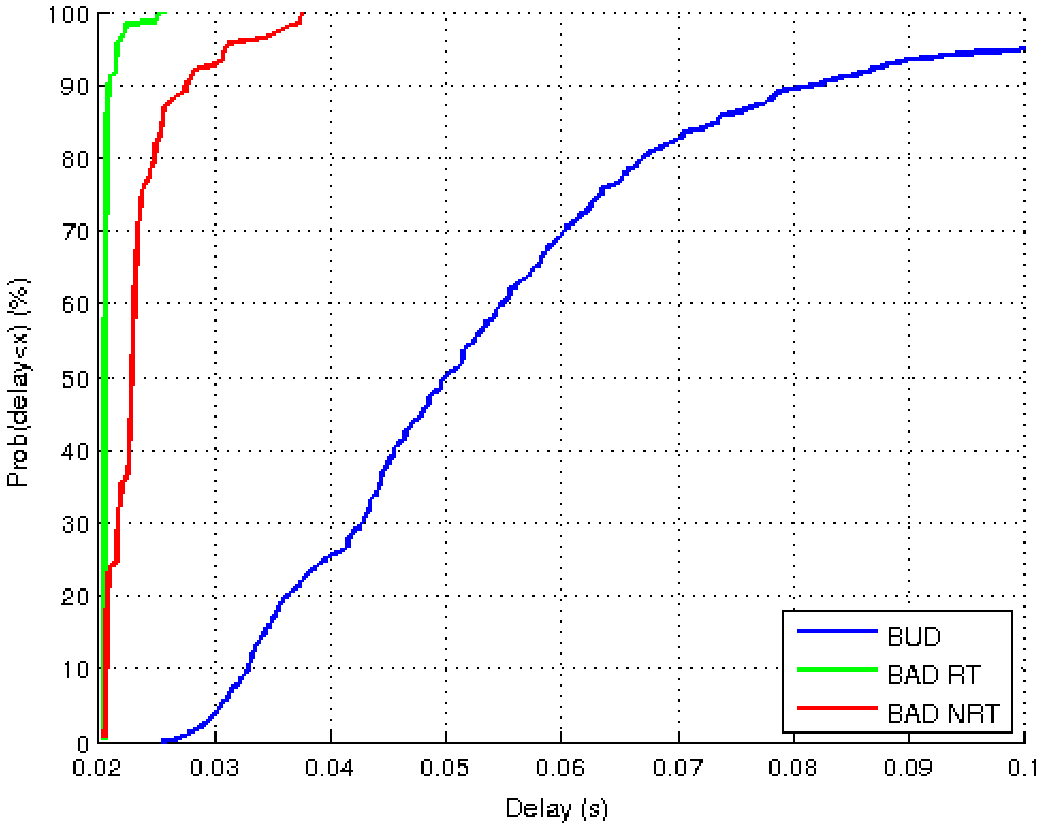

Figure A.25: CDFs of mean E2E user latency for each traffic type.

A.3.3.3 Beyond 2020 system

The difference between the legacy system and our beyond 2020 system is the use of moving networks, that is, transmitters and receivers located in cars, with opportunistic caching and mobile relaying. This analysis starts analyzing the impact of these concepts upon the legacy scenario. In this sense, we conducted simulations in which we first focus on users making use of caching capabilities located at cars.

Simulation results have demonstrated that mobile relaying is useless in TC2 scenario. The reason is that TC2 is an interference-limited scenario while mobile relaying is useful in noise-limited scenarios. Therefore, radio transmission delay in base-station-to-relay link is not lower than in the base-station-to-user-device link. The additional relay-to-user-device link increases the E2E latency for relayed user-devices.

However, simulations have proven two positive effects of caching. First, caching reduces E2E latencies of cached users. This reduction increases with smaller packets, that is, when the non-radio-transmission delay is more relevant over the whole E2E latency. In Table A.9 it is shown that with just 10 MHz allocated to caching users experience a latency for BAD RT packets in the order of that experienced in the legacy system (with packets 100 times smaller). With 80 MHz, that is the bandwidth allocated to micro-cells in the legacy system, BAD RT E2E latency is reduced to 60 %.

Table A.9: Median of mean user E2E latency in the system for users using caching.

Traffic type	Caching with 10 MHz E2E latency [s]	Caching with 80 MHz E2E latency [s]
BUD	4.2285	0.5325
BAD RT	0.0315	0.0079
BAD NRT	0.4275	0.0574

The second positive effect of caching, as proposed in this assessment, is the offloading of traffic. About one fourth of the users are offloaded from the macro and micro layers. With the traffic type distribution and caching probabilities of each traffic type presented above, about one half of the traffic load is offloaded.

In order to evaluate the effect of caching we have conducted simulations with and without caching in a scenario with a heavier traffic load than that considered for the legacy system. The same number of users as in the legacy system has been considered (1300) and packet sizes are those indicated in Table 9.6 [MET13-D61]. We have considered 80 MHz bandwidth for macro-cells, 320 MHz for micro-cells and 10 MHz for the D2D caching interface. This means 4 times the bandwidth allocated to macro-cells and micro-cells in the legacy system. As we have noted for the legacy system, without call admission control some cells surrounding the park in TC2 scenario are heavily loaded and are limiting the global system performance. Therefore we apply a simple admission control that limits the number of users connected to each cell. This admission control provides a more balanced user load around the cells surrounding the park. A maximum number of 70 users were allowed to be connected to macro-cells and up to 210 users were allowed to connect to micro-cells. These numbers are not fully optimized. The idea behind them is to keep the same 1:3 ratio that we saw in the full buffer assessment.

In Table A.10 E2E latencies are shown for users connected to macro-cells and micro-cells, that is, those not cached. In Table A.11, results are presented independently for macro-cells and micro-cells.

E2E latencies are clearly reduced for users connected to macro-cells and micro-cells when part of the traffic is offloaded. It is interesting to note that, for our setup, reduction is more important for macro-cells and large packets.

BAD RT E2E latency is similar to that reported in Table A.8 for the legacy system. But, note that, in our setup only 1300 users are being simulated instead of the 13000 users required by METIS in TC2. Therefore, to achieve the same latency as in the legacy with 10 times more users about 10 times more bandwidth would be needed (800 MHz for macro-cells and 3200 MHz for micro-cells and from 20 MHz to 100 MHz for the caching service, depending on the propagation characteristics of the D2D link).

Table A.10: Median of mean E2E user latencies for users connected to the cellular system.

Traffic type	E2E latency without caching [s]	E2E latency with caching [s]
BUD	2.2025	0.8935
BAD RT	0.0367	0.0277
BAD NRT	0.2370	0.1174

Table A.11: Median of mean E2E user latencies per type of cell.

Traffic type	E2E latency without caching [s]		E2E latency with caching [s]	
	Macro	Micro	Macro	Micro
BUD	15.6985	1.8093	3.2299	0.7598
BAD RT	0.1165	0.0342	0.0476	0.0259
BAD NRT	1.5498	0.123	0.3226	0.1009

A.3.4 Conclusions

Performance of legacy system in TC2 scenario with 10 times less users and 100 times less traffic load per user than required by METIS has been presented in this section.

Two techniques have been presented under the umbrella of the MN HT. Mobile relaying is not useful in TC2 because it is an interference-limited scenario. Opportunistic caching reduces E2E latency of cached users and offloads the macro-cells and micro-cells reducing the latency of users connected to those cells. Results show that, without interference in the D2D link, only 20 MHz are enough to provide a performance similar to that experienced in the legacy system. On the other hand, with the expected increase in the traffic load, the cellular system should increase its allocated bandwidth up to 4 GHz. As compared with the legacy situation, with 100 MHz allocated, that means an increase of 40 times in the available bandwidth. Although this increase seems (and is) huge, we should take into account that the amount of traffic has increased 1000 times.

A.4 Intermediate system evaluation of UDN

Network densification is one of the key methods that allows creating the high capacity network that can accommodate traffic predicted for the year 2020 and beyond. It is capable of boosting capacity in both indoors and outdoors, and is usually realized by the deployment of a layer of small cell nodes that complement the macro coverage and provide good conditions for wireless connectivity over limited area. However, network densification brings both technical and economic challenges. From the technical point of view one of the main challenges is the interference limitation that arises due to the close proximity of radio nodes operating in the same frequency. From the economical point of view, provision of high quality and reliable backhaul may be hard to realize at reasonable cost level. From both technical and economic point of views dense network of the small cells needs also to be flexible, in a broad sense of this term, to allow for dynamic and long term variations in traffic.

METIS tackles these challenges by providing a system level vision based on the HT Ultra-Dense Network (UDN). Intermediate concept provided in [MET14-D62] assumes tight collaboration of nodes in the area of resource allocation, flexible UL/DL TDD interface, a fast (de)-activation of cells and inbuilt self-backhauling support as the core part of the UDN system. The proposed solution provides also an extension part (that is composed of Context Awareness, mobility enhancements, macro control over small cells etc.), but it is out of the scope of our existing evaluation. Please refer to [MET14-D62] for the description of the components. The general concept for the METIS UDN system is depicted in Figure A.26.

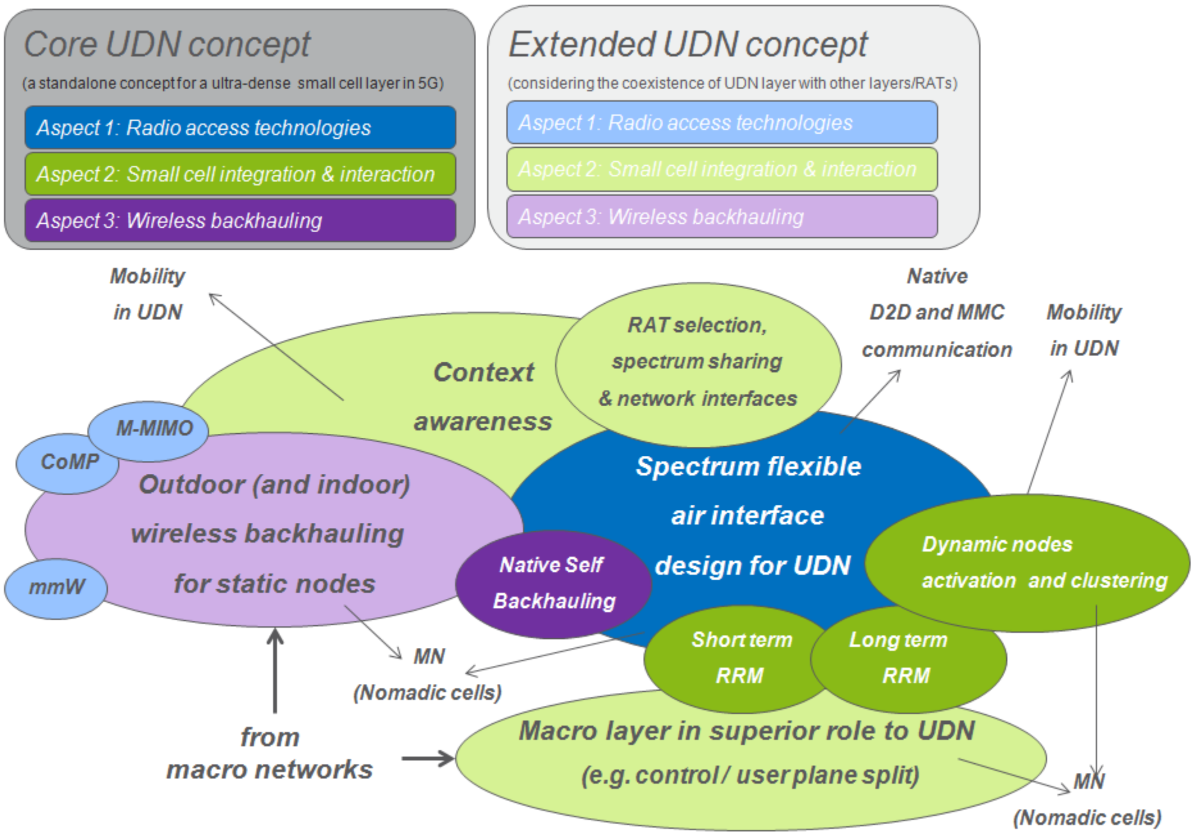

Figure A.26: METIS UDN system concept.

A.4.1 Simulation assumptions

To evaluate METIS UDN system concept, *TC2: Dense urban information society* [MET13-D11] is used. Numerical analysis is performed in quasi-dynamic MATLAB based simulator. As the majority of traffic is expected to be generated indoors, simulations have been conducted in an indoor part of TC2.

A.4.1.1 Environment

One floor of the square building of TC2 is simulated. Each floor consists of 144 rooms with wall width producing 5 dB losses. Each room is 10 m x 10 m. The TC2 area of interest for the UDN analysis is given in Figure A.27.

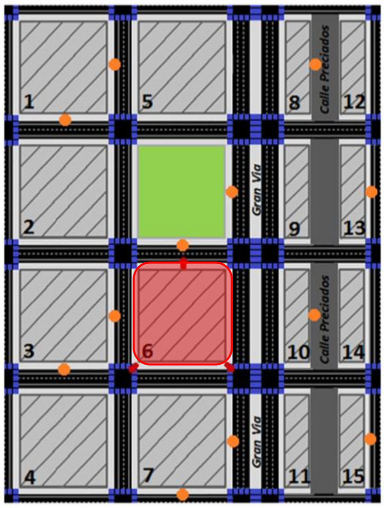

Figure A.27: TC2 and area of interest in the UDN analysis.

A.4.1.2 Deployment

Only small cell layer is assumed. Small cells are deployed in the middle of the ceiling of room at the height of 3 m. Access nodes can be deployed every fourth, second or in every room. Maximum transmission power is set to 30 dBm.

According to [MET13-D61] there are 37500 indoor users in the whole TC2 scenario. Based on the building dimensions there are 14664 rooms in basic layout of TC2. We round up the total number of users to 3 per room.

User's devices antennas are at the height of 1.5 m. Maximum transmission power is set to 20 dBm. Omnidirectional antennas, IRC receivers, 2 RX/TX antennas and Single User MIMO capability is assumed for both users and access devices. Carrier frequency is 2.6 GHz and 20/40 MHz band in TDD mode is available.

A.4.1.3 Traffic

A simplification of traffic for TC2 is used. According to [MET13-D61] major contributor to overall traffic volume in indoor is Bursty User Driven traffic, BUD, based on FTP-2 model 2 [3GPP10-36814] which creates highest traffic volume per area and is used by highest number of users. The model assumes average user data rate of 1.49 Mbps which is simplified to transfer of 1.5 Mb packet every second. Traffic is split between DL and UL using download of 1.2 Mb and upload of 0.3 Mb packets generated according to a Poisson process with the mean inter-arrival time of 1 s.

A.4.1.4 Key performance indicators

To evaluate the performance of UDN system packet delay and packet experienced user data rate are used. Packet delay accounts for radio network transmission of entire packet at the physical layer. Experienced user data rate is calculated as transferred packet size (1.2 Mb in DL and 0.3 Mb in UL) divided by the packet delay. TC2 required KPIs for experienced user data rate are 300 Mbps for DL and 60 Mbps for UL with 95 % availability.

A.4.2 Simulation methodology

The performance of the UDN system is evaluated by checking two gain mechanisms which are described below.

1. Performance improvements due to the introduction of UDN are related to the densification and are modelled by increasing the number of access nodes from 1 per every 4 rooms up to 1 per every room. In result we obtain fewer users per cell which translates into reduced probability of users sharing available radio resources. As a consequence, we have a higher probability of users experiencing higher data rates due to the possibilities of utilization of all radio resources available per cell. On the downsides, we may experience higher interferences due to closer proximity of interfering devices in both UL and DL directions. To reduce the impact of those interferences and provide realistic performance evaluation, IRC receivers are used.
2. Gains introduced by TeCs related to core UDN concept are based on performance evaluation of system with a flexible UL/DL TDD air interface against TDD slot allocation as in LTE Rel-11 (baseline). In flexible TDD, UL/DL radio slots can be dynamically allocated to either UL, DL or muted, depending on the decisions of the scheduler. Frame design allows also sending DL and UL control information in every time slot, regardless of the direction of the data transmission as depicted in Figure A.28. More details on this frame design can be found in [MET14-D23]. For simulation of LTE Rel-11 scheme UL/DL slot allocation reflects UL/DL traffic imbalance (2:8 ratio).

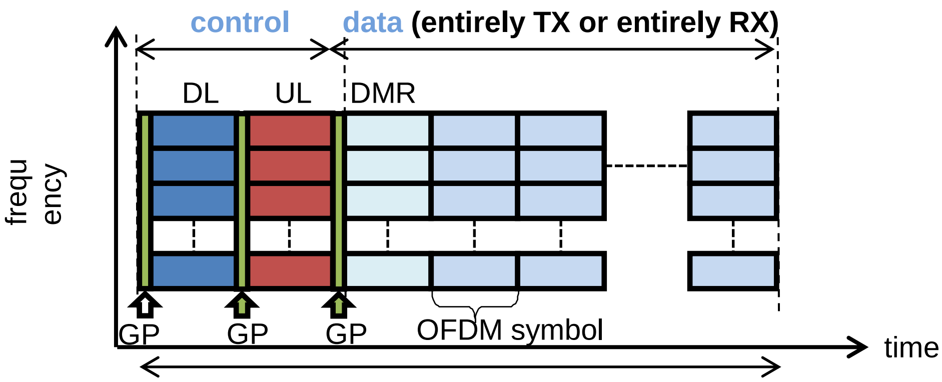

Figure A.28. Flexible UL/DL TDD frame structure. DL and UL control symbols are separated using Guard Periods (GPs). Each frame contains also DeModulation Reference Symbols (DMRS).

In order to create a realistic interference profile, statistics used for evaluation are collected only from the central 64 rooms, as depicted in Figure A.29.

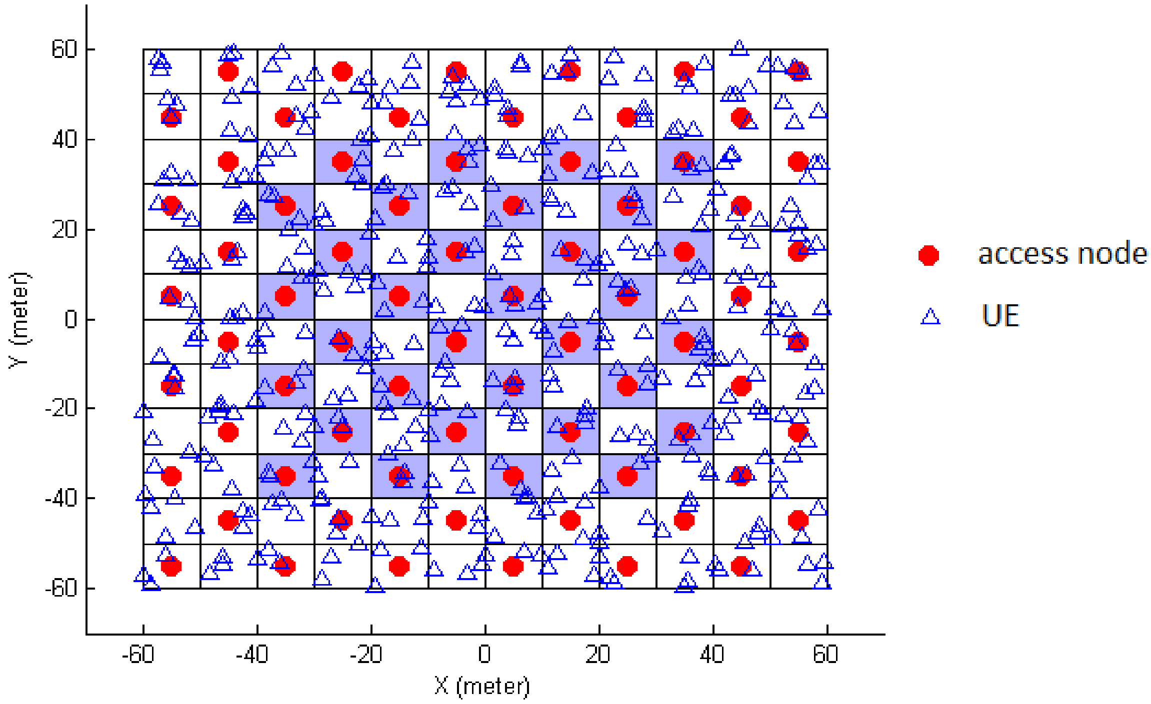

Figure A.29: Example of simulation layout for indoor TC2. 1 AP per 2 rooms (scenario 5G UDN 2). APs in blue cells are used to collect the evaluation results.

Five simulation scenarios are assumed, these are:

1. LTE-A Rel-11: Access nodes deployed every 4 rooms, fixed UL/DL slot allocation, 20 MHz bandwidth available.
2. 5G UDN 1: Access nodes deployed every 4 rooms, flexible UL/DL slot allocation, 20 MHz bandwidth available.
3. 5G UDN 2: Access nodes deployed every 2 rooms, flexible UL/DL slot allocation, 20 MHz bandwidth available.
4. 5G UDN 3: Access nodes deployed every 1 rooms, flexible UL/DL slot allocation, 20 MHz bandwidth available.
5. 5G UDN 4: Access nodes deployed every 1 rooms, flexible UL/DL slot allocation, 40 MHz bandwidth available.

Both UL and DL are simulated simultaneously.

A.4.3 Results

CDFs of packet delays for each simulation scenario are shown in Figure A.30 and Figure A.31, for uplink and downlink respectively.

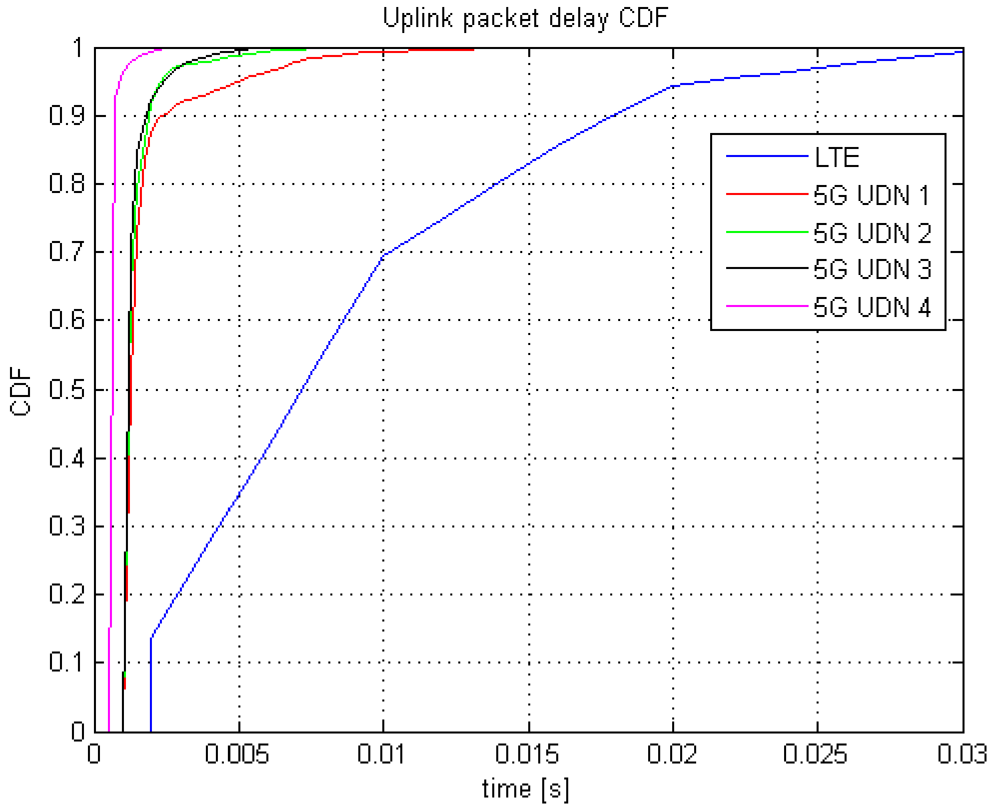

Figure A.30: CDF of packet delay of UL transmission.

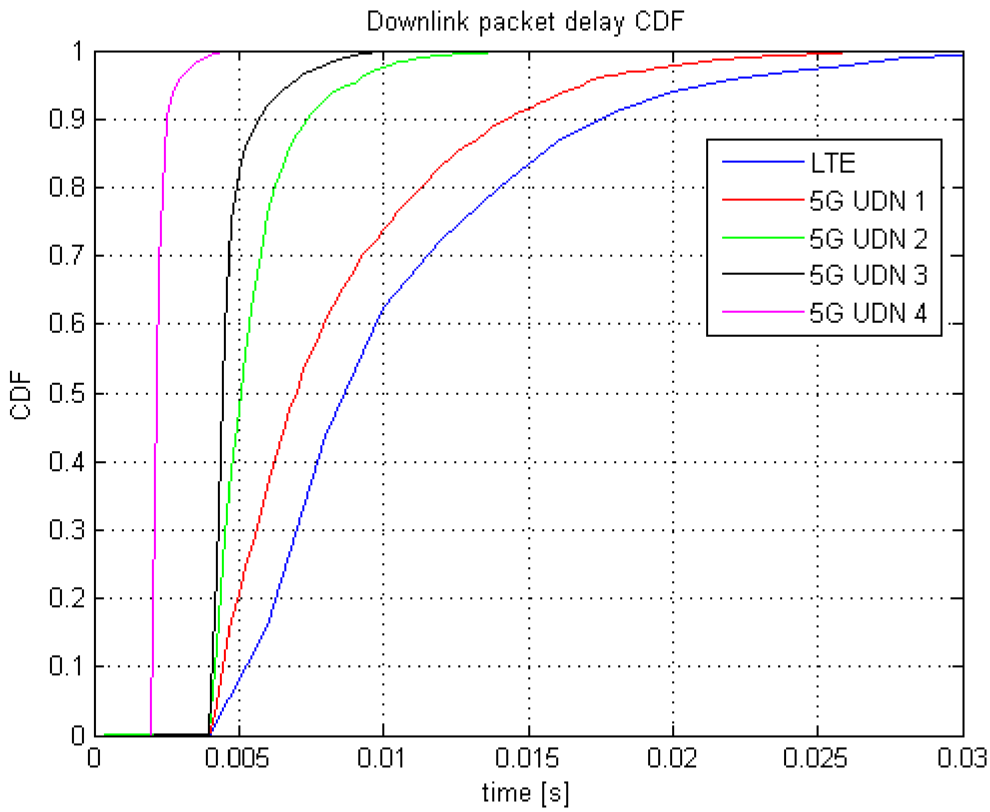

Figure A.31: CDF of packet delay of DL transmission.

95th percentile packet delay was used as an input to calculate 5th percentile experienced data rate as described in Section A.4.1.4. The summary is presented in Table A.12.

Table A.12: 5th percentile packet throughput.

Scenario	UL [Mbps]	DL [Mbps]
LTE	15	55
UDN 1	60	71
UDN 2	120	137
UDN 3	120	200
UDN 4	300	436

The results show that flexible UL/DL air interface design is a good method to dynamically adjust for rapidly changing traffic variations. In case of baseline solutions it is also possible to adapt UL/DL slot allocation with the resolution of 80 ms, but this may be insufficient in many cases (e.g. in case of considered evaluation 90 % of packets were transmitted within 18 ms). Performance gains of UDN 1 over LTE are much higher in UL than DL (factor of 5.8 and 1.2 respectively for average packet delay, cf. Table A.13) and this is due to the fact that in LTE, before the slot allocation could be changed to adapt to UL heavy slot allocation, only 20 % of radio resources (i.e. 2 out of 10 slots) could be used to carry UL traffic.

The user performance does not scale up linearly with the node densification due to increased impact of interference. However, we still observed significant gains due to the reduced number of users served per cell. Providing additional spectrum for TDD transmission proved to be an efficient way of improving end user experience. In the considered scenario with 40 MHz bandwidth available, more than 90 % of the users were able to finish 1.2 Mb packet download within 2 ms. Using 20 MHz bandwidth, 4 ms were needed to finish packet download.

Table A.13: Packets delay decrease ratio over LTE results.

Simulation scenario	Allocated spectrum [MHz]	Av. #users per node	UL packets delay decrease ratio over LTE results		DL packets delay decrease ratio over LTE results	
			median	95th	median	95th
UDN 1	20	12	5.8 %	4.2 %	1.2 %	1.2 %
UDN 2	20	6	6.1 %	8.4 %	1.8 %	2.4 %
UDN 3	20	3	6.1 %	8.4 %	2.0 %	3.1 %
UDN 4	40	3	11.8 %	21.0 %	4.0 %	7.3 %

Table A.14: User experienced data rates.

Simulation scenario	Allocated spectrum [MHz]	Av. #users per node	User experienced UL data rates [Mbps]		User experienced DL data rates [Mbps]	
			median	95th	median	95th
LTE	20	12	41.7 %	14.3 %	138.6 %	57.1 %
UDN 1	20	12	240.0 %	60.0 %	171.4 %	70.6 %
UDN 2	20	6	254.7 %	120.0 %	244.9 %	137.1 %
UDN 3	20	3	254.7 %	120.0%	272.7 %	177.8 %
UDN 4	40	3	491.8 %	300.0 %	550.0 %	416.7 %

A.4.4 Conclusions

UDN is one of the key components of the 5G network and one of the key enablers to meet the overall METIS objectives, e.g. coping with 1000x traffic growth. One of the key features of UDN is flexible UL/DL TDD air interface design that allow for increased spectral efficiency. Comparing to performance of fixed UL/DL slot allocation (LTE-A) it allows for fast adaptation to changing traffic. Higher interferences experienced by users/access nodes due to mismatch in slot allocation between neighbouring cells in case of larger traffic loads, can be tackled using centralized short term RRM and decoupling of control/user plane mechanisms [MET13-D41], that are also part of UDN concept.

According to provided evaluation, HT UDN is capable of meeting these KPIs. Results for UDN 4 scenario meet TC2 required KPIs for experienced user data rate (300 Mbps for DL and 60 Mbps for UL with 95 % availability). With TC2 defined assumptions, key enablers are flexible UL/DL TDD air interface and network densification up to 1 AP/room for indoor scenario. Additional spectrum, 40 MHz in TDD mode in total, is needed, although evaluation results suggest that by careful adjustment of scheduler settings lower value may be sufficient.

A.5 Intermediate system evaluation of URC

In order to improve traffic efficiency and to aid the driver to avoid the occurrence of an accident, Cooperative Intelligent Traffic Systems (C-ITS) [MET13-D11] which rely on timely and reliable exchange of information can be exploited. This refers to the collection of information about the state of other vehicles (e.g. position, velocity and acceleration) through communications and also to the information exchange between Vulnerable Road Users (VRU) and vehicles. The main challenge here corresponds to the required reliability, e.g. latency and successful packet transmission rate, of the information transmission.

Above scenario refers to a communication process where a vehicle tries to transmit its information to vehicles and pedestrians in its proximity. Our system level evaluation of HT URC is focused on these Vehicle-to-vehicle (V2V) and Vehicle-to-Pedestrian (V2P) transmissions under TC2 '*Dense urban information society scenario'* [MET13-D11]. U-plane latency of this communication process is inspected here to evaluate the impact of HT URC on legacy LTE FDD network and whether our current LTE FDD network is capable to fulfil reliability requirement of above V2V and V2P applications.

In legacy LTE network, information exchange and collection process described above can be executed by the following process:

- An information packet is generated at transmitter with certain periodicity.
- The packet is transmitted to the serving eNodeB of transmitter.
- Serving eNodeB of transmitter forwards the packet to serving eNodeBs of receivers.
- Packets are transmitted to receivers from their serving eNodeBs.

In the simulated network it is assumed that packet transmission between eNodeBs could be done rapidly, without traversing the core network.

A.5.1 Simulation assumptions

TC2 defined in [MET13-D11; MET13-D61] is used here for simulation purpose and detailed simulation assumptions of this test case can be found in [MET13-D61]. Since HT URC is specifically evaluated here under this test case, important information related with this individual evaluation is highlighted now.

A.5.1.1 Environmental model

As shown in Figure A.32, the red circle shows the inspected area of V2V and V2P communications in our scenario.

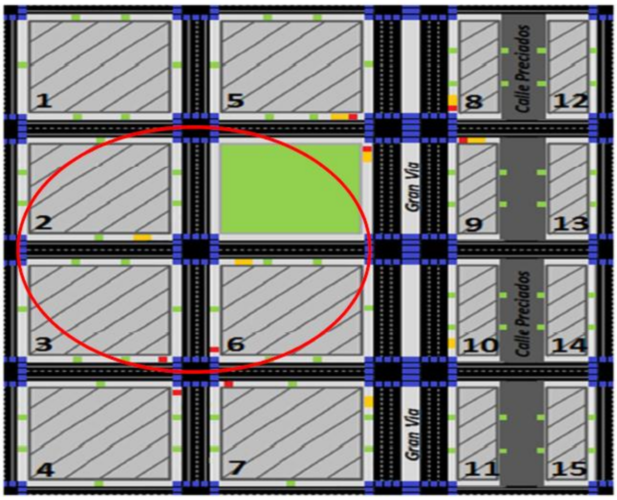

Figure A.32: TC2 and area of interest in the URC analysis.

A.5.1.2 Deployment model

2.6 GHz of operating frequency and a dedicated bandwidth for V2V and V2P communications are assumed here. Therefore, no traditional cellular users reuse the same frequency resource. The bandwidth resource of both uplink and downlink will be increased from 10 MHz up to 400 MHz in our simulation to check the improvement of system performance due to this increase.

A.5.1.3 Traffic model

A small packet of 800 Bytes is generated by one vehicle with 10 Hz periodicity and this vehicle wants to transmit this packet to all vehicles and vulnerable road users located in its proximity with a radius of 100 meters.

In the whole scenario, 6250 vehicles are deployed and vulnerable road users in this case are referred to following outdoor pedestrians:

- pedestrians walking on sidewalks, with a total number of 2125 in the whole scenario;
- pedestrians waiting in front of traffic lights, with a total number of 500 in the whole scenario;
- pedestrians waiting in bus stops, with a total number of 1000 in the whole scenario;

As described before, our inspected area is restricted to a certain area of the whole scenario. The simulated area is about 11.14 % of the whole TC2 area. Then, the number of vehicles simulated in the inspected area should be 697 and the number of VRUs should be 403. Due to simulation complexity reasons, above numbers are downscaled by ten times and therefore 70 vehicles and 41 VRUs are actually modeled in the simulation.

A.5.1.4 Mobility model

Mobility model is aligned with description of [MET13-D61] and only outdoor vehicles and VRUs are under inspection.

A.5.1.5 U-plane latency parameters

In Table A.15, U-plane latency parameters for our evaluation are listed.

Table A.15: U-plane latency parameters.

Description	Value
UE processing delay	1 ms
Frame alignment	0.5 ms
TTI for UL/DL packets	Packet specific
HARQ retransmission	7 ms
eNB processing delay	1 ms
Packet exchange between eNBs	1 ms

Note that the minimum delay between the end of a packet and the start of a retransmission is 7 ms in LTE FDD mode, in Table A.15, and this value is used in the simulation when HARQ retransmission is inspected. Besides, even though transmitted packets have a fixed number of 800 Bytes, the number of TTIs required for one packet transmission in either uplink or downlink is packet specific, since it depends on the spectrum efficiency of coding and modulation scheme and frequency resource blocks allocated to each packet.

A.5.1.6 Key performance indicators

End to end latency: this latency is calculated as the time difference between packet arrival time at transmitter and successful received time of this packet at receiver. In case one packet is not successfully transmitted to receiver, end to end latency is considered as infinity.

Average latency: mean value of end to end latency with respect to successful transmission. Note that the unsuccessful transmission is not taken into account since they are considered to have a latency value of infinity.

Packet successful transmission rate: ratio between the number of successful packet transmissions and the number of packets which should be transmitted. The number of packets that should be transmitted can be derived as:

$$N = \sum_{i=1}^{M} R(i)$$

where M represents the total number of transmitters trying to transmit packets to receivers located in their proximity and $R(i)$ represents the number of receivers located in the proximity of the i-th transmitter.

A.5.2 Simulation methodology

U-plane end to end latency can be divided into three parts in terms of the logical position of one packet in the LTE network as follows:

- Uplink latency – uplink latency represents the time difference between generation of one packet at transmitter and it is successfully received by serving eNodeB.
- Propagation latency between eNodeBs – propagation latency between eNodeBs represents the packet propagation time between the serving eNodeB of transmitter and the serving eNodeB of receiver.
- Downlink latency – downlink latency represents the time difference between a packet successfully received by the serving eNodeB of receiver and the successful transmission of this packet from the serving eNodeB to the receiver.

A.5.2.1 Uplink latency

The uplink latency can be evaluated by the following methodology:

1) A packet is generated at one vehicle. In a period of 100 ms, packets generation time among different vehicles has a uniform distribution.
2) Perform transport block CRC attachment and code block segmentation on each packet.
3) Decide coding and modulation scheme with respect to SINR value of each transmitter.
4) BLER is derived from SINR value of each transmitter.
5) Round robin scheduler is used to determine how many frequency resource blocks and TTIs are allocated to each uplink packet.
6) Uplink packet starts to be transmitted to serving eNodeB.
7) If a packet is not received error free, with respect to BLER of step 4), we start HARQ retransmission and inspect on whether HARQ retransmission is possible and successful for each packet.
8) Once a packet is successfully received by serving eNodeB, the time instance of when this packet is received is recorded. If the packet transmission is not successful, the packet delay is considered as infinity.

To illustrate step 3) and 4), an example is given in Figure A.33 to show mapping from SNR to coding and modulation scheme and BLock Error Rate (BLER) in LTE network. For a link which has a SNR value of 8.7 dB, a CQI report will be fed back from receiver to transmitter. After receiving this CQI report, in order to fit the transmission strategy with radio link quality, transmitter selects the coding and modulation scheme which has the maximal transmission rate and a BLER less than 10 %. Thus without running a link level simulator in real time, the BLER of one radio link can be decided by mapping from SNR to BLER curve which is already offline stored in the database of system level simulator.

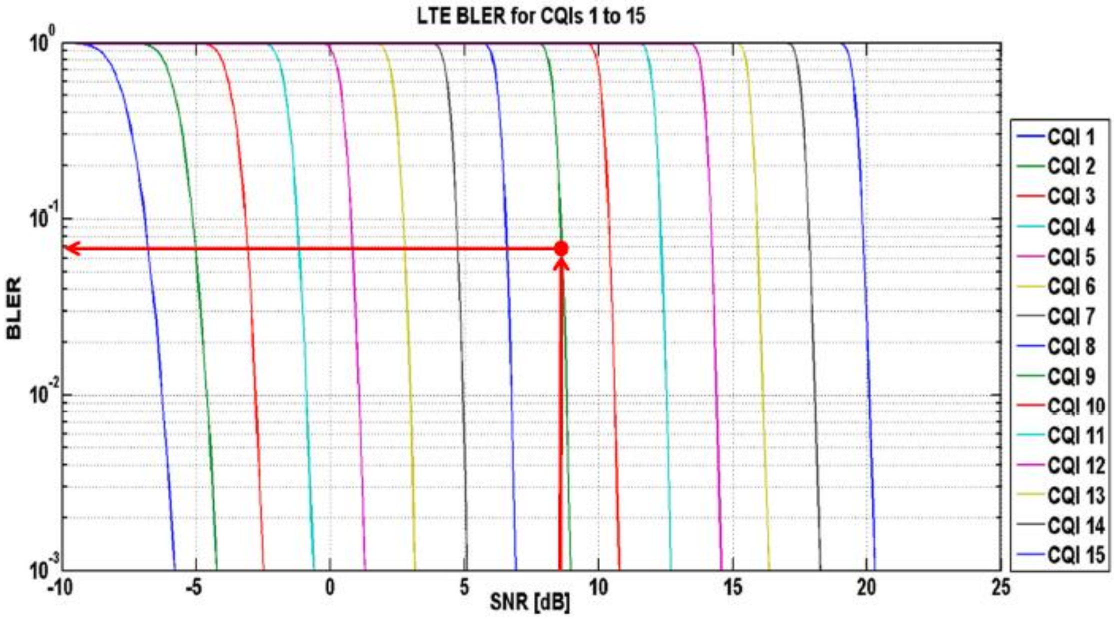

Figure A.33: Mapping from SNR to block error rate, BLER.

A.5.2.2 Propagation latency between eNodeBs

Packet propagation through serving eNodeB of transmitter to eNodeB of receiver may involve the behavior of the Core Network (CN). However, since receivers are located in the proximity of transmitter from location point of view, the distance between corresponding two eNodeBs is normally small and therefore it introduces a small value of propagation latency here.

In case transmitter and receiver are served by the same eNodeB, this propagation latency has a value of zero. Besides, in our evaluation, it is assumed that the packet can always be successfully transmitted from serving eNodeB of the transmitter to eNodeB of the receiver.

A.5.2.3 Downlink latency

The downlink latency from eNodeBs to receivers can be evaluated by the following methodology:

1) Only packets successful received by eNodeBs in the uplink will be transmitted in downlink.
2) A packet arrives at eNodeB, packet arrived time is decided by the uplink and the propagation latency between eNodeBs.

3) Perform transport block CRC attachment and code block segmentation on each packet.
4) Decide coding and modulation scheme with respect to SINR value of each receiver.
5) BLER is derived from SINR value of each receiver.
6) Round robin scheduler is used to determine how many frequency resource blocks and TTIs are allocated to each downlink packet.
7) Downlink packet starts to be transmitted to receiver.
8) If a packet is not received correctly, with respect to BLER of step 4), we start HARQ retransmission and inspect on whether HARQ retransmission is possible and successful for each packet.
9) Once a packet is successfully received by receiver, the time instance when the packet is received is recorded. If the packet transmission is not successful, the packet delay is considered as infinity.

A.5.3 Results

Figure A.34 shows the CDF plot of packet end to end latency with respect to number of resource blocks dedicated to V2V and V2P communications. Latency CDF curves demonstrate system performance with varied number of Resource Blocks (RBs) from 50+50 to 2000+2000, which corresponding to 10 MHz + 10 MHz and 400 MHz + 400 MHz for uplink + downlink bandwidth, respectively. Note that the number of users used in simulation has been downscaled by ten times, therefore the number of RBs required to provide same performance for TC2 model should be upscaled by ten times.

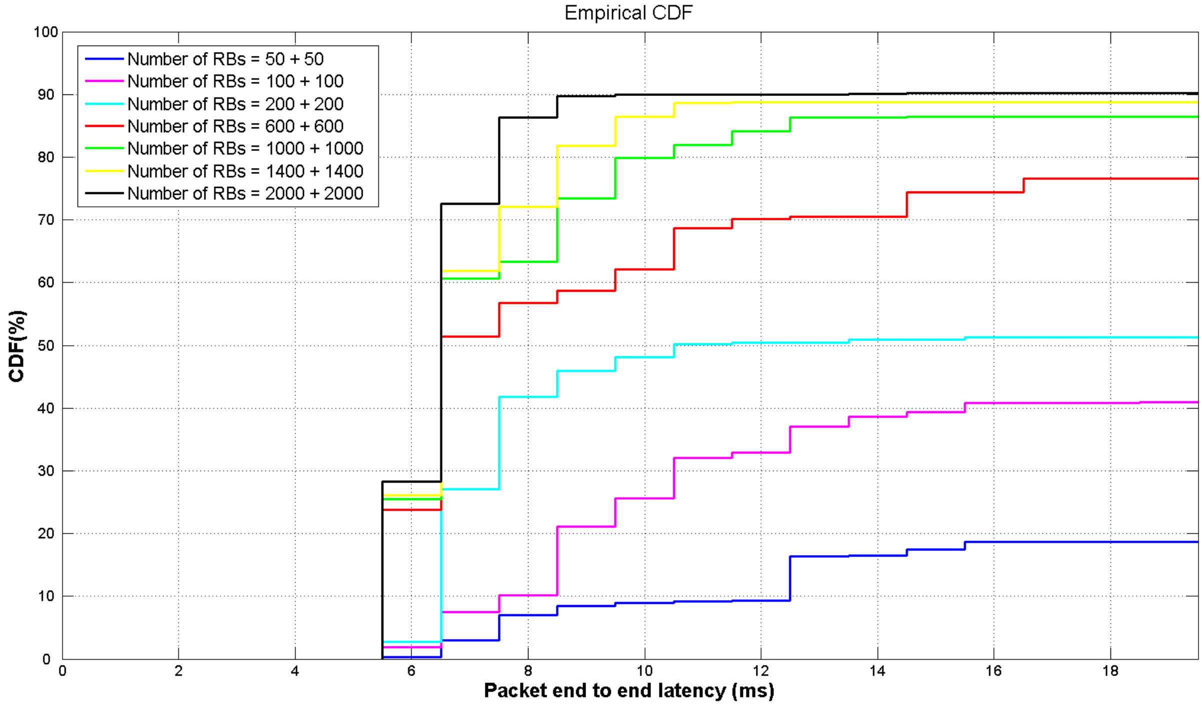

Figure A.34: CDF plot of end-to-end latency.

In Table A.16, the average latency and packet successful transmission rate are listed with respect to the number of resource blocks dedicated to V2V and V2P transmission. As can be seen from this table, when the number of RBs is increased above 1000, the improvement of system performance is less and less distinct, which shows the limitation of today's LTE network.

Table A.16: Average latency and packet successful transmission rate.

Number of RBs (Uplink+Downlink)	Average latency [ms]	Packet successful transmission rate
50+50	10.3	18.6 %
100+100	9.49	41 %
200+200	7.34	51.3 %
600+600	7.6	76.4 %
1000+1000	7.38	86 %
1400+1400	6.82	89 %
2000+2000	6.43	90.1 %

A.5.4 Conclusions

In order to fulfill the requirement of V2V and V2P communications in traffic safety scenario, an end to end latency below 5 ms and a packet successful transmission rate above 99.999 % are required. The system performance presented in previous section clearly shows the difficulty of exploiting current LTE network for V2V and V2P communications, even with direct transmission of packets between eNodeBs, since the latency and packet successful transmission rate cannot fulfill the KPI requirements of this scenario.

In order to have a latency value below 5 ms, a network controlled D2D communication where user data transmission does not go through network infrastructure is considered as a key promising solution in METIS. However, to have the network controlled D2D communication implemented and integrated into legacy network, a whole set of technology components are under development of METIS from physical layer to other relevant higher layers with consideration on both user and control planes. For instance, METIS is addressing and developing a new frame structure with a reduction of transmission time interval from 1 ms to 0.25 ms, robustness physical layer transmission technology and latency critical HARQ scheme. Besides, packet successful transmission rate can be increased with more bandwidth.

Annex B

B. Intermediate technology components evaluations

In Annex B the intermediate technology components (TeCs) evaluations are presented. The evaluation of the TeCs focuses on the promising components in terms of an overall METIS 5G system perspective, taking the METIS goals, horizontal topics and architectural aspects into consideration. Those TeCs are assessed against LTE-A baseline to estimate their contribution to METIS goals and to identify the most promising ones. Note that this evaluation is made using the self-assessment of the proponents of each TeC, that in most cases consists of a simulation following the guidelines provided in [MET13-D61].

This assessment is separated into four sections dealing with the components coming from the following Work Packages (WPs):

- WP2: Radio-link concepts,
- WP3: Multi-node/Multi-antenna transmissions,
- WP4: Multi-RAT/Multi-layer networks,
- WP5: Spectrum.

B.1 Interest for METIS concept and the system evaluation

In Table B.1 we show the preliminary list of TeCs identified by METIS as most promising for their integration into the evaluation process towards D6.5, the final deliverable on METIS concept results. It is worth noting that not being in this list does not mean that the TeC lacks interest. On the contrary, all TeCs listed in the subsequent sections are found of highest scientific interest but some of them could be more difficult to integrate into a single system due to the incipient stage in the research. The identification of the contribution to the METIS goals is made using the simulation results provided in the description of each TeC.

Table B.1: Identified TeCs with high interest for the METIS concept and system evaluation.

TeC	Name	Contribution to the METIS goal(s)	Enabler for HT(s)
WP2-TeCC1	Air interface for dense deployments	Data volume, data rate, battery lifetime, latency, energy efficiency	UDN, D2D, MMC
WP2-TeCC8	Filtered and filter-bank based multi-carrier	Data volume, data rate	MMC, D2D, UDN
WP2-TeCC11.1	Non- and quasi-orthogonal multiple access	Data volume, data rate, number of devices	D2D, MMC, MN, UDN
T3.1-TeC1b	DFT based Spatial Multiplexing and Maximum Ratio Transmission (DFT-SM-MRT) for mmW large MIMO	Data volume, data rate	UDN (Wireless Backhaul)
T3.1-TeC6	Adaptive large MISO downlink with predictor antenna array for very fast moving vehicles	Energy efficiency	MN
T3.1-TeC7	Massive MIMO transmission using higher frequency bands based on	Data volume, data rate	UDN

	measured channels with CSI error and hardware impairments		
T3.1-TeC11	Heterogeneous multi-cell, MU Massive-MIMO, massive SDMA	Data volume, data rate, energy efficiency	UDN
T3.2-TeC7	Dynamic Clustering with Multi-antenna Receivers (DCMR)	Data volume, data rate	UDN
T3.2-TeC12	Network-assisted co-channel interference robust receivers for dense cell deployments	Data volume, data rate	UDN
T3.2-TeC13	Interference mitigation based on JT CoMP and massive MIMO	Data volume, data rate	UDN
T3.2-TeC3	Precoding scheme for interference mitigation in multi-cell multi-antenna systems based on local CSI and data sharing	Data volume, data rate	UDN
T3.2-TeC8	Non-Orthogonal Multiple Access (NOMA) with multi-antenna transmission schemes.	Data volume, data rate	UDN, MN
T3.3-TeC2	Interference aware routing and resource allocation in a mmW UDN	Data volume, data rate	UDN
T3.3-TeC3	Virtual Full-Duplex Buffer-aided Relaying (VFD-BR)	Data volume, data rate	UDN
T4.1-TeC3-A1	Distributed CSI-based mode selection for D2D communications	Energy efficiency, data volume	D2D
T4.1-TeC4-A1	Multi-cell coordinated resource allocation for D2D	Latency	D2D, UDN
T4.1-TeC6-A1	Smart resource allocation in a UDN scenario – legacy network models	Latency	D2D, UDN
T4.1-TeC7-A1	Time-sharing interference mitigation using resource auctioning and regret-matching learning	Latency	UDN, MMC
T4.1-TeC9	Dynamic clustering	Data volume, data rate, energy efficiency	UDN
T4.1-TeC10	Overlapping supercells for dynamic effective user scheduling across bands	Data volume, data rate	UDN
T4.1-TeC15	Further enhanced ICIC in D2D enabled HetNets	Data volume, data rate, latency	D2D
T4.2-TeC2	Context awareness through prediction of next cell	Data volume, data rate	MN, UDN
T4.2 - TeC5-A1	User-oriented context-aware vertical handover	Data volume, data rate	UDN
T4.2-TeC9-A2	Long-term context-aware scheduling for ultra-dense networks	Data volume, data rate, Latency	UDN
T4.2-TeC12	Context-based device grouping and signalling	Latency	MMC
T4.2-TeC13-A1	Network assisted small cell discovery	Energy efficiency	UDN
T4.2-TeC17	Downlink Multi-User SCMA (MU-SCMA) for mobility-robust and high-data rate MN-M	Data volume, data rate	MN
T4.3-TeC3-A2	Dynamic nomadic node selection for backhaul optimization	Data volume, data rate	MN
T4.3-TeC5	Self-management enabled by central	Energy efficiency	UDN

	database for energy savings in the phantom cell concept		
WP5-TeC04	Coordinated multi-carrier waveform based sharing technique	Data volume, data rate	UDN
WP5-TeC14	Spectrum sharing and mode selection for overlay D2D communication	Data volume, data rate	D2D

B.2 WP2: Radio-link concepts

In this section the selected technology component clusters of WP2, the radio-link concepts, are presented in more detail. A description and the respective degrees of impacts of each Technology Component Cluster (TeCC) are provided. More detailed information on these TeCCs can be found in the corresponding deliverables of WP2, see e.g. [MET14-D23].

B.2.1 WP2-TeCC1: Air interface for dense deployments

WP2-TeCC1 is the Unified air interface design for UDN. This technology component cluster contains three technology components, these are:

- TeC1: Frame structure (including multi-antennas and beamforming),
- TeC2: Dynamic TDD,
- TeC3: Harmonized OFDM / PHY layer numerology.

WP2-TeCC1 has been introduced in [MET14-D23, in Section 2.1 and Section 5.1].

The WP2-TeCC1 is designed for UDN with an optimized TDD scalable frame structure. It enables flexibility and short PHY layer latency, and by that support highly asymmetric traffic and has fast reaction time.

In terms of addressing the METIS goals, WP2-TeCC1 is highly relevant. Initial simulation results show that the user data rate is improved by at least 10x, together with around 8x reduced latency. Beamforming and small cell size reduces energy consumption and is an important enabler for higher frequency bands. Further, the battery lifetime of the devices can be reduced by 7-40x, see [MET14-D23], and also the energy efficiency of the system can be improved by this technology component cluster.

B.2.2 WP2-TeCC8: Filtered and filter-bank based multi-carrier

WP2-TeCC8 is the Filtered and filter bank based multi-carrier. This technology component cluster contains two technology components, these are:

- TeC1: Filter-bank based multi-carrier, FBMC, based waveform and TRX design;
- TeC2: Universal filtered multi-carrier, UFMC.

WP2-TeCC8 has been introduced in [MET14-D23, in Section 2.8 and Section 5.8]. In Section 2.3.2, i.e. under possible air interfaces that are alternatives to OFDM, both FBMC and UFMC are described.

In terms of addressing the METIS goals, WP2-TeCC8 improves both the data rate and data volume with 2-4x according to the first evaluation results.

B.2.3 WP2-TeCC11.1: Non- and quasi-orthogonal multiple access

WP2-TeCC11.1 is the Non- and quasi-orthogonal multiple access allowing spectrum overload. This technology component cluster contains two technology components, these are:

- TeC1: Non-Orthogonal Multiple Access (NOMA),
- TeC2: Sparse Coded Multiple Access (SCMA).

WP2-TeCC11.1 has been introduced in [MET14-D23, in Section 2.11.1 and Section 5.11.1].

WP2-TeCC11.1-TeC1 is the Non-orthogonal multiple access, NOMA, which is a downlink scheme where multiple users are power-domain multiplexed on the transmitting base station and where signal separation at the receiving side.

WP2-TeCC11.1-TeC2 is the Sparse coded multiple access, SCMA. The overall complexity of the SCMA nonlinear receiver is about four times more than a typical linear MIMO detector [MET14-D4.2].

The METIS goals addressed by WP2-TeCC11.1 are the data rate improvements with up to 1.5x, see [MET14-D23], and enabling the number of devices increase with at most 3x according to the first simulation results.

B.3 WP3: Multi-node/Multi-antenna transmissions

WP3 is working with many topics related to multi-nodes and multi-antennas. The work is divided as follows:

<u>T3.1 Multi-antenna/massive MIMO</u>

Assess implications of new scenarios/requirements and new radio-link solutions on multi-antenna transmission/reception, and develop solutions to exploit the potential of massive antenna configurations, including the higher frequencies above 3 GHz.

<u>T3.2 Advanced inter-node coordination</u>

Develop novel inter-node coordination techniques in particular in dense heterogeneous networks and analyse their architectural impact, performance and computational complexity.

<u>T3.3 Multi-hop communication/wireless network coding</u>

Provide innovative multi-hop communication concepts and wireless network-coding solutions for the relevant scenarios.

This WP also contributes to a number of horizontal topics, in particular:

- Advanced inter-node coordination in ultra-dense/multi-layer deployments (T3.2).
- Performance enhancing techniques for multi-hop communications related with MMC or D2D communication and moving networks (T3.3).

The selected technology components, TeCs, of WP3 are presented below. More detailed information on these TeCs can be found in the corresponding deliverables of WP3, see e.g. [MET14-D32].

B.3.1 T3.1-TeC1b: DFT based Spatial Multiplexing and Maximum Ratio Transmission for mmW large MIMO

TeC1b proposes a solution for the wireless backhaul links:

- Spectral efficient,
- Low complexity,
- Suitable for an Ultra-Dense Network (UDN).

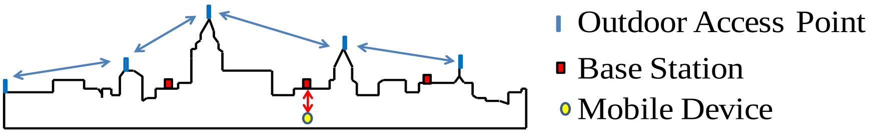

Figure B.1: Wireless backhaul links in an ultra-dense network.

The proposed scheme is particularly interesting to the links between nodes in Line Of Sight (LOS) or near to LOS of each other (typically base stations on roof tops of buildings).

According to the antenna spacing and transmitter-receiver distance, the large MIMO channel in mm-wave communications is likely to be ill-conditioned. In such conditions, highly complex schemes such as the Singular Value Decomposition (SVD) are necessary. A new low complexity system called Discrete Fourier Transform based Spatial Multiplexing (DFT-SM) with Maximum Ratio Transmission (DFT-SM-MRT) is proposed. When the DFT-SM scheme alone is used, the data streams are either mapped onto different angles of departures in the case of aligned linear arrays, or mapped onto different orbital angular momentums in the case of aligned circular arrays. Maximum ratio transmission pre-equalizes the channel and compensates for arrays misalignments.

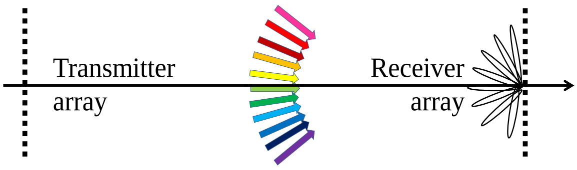

Figure B.2: With linear arrays, data streams are mapped onto angles of arrivals.

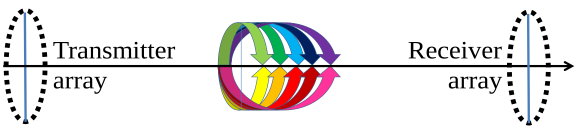

Figure B.3: With circular arrays data streams are mapped onto vortices of various orbital angular momentums.

Depending on the scenario, DFT-SM-MRT achieves hundreds of bits/s/Hz. In comparison with SVD, DFT-SMR-MRT achieves 1/3 to 1/14 of SVD performance, with a complexity which is around 3×10^{-5} times lower, for the considered number of antennas (N=512).

Table B.2: DFT-SM-MRT Performance at m=40.

Effects	DFT-SM-MRT spectral efficiency [bits/s/Hz]		Ratio between DFT-SM-MRT and SVD spectral efficiencies	
	Circular Array	Linear Array	Circular Array	Linear Array
Translation	770	224	>1/3	≈3/4
Rotation	1000	215	≈1/3	≈5/7
Reflection	440	135	>1/7	≈4/9
All	215	189	>1/14	≈5/8

Compared to a mmW SISO system (achieving 6 bits/s/Hz with 64 QAM), the gain of the proposed system, in terms of spectral efficiency, reaches around 1000/6, i.e. 166.

The achieved spectral efficiencies are huge (215 to 1000 bits/s/Hz), due to the fact that up to 512 streams can be multiplexed spatially.

DFT-SM-MRT provides high spectral efficiency without inter-antenna spacing optimization with respect to the distance, and is robust to misalignment plus one reflector. This TeC is an enabler for wireless backhaul.

B.3.2 T3.1-TeC6: Adaptive large MISO downlink with predictor antenna array for very fast moving vehicles

A new scheme called Polynomial Interpolation (PI) is proposed specifically for large MISO downlink beamforming in TDD. The objective is to provide a highly efficient wireless backhaul, in terms of energy consumption, for fast moving vehicular relays.

Beamforming miss-pointing occurs at high speed, due to outdated channel state information at the BS.

An array of aligned predictor antennas, placed upon the roof of the vehicle periodically sends pilots to the BS, to provide a very dense pattern of channel measurements in space. The BS interpolates the measurements to predict the channel between the BS and the receive antenna, accurately.

The Polynomial Interpolation scheme is compared to several less complex prediction techniques derived from the Separate Receive and Training Antenna (SRTA) scheme [PHH13], namely a Random Switch Off Scheme (RSOS), the Border Switch Off Scheme (BSOS) and a Reference System (RS).

As illustrated in Figure B.4, thanks to SRTA-PI the target BLER is met for all speeds up to 300 km/h.

Energy saving is defined as the ratio of the power that would be radiated by the Base Station in SISO mode over the power effectively radiated by the Base Station when Large MISO beamforming is activated. As illustrated in Figure B.5, there is no sacrifice of energy saving at high speeds.

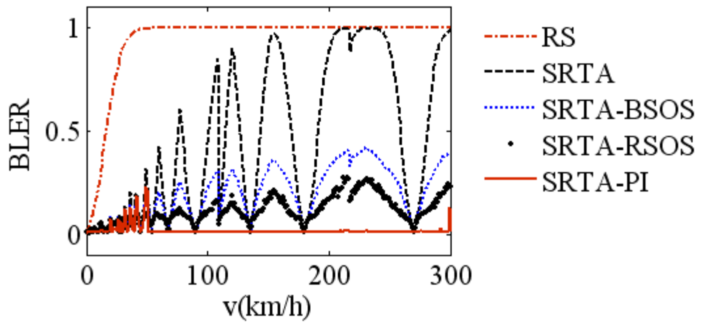

Figure B.4: BLER versus speed. The RS (Reference System) is an LTE-A like system, SRTA (Separate Receive and Training Antenna), BSOS (Border Switch Off Scheme), RSOS (Random Switch Off Scheme), PI (Polynomial Interpolation).

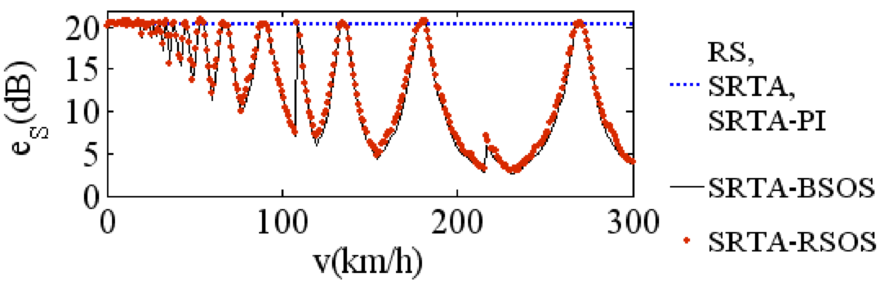

Figure B.5: Energy saving versus speed.

TeC6 is therefore proposing a candidate solution to support TC8.

B.3.3 T3.1-TeC7: Massive MIMO transmission using higher frequency bands based on measured channels with CSI error and hardware impairments

This TeC relates to performance evaluation of Massive-MIMO transmission using higher frequency bands. In order to clarify the requirements, the influences of the CSI error and the hardware impairments on the throughput performance are evaluated. From these investigations, novel precoding and compensation methods will be proposed so as to satisfy the requirements for Massive-MIMO using higher frequency bands.

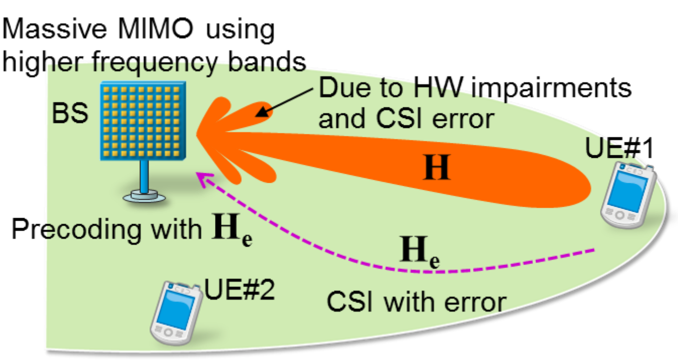

Figure B.6: System model.

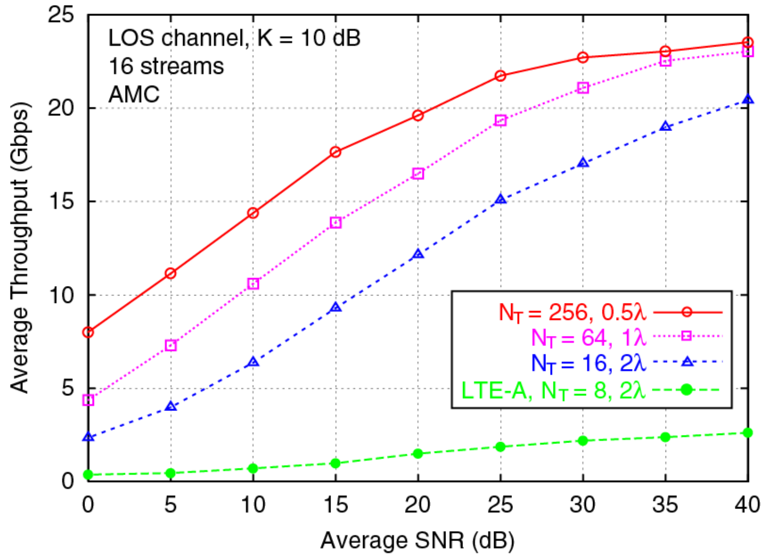

Figure B.7: Throughput performance of 20 Gbps massive MIMO.

Figure B.7 shows the throughput performance of the Massive MIMO when the number of transmitter antennas, NT, is set to 16, 64, and 256. In order to keep the entire antenna array size, the TX antenna spacing is changed to 2λ, 1λ, and 0.5 λ for each NT, respectively. In addition, the throughput performance of LTE-A using NT = 8, NR = 8, and 100 MHz bandwidth is added for comparison. The total TX power is constant regardless of the NT. Compared to NT = 16, NT = 64 obtains the diversity gain in addition to the BF gain. With NT = 256, the additional BF gain can reduce the required SNR to achieve 20 Gbps throughput by 17 dB and 6 dB compared to NT = 16 and 64, respectively. Moreover, when the average SNR = 21 dB, NT = 256 achieves the 20 Gbps throughput which is more than 10 times as high as the throughput in LTE-A.

B.3.4 T3.1-TeC11: Heterogeneous multi-cell, MU Massive-MIMO, massive SDMA

This technology component aims on downlink in a TDD system where we assume a 8x16 rectangular active antenna array. In contrast to the term “massive” MIMO that inherently considers that the number of antennas N_t is much larger than the number of user N_k in the systems, i. e. $N_t \gg N_k$, we introduce the term “massive SDMA” considering the regime $N_t \approx N_k$. Further on, we assume that the channel state information at the transmitter is obtained by channel reciprocity in the TDD system.

For multi-user MIMO precoding Zero-Forcing (ZF) is considered in combination with either sum-rate maximizing semi-orthogonal user selection henceforth called PBZF or simple Round Robin (RR) grouping. By increasing the number of users in the system, we observe a sum SE gain exploiting user diversity for PBZF. The drawback is that the number of simultaneously served Mobile Stations (MSs) is approximately constant. Using instead RR grouping the SE performance is degrading increasing the number of MSs. This is due to the reduction of signal power by an equal spread over more streams and an imbalance between intra and Inter-Cell Interference (ICI). This means that cancelling intra-cell interference to zero sacrificing signal power is not necessary in the presence of ICI. Our solution for this is that information about the interference situation experienced by MSs needs to be fed back to the BS. Then Regularized ZF (RZF) precoding can be used where the idea is that inter-stream interference is only reduced to the same level as the already existing ICI. To keep the additional feedback overhead low we propose to use a wideband power value per MS which can be obtained by

$$P_{reg,k} = \frac{1}{N_{RB}} \sum_{i=1}^{N_{RB}} \mathrm{trace}\left(\mathbf{Z}_{k,i}\right),$$

where N_{RB} is the number of Resource Blocks (RBs) and $\mathbf{Z}_{k,i}$ the inter-sector covariance plus noise matrix of MS k and RB i.

Another aspect arising with the limited transmission power spread over a larger number of antennas is that power constraints in today systems such as the maximum power per antenna [3GPP12-36213] due to power amplifier requirements can be relaxed. We showed that changing the per antenna power constraint into a pool power constraint improves system-performance and still keeps the maximum transmitted power per antennas far below today requirements.

A seven times gain compared to the LTE-A baseline scenario regarding the median value of the sum SE is observed by utilizing the beamforming gain of a large antenna array, serving more users simultaneously and relaxing power constraints. This TeC is especially suited for the operation of UDN.

B.3.5 T3.2-TeC7: Dynamic Clustering with Multi-antenna Receivers (DCMR)

The work develops a dynamic clustering and scheduling algorithm for downlink cellular networks with joint transmission. The algorithm allows a dynamic optimization, in each time slot, of the set of non-overlapping clusters and the UEs scheduled within each cluster, maximizing the network weighted sum rate.

This TeC shows up to 43 % gain on cell edge user throughput with Dynamic Clustering against no cooperation (LTE-A baseline). This CoMP TeC is especially suited for the operation of UDN.

B.3.6 T3.2-TeC12: Network-assisted co-channel interference robust receivers for dense cell deployments

This TeC proposes the introduction of Network Assistance (NA) to further enhance the co-channel inter-cell interference mitigation ability of UE receivers. Network assistance, in forms of interference signal parameter signalling and/or network side transmission coordination, is utilized to improve the accuracy of interference estimation and consequently the Interference Suppression and Cancellation (IS/IC) performance of NA-enabled UE receivers. The improved interference robustness, in the form of a higher effective post-IS/IC SINR, enables higher user throughput / network capacity and increased spectral-efficiency in co-channel interference limited networks.

NA shall brought approximately 100 % gain on user throughput at low SINR (-14 dB), and approximately 20 % at moderate SINR (-6 dB) and is especially suited for UDN.

B.3.7 T3.2-TeC13: Interference mitigation based on JT CoMP and massive MIMO

T3.2-TeC13 has the goal to combine Joint Transmission (JT) Coordinated Multi-Point (CoMP), massive MIMO and small cells into an overall network concept. The basis is an interference mitigation framework with interference floor shaping –the so called tortoise concept– as one of the main pillars. This allows concentrating the optimization and the performance evaluation to cooperation areas of limited size like e.g. three sites and/or nine cells.

The centralized or distributed joint processing applies an opportunistic CoMP scheme, meaning that the optimum precoding and scheduling decisions are done based on available context information like number of relevant channel components, reliability of channel state information, backhaul capabilities to certain cells, load conditions and so on. It combines coordination with cooperative transmission and ensures robust and low effort processing per cooperation area.

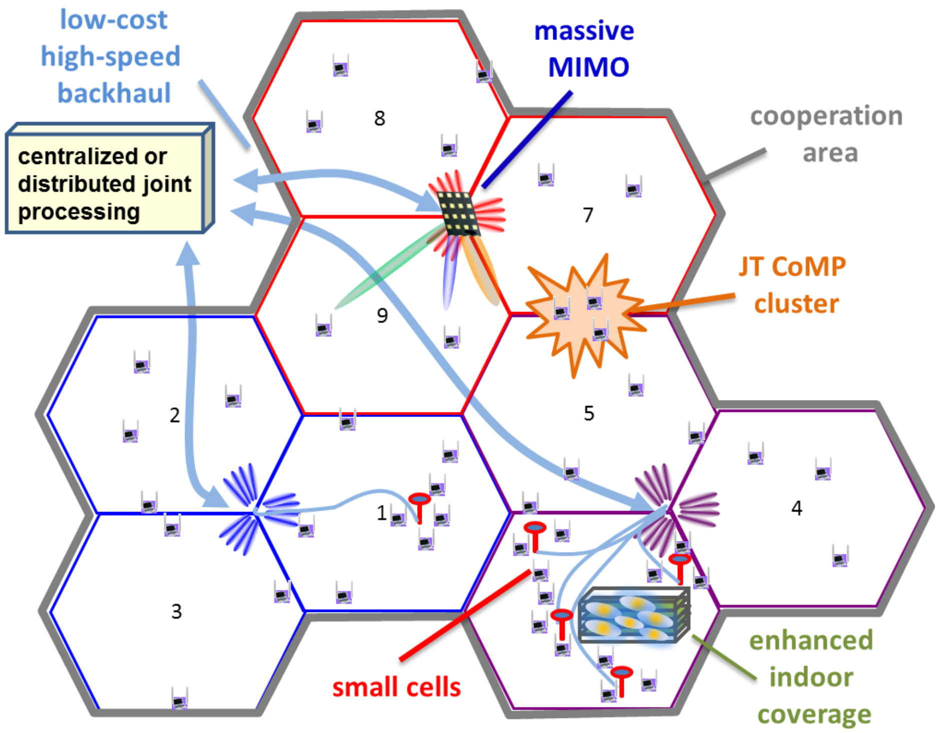

Figure B.8: Integrated mobile network concept including small cells, JT CoMP and massive MIMO.

Massive MIMO (128 antenna elements) allows a factor 2 to 3 compared to 3GPP Case 1 MIMO 4x2. With powerful interference mitigation schemes, spectral efficiency of 25 bit/s/Hz/cell seems possible accounting with 43 % overhead, which gives a factor 8 over LTE-A MU-MIMO 4x2.

Nonetheless, all results so far indicate the great potential of massive MIMO and CoMP. For similar performance a solution using CoMP and small cells in addition to massive MIMO seems to allow for a reduction of overall antenna elements by a factor of three to four.

For real world deployments that might be an important argument to go for a moderately more complex solution being awarded by according HW cost savings and a more reasonable size of the antenna arrays. This is particularly suited for UDN.

B.3.8 T3.2-TeC3: Precoding scheme for interference mitigation in multi-cell multi-antenna systems based on local CSI and data sharing

This TeC develops a precoding scheme for interference mitigation based only on local channel state information for downlink TDD multi-cell multi-antenna systems with joint transmission and cached user data. The investigated scheme places interference components at the receivers coming from the different transmitters in predefined subspaces, so that they are completely or approximately cancelled.

This concept show an improvement of up to a factor 3 in spectral efficiency for high SNR compared to LTE-A with CoMP and is a promising technique in UDN context.

B.3.9 T3.2-TeC8: Non-Orthogonal Multiple Access (NOMA) with multi-antenna transmission schemes.

The main idea is to combine Non-Orthogonal Multiple Access (NOMA) schemes with multi-antenna transmission schemes. One example is to use multiple antennas at the transmitter to form multiple beams and within each beam, multiple users are multiplexed using a non-orthogonal multiple access based technique.

This idea is extended to multi-site operations by introducing inter-site interference coordination (e.g. in frequency, space and/or power domains).

The benefits of NOMA (i.e. OFDMA plus power-domain user multiplexing) compared to OFDMA are:

- Improved spectrum efficiency/system capacity/cell-edge user performance in both macro-cells and small cells (30 % gain is expected);
- The number of simultaneously served users can be almost doubled (up to 2 users multiplexed in power-domain);
- Spectrum efficiency/system capacity/cell-edge user performance can be improved even in high mobility scenarios (up to 250 km/h).

Consequently, NOMA targets UDN and MN HTs.

B.3.10 T3.3-TeC2: Interference aware routing and resource allocation in a mmW UDN

In order to enhance spectrum efficiency, the wireless backhaul and wireless access share the same spectrum. The purpose is to investigate low complexity sub-optimal algorithms for sharing and coordinating the resources among the backhaul and the access network. In particular, solutions are proposed to route simultaneous users through the mesh to one or several access gateway.

Based on the high level and yet far from optimized solution, the TeC 2 of T3.3 has strong potential in improving over LTE-A 100 MHz bandwidth for both UL and DL indoor baseline, with a factor of 10 or more by enabling usage of available spectrum in the 60 GHz area and an unprecedented densification of wirelessly connected access nodes.

This TeC is particularly suited for indoor situations in UDN.

B.3.11 T3.3-TeC3: Virtual Full-Duplex Buffer-aided Relaying (VFD-BR)

Buffers at the relay enable a virtual full duplex communication in a network where two relays allow of concurrent transmissions with inter-relay interference cancellation. One relay receives the information from the source while the other forwards the information to the destination. The idea is to find the best relay-pair selection for Source-Relay and Relay-Destination links with an optimal beamforming design at both transmitting and receiving relays.

With Virtual Full-Duplex Buffer-Aided Relaying almost double spectral efficiency can be achieved in a virtual full-duplex relaying network exploiting buffer and multiple antennas, compared to state-of-the-art half-duplex relaying.

B.4 WP4: Multi-RAT/Multi-layer networks

The selected technology components from WP4, Multi-RAT/Multi-layer networks, are given in the following section with a description and the respective degree of METIS impact of each technology component. The numbering of the TeCs is based on the task where the TeC was developed. There are three tasks within WP4. T4.1 is Co-existence, collaboration and interference management; T4.2 is Demand, traffic and mobility management; and T4.3 is Functional network enablers.

B.4.1 T4.1-TeC3-A1: Distributed CSI-based Mode Selection for D2D Communications

Distributed CSI-Based Mode Selection for D2D Communications, deals with mode selection and resource allocation for network assisted D2D communications. It exploits limited channel state information to select one of three possible communication modes for two D2D capable devices that are in the proximity of one another. Forced cellular mode implies the traditional cellular (via the cellular base station) communication mode, D2D mode without cellular resource reuse allows proximity users to use a direct D2D link with dedicated resources (no overlap with cellular users), while D2D with resource reuse allows D2D links to use cellular resources that are used by the cellular layer. This TeC takes into account both channel state information, resource availability and current load situation to select one of these three communication modes. The TeC can be combined with various other RRM and in particular power control algorithms to fully take advantage of D2D communications.

B.4.2 T4.1-TeC4-A1: Multi-cell coordinated resource allocation for D2D

Multi-cell coordinated and flexible resource allocation for D2D investigates a holistic system with both cellular and direct D2D traffic. Network controlled D2D is assumed and the performance of centralized vs. decentralized performance of the radio resource management in case of Ultra-Dense Networks is evaluated. Initial evaluation results show a 45 % D2D delay reduction compared to using a baseline LTE macro network.

B.4.3 T4.1-TeC6-A1: Smart resource allocation in a UDN scenario – Legacy Network Models

Smart resource allocation in a UDN scenario is a TeC which aims to benchmark the performance of UDN small cells using flexible uplink and downlink switching and centralized scheduling. Performance with decentralized scheduling is also simulated to further understand the benefits with coordination in the case of ultra-dense networks. Fixed uplink and downlink with predefined uplink and downlink ratio as per traffic requirements for decentralized scheduling is considered as baseline.

Delay-reduction of 22 % (38 %) – 71 % (22 %) UL (DL) reduction for packet size of 640 kb – 160 kb, compared to baseline is demonstrated considering support for 4x4 MIMO.

B.4.4 T4.1-TeC7-A1: Time-sharing interference mitigation using resource auctioning and regret-matching learning

This TeC deals with time-sharing interference mitigation using resource auctioning and regret-matching learning. This TeC exploits usage of resources in time, frequency and power domain with the aim to increase the aggregate throughput in small-cells and, consequently, increasing the aggregate throughput in the network. Although the proposed approach considers optimization of resource usage, similarly to LTE-A eICIC, it is performed in a decentralized manner, with game theoretic approach used to find the optimum solution. Moreover, additional constraints may be taken into account (besides interference) when using game theoretic optimization, such as the different cells load or traffic patterns. First simulations show, that the proposed provide up to 15 % increase in aggregate cell throughput and up to 20 % increase in small-cell throughput comparing to LTE-A eICIC.

B.4.5 T4.1-TeC9: Dynamic clustering

Dynamic clustering, a reduced area of TC2 has been simulated in order to optimize the cluster formation in this particular scenario. Simulations are used to compare the performance of the network when using clusters of different size. Initial simulations show a 60 % increase in user throughput compared to a baseline LTE system, considering 100 static users per floor with four pico cells per floor and 20 MHz bandwidth per cell.

B.4.6 T4.1-TeC10: Overlapping Supercells for Dynamic Effective User Scheduling Across Bands

In “Overlapping super cells for dynamic effective user scheduling across bands”, simulations are used to measure the improvement in terms of user throughput when using the idea of super cells. A static and overlapping optimized clustering is applied in a reduced area of TC2, simulating the behaviour of the network in different load situations. Simulations compare the idea of the supercell usage against LTE-A conventional use of carriers.

The inclusion of the dynamic clustering together with the supercell concept shows an improvement of user throughput above 120 %, going from an average user experience of 0.387 Mbps with LTE-A without any cooperation between femtocells up to 0.874 Mbps. This TeC is especially suited for the operation of UDN.

B.4.7 T4.1-TeC15: Further enhanced ICIC in D2D enabled HetNets

In “Further enhanced ICIC in D2D enabled HetNets” UEs of a D2D pair measure during muted subframes of macro BS (that is controlling them). If a strong small cell is not detected nearby, the D2D pair can be allocated resources within those muted resources for their communications, otherwise unmuted resources are used.

Initial results in TC2 show over 60 % throughput gains compared to the reference. Increased usage of D2D will also reduce latency.

B.4.8 T4.2-TeC2: Context awareness through prediction of next cell

In “Context awareness through prediction of next cell”, the impact of user mobility on user E2E performance in terms of throughput is studied. Means for user movement prediction are implemented. Further, mobility related KPIs, such as connection dropping, blocking, and HO failure ratios, are evaluated.

Initial results show a 46 % reduction of handover failures and 10 % reduction in connection drops. In addition, user throughput gains of up to 100 considering full buffer traffic and max C/I scheduling and up to 60 % using PF scheduling have been demonstrated.

B.4.9 T4.2-TeC5-A1: User-oriented context-aware vertical handover

This TeC proposes a context-aware vertical handover mechanism, which is able to dynamically adapt its decisions per IP flow based on network indicators such as the load of the base stations, or UE-oriented characteristics, such as the IP flow's sensitivity to latency or UE mobility. Primarily, it is based on the RSS of the available RATs, which is insufficient for test cases such as TC3 of METIS, where ultra-dense environments with high user requirements are present.

Initial results show a 15 % to 30 % reduction in the number of handovers, a 25 % to 50 % increase in DL throughput and an 80 % to 200 % increase in UL throughput depending on load.

B.4.10 T4.2-TeC9-A2: Long-term context-aware scheduling for ultra-dense networks

In "Long-term context-aware scheduling for ultra-dense networks", context-ware functionality is proposed to overcome the problem of large packet delay for users that approaching outage zones within the building. The scheme prioritizes the user scheduling decision on a time-unit bases so that it can send/receive the intended traffic as best as possible before entering the outage zone. Simulations results show a 40 % to 50 % decrease in packet delay compared to the baseline.

B.4.11 T4.2-TeC12: Context-based device grouping and signalling

Context-based device grouping and signalling uses context information to improves upon the current legacy solutions, which do not include efficient resource coordination mechanisms to the Random Access (RA) procedure to handle the bursty network accesses from massive machine-type communications. The excessive amount of signalling by the requested devices in this scenario can easily lead to network overload and congestion of the signalling channels, meanwhile introducing long RA delays.

Simulation results demonstrate a 30 % reduction in signalling congestion probability considering 30000 M2M devices, a 60 % reduction in random access delay and a 30 % overhead signalling reduction compared to the LTE baseline.

B.4.12 T4.2-TeC13-A1: Network assisted small cell discovery

In "Network assisted small cell discovery", UE gets assistance information from the network to target the search of small cells. This consists of radio fingerprints of the coverage carrier (e.g. RSRP of neighboring macro-cells) that indicate a small cell location or a HO region. UE reports to network when there is a fingerprint match and based on this the network can configure targeted measurements (on specific carrier) for finding the corresponding small cell.

Initial simulation results in TC2 show 60 % reduction in UE power consumption during small cell search.

B.4.13 T4.2-TeC17: Downlink Multi-User SCMA (MU-SCMA) for mobility-robust and high-data rate moving networks

In this TeC, DL MU-SCMA is implemented to show the advantage of SCMA user pairing to increase throughput of downlink for a highly loaded network for both low and high speed users. The robustness of MU-SCMA to user speed is evaluated to illustrate the benefit of open-loop MU-SCMA for high mobility users.

The detailed algorithms are designed to implement MU-SCMA. In this TeC, MU-SCMA and SU-SCMA are compared to LTE OFDMA for downlink with low and high speed of users. Initial evaluations show at least 30 % cell throughput and coverage gain in both low and high mobility scenarios and up to 50 % increase in aggregate cell throughput for a given coverage rate requirement.

B.4.14 T4.3-TeC3-A2: Dynamic nomadic node selection for backhaul optimization

Dynamic Nomadic Node Selection for Backhaul Optimization exploits dynamic Nomadic Node (NN) selection to overcome the limitations of the backhaul link and, thus, to enhance the system performance by enable flexible backhaul link selection. To this end, dynamic NN selection is carried out via selecting the serving NN from a set of available candidates considering the Signal to Interference-plus-Noise Ratio (SINR) on the backhaul link as the selection criterion. In this regard, the so-called coarse NN selection takes into account only large-scale fading due to shadowing.

Simulations show a 12 dB gain in backhaul SINR compared to baseline, a 12 % E2E rate gain for median user and up to 600 % E2E rate gain for 5 % user at a cost of E2E rate loss for higher percentile users.

B.4.15 T4.3-TeC5: Self-management enabled by central database for energy savings in the phantom cell concept

This TeC, Self-management enabled by central database for energy savings in the Phantom Cell Concept, exploits control and user-data plane separation to provide energy-saving mechanisms through a macro-database-enabled sleep mode mechanism for small cells. The goal is to realize energy savings without degrading network availability and user QoE compared to a legacy system with no sleep mode mechanisms.

Energy savings of up to 85 % in low load and up to 30 % in high load were shown. In addition, initial results show no throughput loss in high load scenarios and up to 25 % throughput gains in low load scenarios when this TeC is employed.

B.5 WP5: Spectrum

The selected technology components from WP5, Spectrum, are given in the following section with a description and the respective degree of METIS impact of each technology component.

B.5.1 WP5-TeC04: Coordinated multi-carrier waveform based sharing technique

This TeC proposes a coordinated multi-carrier waveform based sharing technique. Spectrum sharing solutions are usually assuming shared RAN or perfect synchronization between the network of different operators. The simulation investigates the influence of interference between different links from different operators when they transmit in the same frequency band. For simplicity, only one Base Station (BS) per operator is considered. The BS of each operator transmits signal in certain fragments of the shared frequency band to its User Terminal (UT). Different operators use orthogonal sets of spectrum fragments. Different multi-carrier waveforms including FBMC and OFDM are applied. Initial results show more than 40 % increase in spectral efficiency compared to a legacy system without sharing.

B.5.2 WP5-TeC14: Spectrum sharing and mode selection for overlay D2D communication

Spectrum sharing and mode selection for overlay D2D communication studies how much the spectral efficiency can be enhanced with algorithms for D2D communications in comparison with the legacy solution without D2D functionality. This is studied for different deployment densities of D2D users: from sparse to ultra-dense deployments. The proposed algorithm for mode selection is based on a carrier sensing threshold. Due to the decentralized nature of mode selection, added complexity to the legacy system is expected to be low. Evaluation results show up to 4.5 times gain in spectral efficiency depending on D2D density, compared to a legacy LTE system with no D2D overlay.

Annex C

C. Intermediate system architecture

In Annex C the intermediate system architecture is presented. In Section C.1 the role of the horizontal topics and methodology for architecture development is given. A horizontal topic building block analysis is then provided in Section C.2. Finally, Section C.3 contains a discussion on how to cope with wide spread service provisioning within the METIS 5G architecture.

C.1 Role of HTs and methodology for architecture development

The METIS objective to develop a wireless communication system that supports the connected information society leads to widespread service requirements including support of higher data volumes, higher end user data rates, higher number of connected devices, and lower latency as well as longer battery life (improved energy efficiency) compared to former mobile radio generations.

In order to alleviate the system development METIS has defined the horizontal topics, HTs. In a first step the HT concepts have been defined and described in METIS Deliverable D6.2 [MET14-D62] in a separated manner. The next steps shall prepare the integration of the different HT concepts into a common 5G system. It is expected that the primary defined concepts will have to be refined in order to support the integration process.

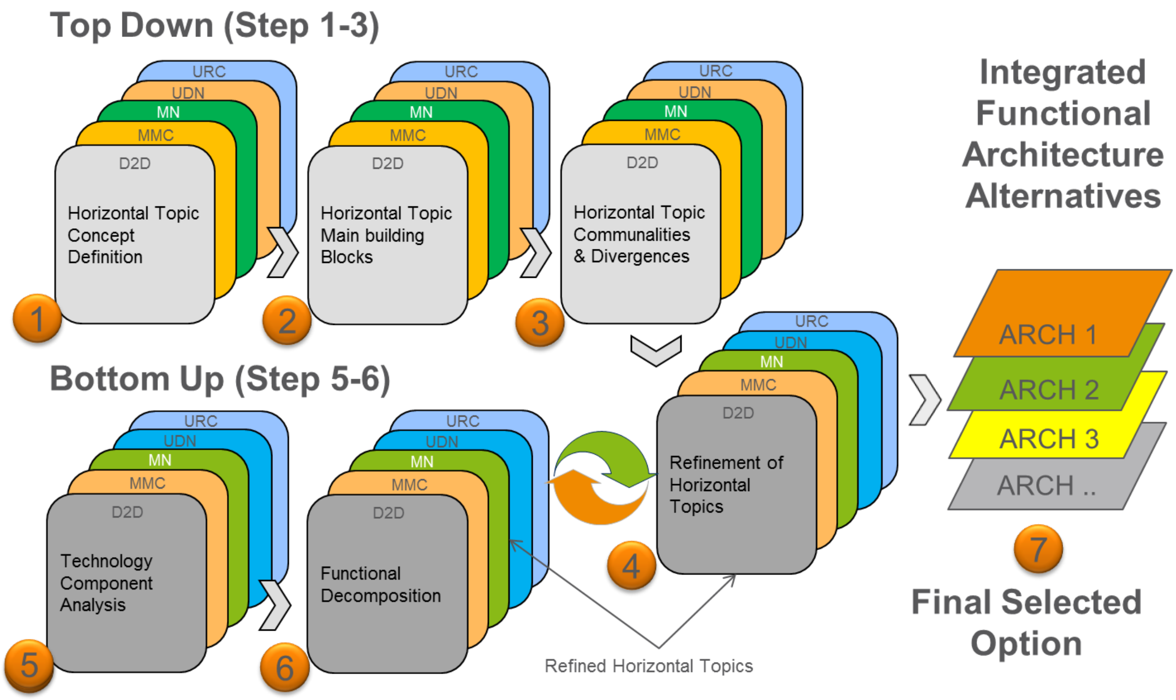

Figure C.1: Methodology for architecture development in METIS.

METIS work on system architecture accompanies the system development by provisioning of clearly defined HT clusters. Clearly defined in that context means that based on the concept definition in [MET14-D62] the HT concepts are resolved into its main Building Blocks (BBs)[1]. The functionalities of BBs are described taking care that the composition of all blocks yields in a proper working system, Figure C.1 Step 1-2.

After application of these two steps to all HTs the commonalities and divergences between different HT clusters[2] can be identified by comparison of the functional descriptions, Figure C.1 Step 3.

The top down approach is complemented by assignment of METIS technology components to the different main BBs.

The described top-down analysis methodology decomposes the HT concepts into well-defined BBs. Some BBs appear in more than one HT concept with identical functionalities and can be realized by identical Technology Components (TeCs). These blocks are denoted as “frameworks”. In some cases different HTs topics comprise of BBs with the same name but including slightly different functionalities and TeCs. In those cases the BB is denoted as “common building block”. There exist even BBs that appear only in one specific HT concept. These BBs are called “HT specific building blocks”.

Results of top-down analysis facilitate the refinement of the HT concepts by provisioning of clearly defined modules that may be reused in the different HT clusters, hence utilizing synergies between the different HT concepts, Figure C.1 Step 4.

Top-down analysis mainly contributes to a high level view of the functional architecture. When it comes to assessment of different architectural alternatives more detailed information with respect to interface requirements is needed. To get this information, top-down analysis is complemented by a bottom-up approach, Figure C.1 Step 5-6. Conducting for each of the selected components an in-depth TeC analysis the functional decomposition is disclosed and detailed interface descriptions can be provided. More detailed analysis as done in these steps may lead to recursive refinements of the HT concepts again.

In a last step, different options for integration of the HT concepts will be investigated from functional point of view. Selection of alternative TeCs as well as different options for multi-RAT and multi-layer with respect to integration of legacy networks and wide area networks into the METIS HTs as well as consideration of different concepts for multi-operator deployments will span the full range of architectural alternatives under investigation.

C.2 Horizontal topic building block analysis

HT BBs are derived from the HT concept descriptions in [MET14-D62]. Three different kinds of BBs have been identified:

- HT specific building blocks,
- Common building blocks,
- Frameworks for specific purposes.

[1] A Building Block in the architectural work addresses a collection of functionalities that are linked together providing higher level function (e.g. mobility management).
[2] In D6.2 the HT concepts have been segmented into clusters.

HT specific BBs appear only in the corresponding HT architecture. Common BBs appear in more than one HT architecture, but may have different realizations for the different HTs. Frameworks appear in more than one HT and subsume identical functionalities.

C.2.1 Main building blocks and their functionalities for D2D

Based on the HT D2D concept description in Section 3.2.1 of D6.2 [MET14-D62], the following architectural BBs can be identified (see Figure C.2):

- *Air Interface* (AI) consisting of
    - AI Management,
    - D2D Multi-hop,
    - D2D for time uncritical services (related also to UDN Flexible Air Interface),
    - AI Framework for M2M,
    - AI Framework for URC,
    - AI Framework for MN,
    - MAC for D2D.
- *Radio Node Management* consisting of
    - Long and Short Term RRM and Interference Management,
    - D2D Device Discovery & Mode Selection,
    - Mobility Management,
    - Interference Identification & Prediction.
- *Network Management* consisting of
    - Context Management,
    - Spectrum Management,
    - Novel Network Interfaces.

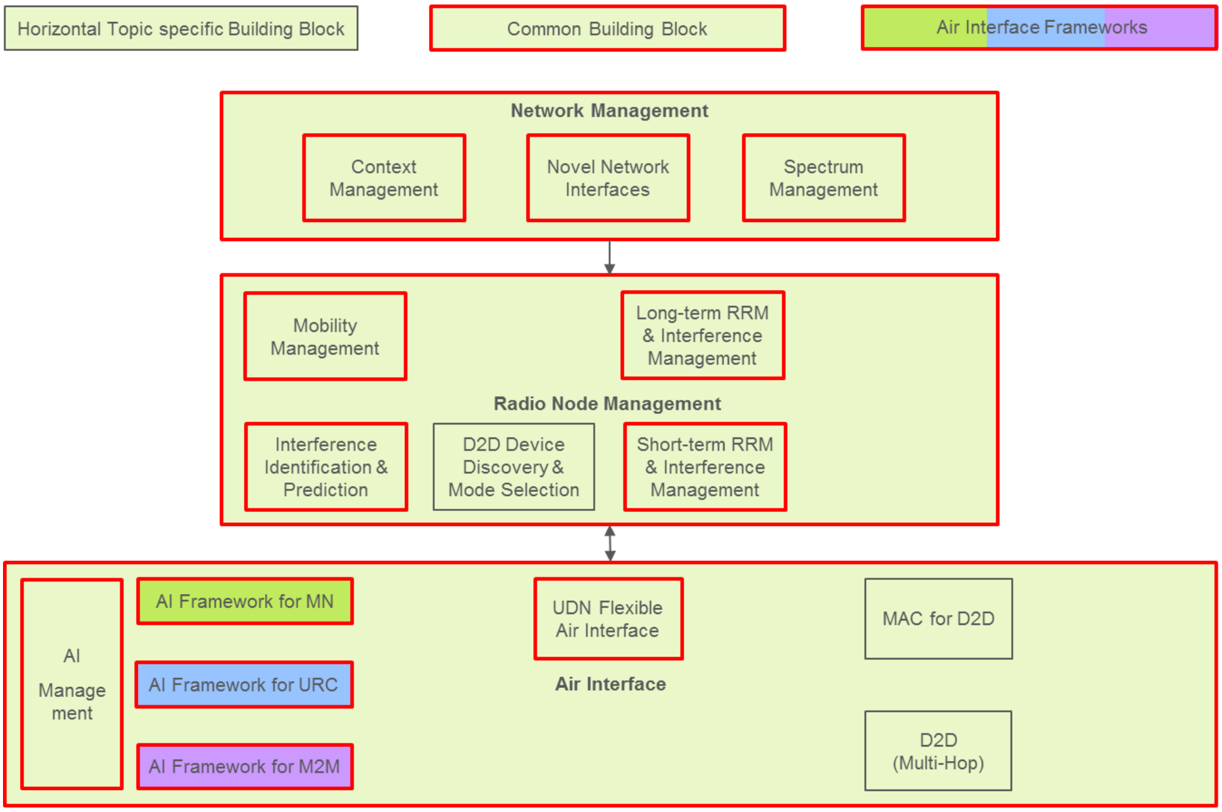

Figure C.2: HT D2D building blocks (HT common BBs marked by red frames).

From D2D point of view the *Air Interface* represents a central BB. The AI must enable:

- Provisioning of adequate information for transmission mode selection.
- Means for flexible configuration and adaptation to different services and network use cases (AI Management):
    - UL/DL partitioning in TDD mode.
    - Usage of FDD mode natively integrated into the air interface for wide area communication even for D2D communication (according to [MET14-D62]).
    - Mode dependent adequate transmission between the local peers coexisting (underlay or overlay D2D) or non-coexisting with cellular usage (out of band D2D).
    - Best effort services (D2D for time uncritical services) utilizing mostly properties of the air interface already provided for UDN.
    - Ultra-reliable services for D2D by using features provided by the Frameworks for URC (URC-L, URC-S).
    - Robust PHY layer for V2X communication may be reused for D2D (AI Framework for MN-N, MN-V).
    - Interference suppression by receivers (AI Framework for MN-N, MN-V).
    - Network controlled as well as ad hoc operation (reuse from MN-V).
    - Distributed network synchronisation for ad hoc D2D operation

    - M2M communication by integrating a wide span of requirements, such as: coexistence of low cost and low rate devices with high end devices; realizing extremely low power consumption and how it can be reused from MMC (AI Framework for M2M); as well as signalling for low cost and low power sensors.

- D2D Multi-hop providing backhaul to the infrastructure via other devices as well as local D2D communication via third party devices; in addition providing D2D communication via D2D relays.
- MAC and RRM functionalities at PHY layer, i.e. means to synchronize devices in D2D mode.

The *D2D Radio Node Management* represents a couple of common BBs:

- Long and Short Term Radio Resource Management (RRM) and Interference Management are essential for coexistence of D2D with cellular networks. Interference Management is closely related to resource allocation. As most of the time imbalance between path loss to cellular and to local peers exists power control is a vital element for coexistence especially in case of underlay D2D. Input for Interference Management has to be provided by the Air Interface as well as by Interference Identification & Prediction algorithms. Main functionalities provided by these BBs are:
    - Proper resource allocation based on air interface interference measurements (centralized or decentralized).
    - Adjustment of transmit powers.
    - Interference suppression by receivers.
    - Spectrum sharing between D2D and cellular in overlay mode.
- D2D Device Discovery & Mode Selection is an important premise for proper usage of D2D services. This is a D2D specific BB and has to provide and combine functionalities as
    - Identification of local link opportunities and
    - Switching between different D2D modes:
        - Underlay, overlay, out of band;
        - D2D Multi-hop.
- Mobility Management has to support:
    - Handover between D2D and cellular as well as inclusion of D2D relays or relayed D2D.
    - Inclusion of Interference Identification & Prediction schemes.

This all might be realized based on information provided by the air interface, as for example location or Channel State Information (CSI) / large scale path loss, as well as by context information provided by the network. In case of multi-cell operation the D2D Mode Selection might be combined with Interference Management.

On *Network Management* level following BBs are to be noted:

- Context Management has to collect relevant information from different parts of the network and to provide it where ever needed. The Context Management might be organized in a centralized and/or in a distributed manner. As in case of D2D in the general more than one cell is affected there will always be a component needed that is located at a hierarchical level that exceeds the radio nodes or access points in the network.
- For D2D the Spectrum Management has to provide:
    - Information on spectrum availability as well as network level assignment of frequency resources for overlay D2D to facilitate:
        - Adaptive spectrum sharing in network assisted D2D communication (e.g. D2D operation in MBB UL/DL or dedicated band).
        - Coexistence among D2D pair/groups.
        - Coexistence between D2D communication and regular cellular communication.
- Novel Network Interfaces to operator external entities to enable e.g. communication among devices from different operators.

C.2.2 Main building blocks and their functionalities for MMC

Based on the HT MMC concept description in Section 3.2.2 of [MET14-D62] the following architectural BBs can be identified (see Figure C.3):

- *Air Interface* consisting of
    - AI Management,
    - MMC-A (accumulation/aggregation point access),
    - MMC-D (direct access),
    - AI Framework for M2M (M2M access – direct M2M communication),
    - UDN Flexible Air Interface.
- *Radio Node Management* consisting of
    - RAT Selection,
    - Long and Short Term RRM and Interference Management,
    - Radio Node Clustering & Dynamic (De-)Activation,
    - Mobility Management,
    - Interference Prediction & Identification.
- *Network Management* consisting of
    - Context Management,
    - Spectrum Management,
    - Novel Network Interfaces.

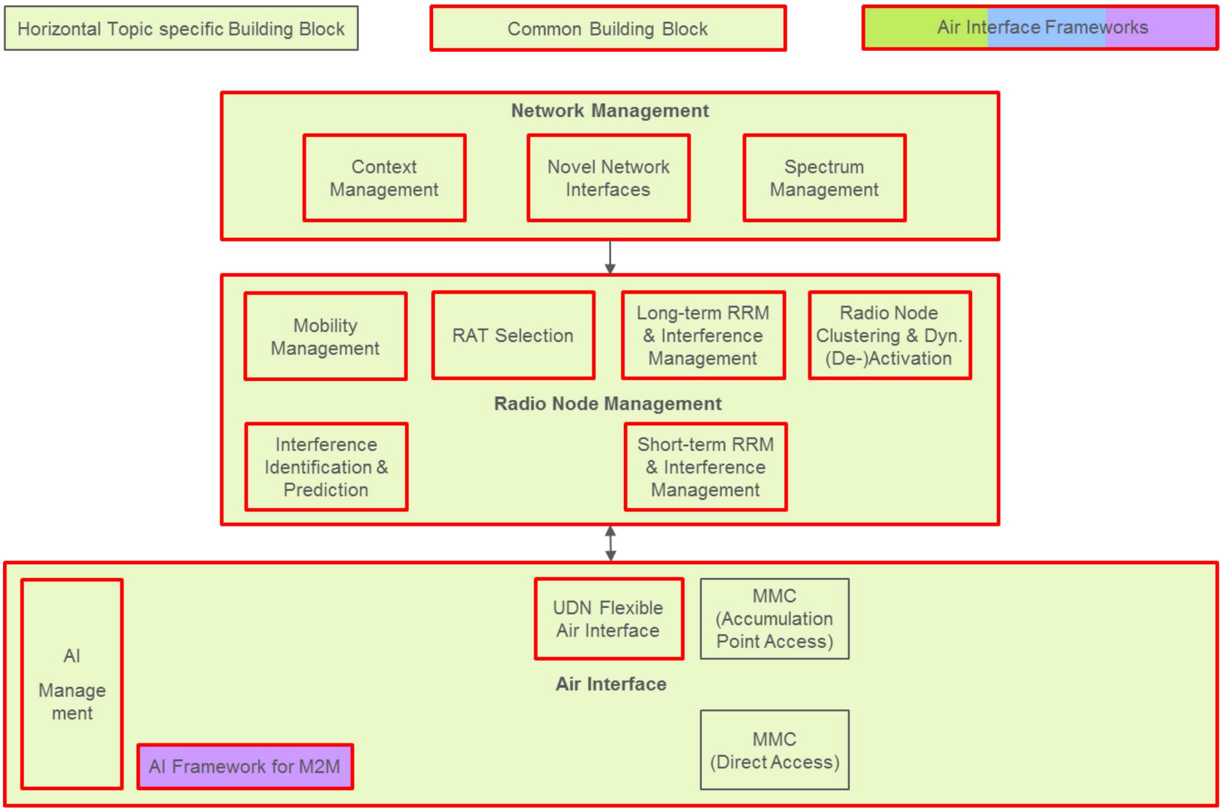

Figure C.3: HT MMC building blocks (HT common BBs marked by red frames).

In the following the required capabilities of the HT MMC BBs are described.

Basically, MMC has to provide scalable connectivity solutions for tens of billions of network-enabled devices. Due to the wide range of future applications/services which will use MMC, machine-related communication will be associated with a wide range of characteristics and requirements (e.g. data rate, latency, cost, power consumption, availability and reliability) that will often deviate substantially from those of human-centric communication in current use. In this context, the challenge is to accommodate the traffic from all of these applications/services and devices, respectively. In addition, machine type communications should co-exist with usual human-centric communication.

The MMC A*ir Interface* has to support:

- Basic requirements, such as
    - Low energy;
    - Low cost;
    - Availability, i.e. coverage;
    - Low signalling overhead;
    - Extremely high number of connected devices.
- Accommodate efficiently traffic from applications/services of totally different nature in terms of data rates, latency and reliability requirements.

- Three types of air interfaces, such as MMC-A, MMC-D and the AI framework for M2M.

The MMC AI BBs have to support:

- MMC-D (direct access):
  - Devices transmit directly to the radio access node.
    - The benefit of this scheme is that it requires no planning when deploying devices, given that access nodes provide full coverage. Another advantage is the provided flexibility in terms of mobility management particularly for non-static devices.
    - The drawback might be the coverage aspect; for low-complexity devices with low output power constraints special attention is needed to reach the coverage KPI in UL direction.
- MMC-A (accumulation/aggregation point access):
  - Traffic from the devices in the proximity is accumulated in a local node before being sent to a radio access node with base station functionality.
  - The accumulation point can either be a relay, a service dedicated gateway, a smart phone connecting personal electronic devices, or a dynamically selected device acting temporarily as the group/cluster head.
  - For this scheme, a varying range of data processing could be applied. From forwarding the data as it is (as a relay), to accumulating data (in order to have few but larger data bundle transmissions to the access node), or even doing processing in the accumulation point (in which case only the relevant and processed data is forwarded to the radio access node).
- AI Framework for M2M (M2M access – direct M2M communication):
  - Focus is on very low bit rates and delay tolerant traffic rather than very high bit rates and tight delay budgets.
  - This type of AI inherits most technical solutions from the D2D communication.
  - One key difference of M2M communication relative to D2D communication is the requirement for very high protocol efficiency (i.e. very low signalling overhead) and the requirement for long device battery life.
  - For the latter requirement, M2M transmissions would be very beneficial in the case where the device is in bad or unstable coverage area and/or is power limited, i.e. when the device has reached the maximum transmit power level. In most other cases, the major factor on the device battery life is the required on-time and the base power consumption of the power amplifier. Because of these two reasons, the normal D2D setup process is not feasible for M2M communication, at least not for battery-

operated devices. Therefore, more long term and static setup would be required for M2M communication compared to D2D communication. That is, for each M2M transmission of very few bytes it is not feasible to repeat the full D2D setup procedure including 1) identifying whether the traffic is E2E, 2) device discovery and link quality analysis, 3) determining if the M2M link quality is good enough such that a direct M2M link would be favourable to routing the traffic via the access node, and 4) determining whether system resources should be reused locally or if dedicated resources should be used for the M2M link. Expressed differently, if M2M traffic is found not to be applicable in a certain case, the above procedures shall be designed in such a way that they only introduce an almost-negligible increase in signalling overhead and battery consumption.

- AI Management:
    - AI Management and selection of the appropriate AI type (MMC-A, MMC-D, and the Framework for M2M) according to the use case where the device is applied.
    - Management and selection of AI based on information provided by the Radio Node Management.
    - Provisioning of adequate information for transmission mode selection.

The MMC *Radio Node Management* BBs have to enable:

- RAT Selection.
- Long and Short Term RRM and Interference Management are essential for coexistence of MMC with cellular networks. Interference Management is closely related to resource allocation. As most of the time imbalance between path loss to cellular and to local peers exists power control is a vital element for coexistence especially in case of underlay D2D. Input for Interference Management has to be provided by the AI as well as by Interference Identification & Prediction algorithms. Main functionalities provided by these BBs are:
    - Proper resource allocation based on air interface interference measurements (centralized or decentralized).
    - Adjustment of transmit powers.
    - Interference suppression by receivers.
    - Spectrum sharing between MMC and cellular in overlay mode.
- Radio Node Clustering & Dynamic (De-)Activation:
    - Radio Node Clustering is needed for AI type MMC-A. According to a specific use case, the Radio Node Clustering has to enable setup of a cluster consisting of several devices. The head of this cluster is led by the accumulation/aggregation point which is able to control and manage the links to the connected devices.

There are two types of accumulation/aggregation points:

- Transparent accumulation/aggregation point:
  - Devices communicate with nodes and/or services in the Internet directly.
- Non-transparent accumulation/aggregation point:
  - Devices communicate with nodes and/or services in the Internet via accumulation/aggregation point which is acting as a proxy.
  - Addressing of the devices is of importance.

  - Dynamic (De-)Activation is needed for MMC in general. One important aspect of this topic is the ability to improve battery life time of battery operated devices. Low energy consumption of the AI and low signalling overhead are of high importance.
- Mobility Management:
  - Handover among all three MMC AI types, such as MMC-D, MMC-A and AI Framework for M2M. In the case of MMC-A the accumulation/aggregation point should be addressed by the Mobility Management while the connected devices are not touched by the Mobility Management. However, in certain cases the Mobility Management can decide to handover a device from an accumulation/aggregation point (MMC-A) to a radio access node with base station functionality (MMC-D). Such a handover decision can be performed based on information provided by the Context Management and/or Interference Identification & Prediction.
- Interference Identification & Prediction :
  - Information delivery to the Mobility Management and to the RRM.

On *Network Management* level, the following BBs are to be noted for MMC:

- Context Management:
  - Collect relevant information from different parts of the network, incl. radio nodes and devices, in order to deliver use case related information to other BBs, such as Mobility Management, Radio Node Management and Novel Network Interfaces.
- In order to cover MMC aspects the Spectrum Management has to support:
  - Flexible spectrum access for low complexity devices to:
    - Licensed spectrum for guaranteed service quality (i.e. controlled resource usage and interference management);
    - Unlicensed spectrum due to global harmonization giving the benefit of economy of scale plus no licensing costs.

- The MMC Novel Network Interfaces BB provides:
  - The ability to offer and/or request information from the accumulation/aggregation point and devices which can be used, e.g. from other actors like other network operators, OTT providers and/or application/service providers.

C.2.3 Main building blocks and their functionalities for MN

Based on the concept descriptions for the three MN clusters in Section 3.2.3 of [MET14-D62] an integrated and unified MN system concept can be described consisting of the following architectural BBs (see Figure C.4):

- *Air Interface* consisting of
  - Framework for MN,
  - Advanced Relaying,
  - Backhaul Link Enhancements (MN),
  - Channel Access for Ad-Hoc Mobile D2D (MN),
  - Framework for URC,
  - AI Management.
- *Radio Node Management* consisting of
  - RAT Selection,
  - Long and Short Term RRM and Interference Management,
  - Radio Node Clustering & Dynamic (De-)Activation,
  - Nomadic Nodes Management,
  - Mobility Management,
  - Interference Identification & Prediction.
- *Network Management* consisting of
  - Context Management,
  - Spectrum Management,
  - Novel Network Interfaces.

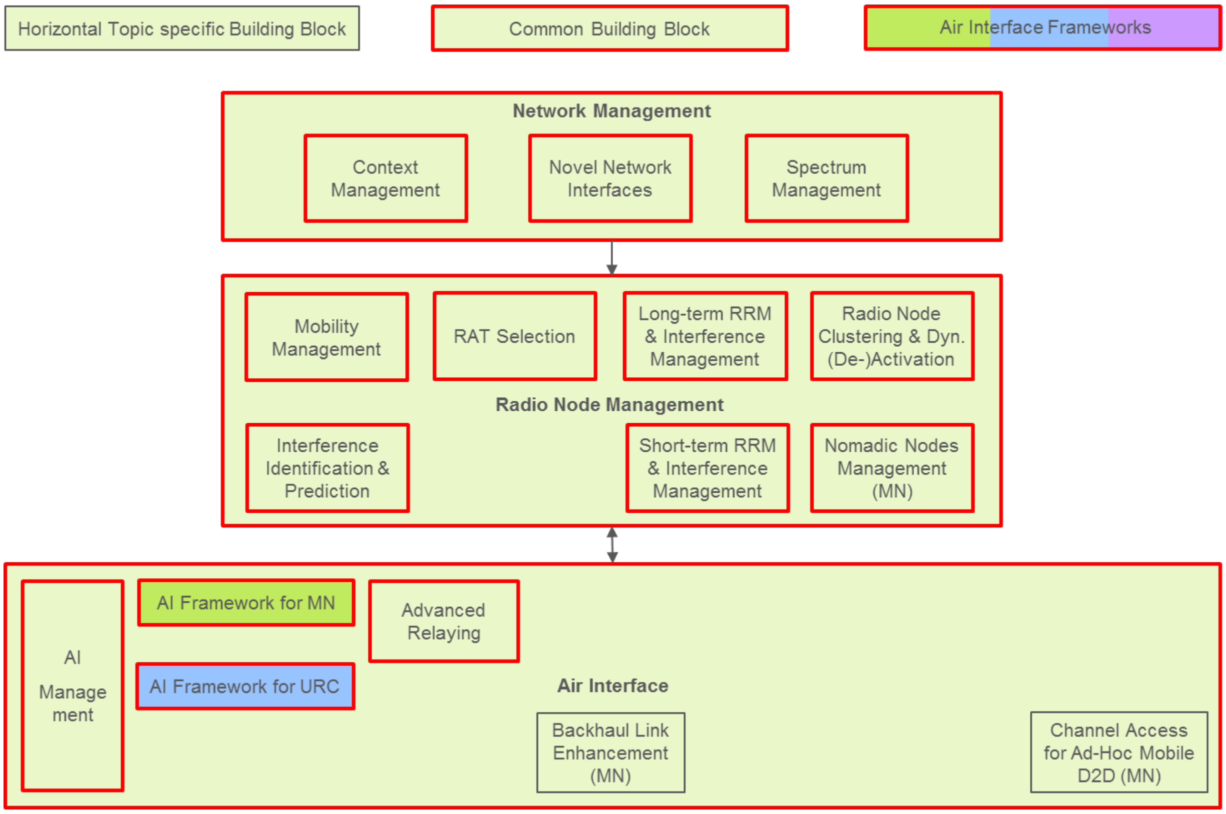

Figure C.4: HT MN building blocks (HT common BBs marked by red frames).

The MN *Air Interface* has to support basic requirements such as:

- Robustness against Doppler shift and imperfect channel knowledge;
- Exploitation of fast fading;
- Improved system capacity and user throughput;
- High data rate and low latency links.

The MN AI BBs have to support:

- AI Framework for MN:
    - New waveforms and channel equalization techniques to improve the robustness against the Doppler shift.
    - Advanced channel coding, link adaptation and HARQ mechanisms to exploit the presence of fast fading.
    - Multi-node and multi-antenna techniques aimed at improving the user throughput and the system capacity while being robust to the imperfect channel knowledge that results from high mobility.
- AI Framework for URC:
    - QoS control over the communication links.
    - Interface to RRM and MAC for efficient radio resource usage.

- AI Management
- Advanced Relaying
- Backhaul Link Enhancements (MN):
    - Enhancement techniques for backhaul links are essential to leverage the gain of nomadic nodes.
- Channel Access for Ad-Hoc Mobile D2D (MN):
    - MAC techniques to allow for satisfactory communication performance, provided limited or no CSI knowledge.

The MN *Radio Node Management* BBs have to support:

- RAT selection.
- Mobility Management:
    - Handover prediction and optimization in order to guarantee seamless connectivity and improved quality of service of mobile users and backhaul links of moving cells.
    - Cell reselection and handover management (i.e. in-bound/out-bound mobility) in order to cope with the challenges posed by the densification of moving and nomadic cells in the case of highly mobile users.
- Long and Short Term RRM and Interference Management:
    - RRM techniques to allow for satisfactory communication performance, provided limited or no CSI knowledge.
    - Interference Management also has to consider the impact of activated nomadic nodes on the inter-cell interference levels.
- Radio Node Clustering & Dynamic (De-)Activation:
    - Device and service discovery schemes optimized for highly mobile devices by considering the time to discovery, the number of discoverable devices/services and the required signalling overhead.
- Interference Identification & Prediction.
- Nomadic Nodes Management:
    - Dynamic (de-)activation of nomadic (moving) cells to provide additional capabilities for energy saving and load balancing for the network. Decisions based on coverage and capacity demands of UEs.
    - Interference Management and advanced cooperative strategies as enablers to provide diversity and capacity enhancement to the network based on the use of nomadic nodes.

The MN *Network Management* BBs have to support:

- Context Management:

    - Collect relevant information from different parts of the network, incl. radio nodes and devices, in order to deliver use case related information to other BBs, such as Mobility Management, Radio Node Management and Novel Network interfaces.
- Novel Network Interfaces:
    - Provide access to network information, e.g. predicted data, for other network entities, operators and service providers.
- Spectrum Management:
    - In order to fulfil MN requirements (e.g. C-ITS, V2X, ...) the Spectrum Management has to facilitate:
        - Access to a sufficient amount of reliable (i.e. exclusively licensed) spectrum;
            - More than the 10 MHz currently dedicated to the road safety at 5.9 GHz;
            - Additional spectrum below 6 GHz or even below 1 GHz.
    - Inter-operator Spectrum Management for mobile D2D.

C.2.4 Main building blocks and their functionalities for UDN

The HT UDN has defined a core specific concept optimized for the potential stand-alone operation of a layer of ultra-densely deployed small cells (UDN-C) plus an extension part offering additional performance improvements (UDN-E). According to [MET14-D62] following main functional BBs can be identified for the overall HT UDN concept:

- *Air Interface* consisting of
    - AI Management,
    - UDN Flexible Air Interface,
    - Wireless Self-Backhauling/Relaying.
- *Radio Node Management* consisting of
    - Short-term RRM & Interference Management,
    - Long-term RRM & Interference Management,
    - Radio Node Clustering & Dynamic (De-)Activation,
    - RAT Selection,
    - Interference Identification & Prediction,
    - Mobility Management,
    - UDN Control via Macro Cell Layer.
    - Enhancements of Macro Layer Backhaul Links for UDN.
- *Network Management* consisting of
    - Context Management,

- Spectrum Management,
- Novel Network Interfaces.

The interrelations between the BBs are shown in Figure C.5 with BBs to be commonly applied by other HT concepts shown with red frames.

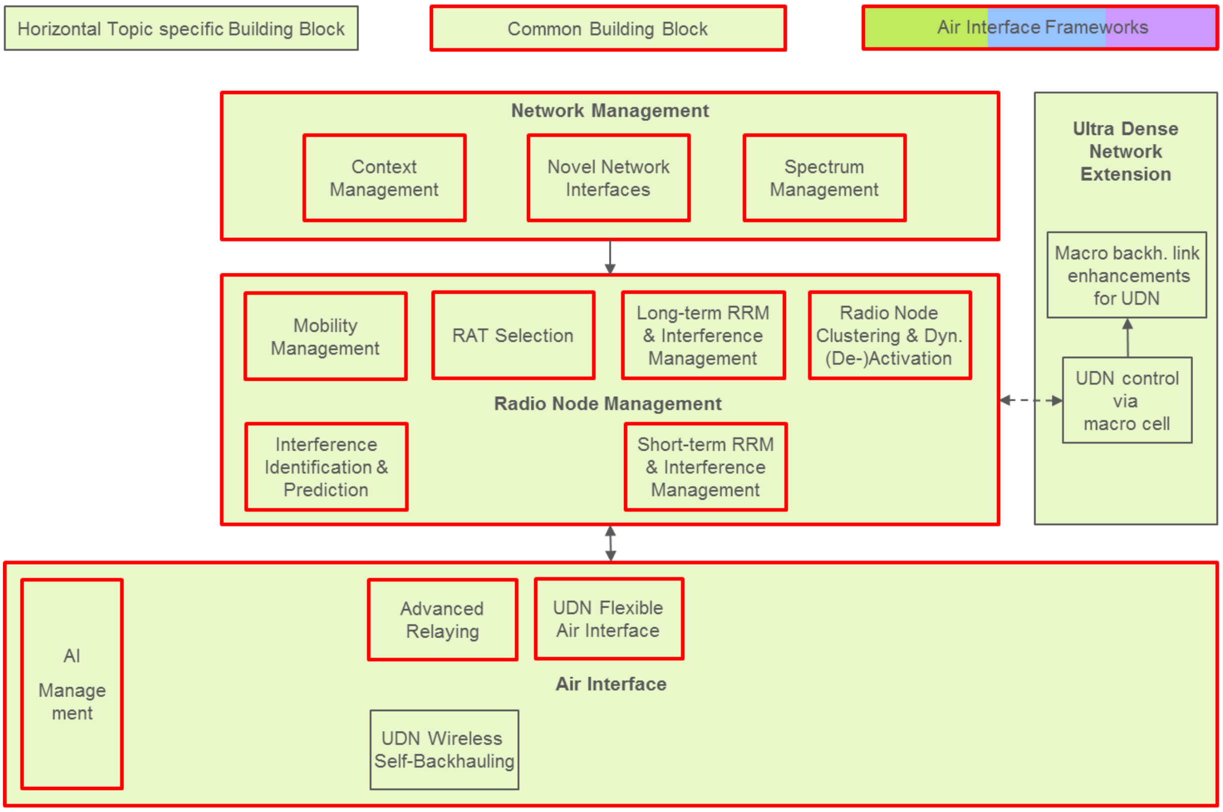

Figure C.5: HT UDN building blocks (HT common BBs marked by red frames).

The *Air Interface* acts as the central block for the UDN core concept. The AI Management (common BB with other HT concepts) will flexibly adjust the UDN-specific AI according to:

- Modulation and coding scheme (link performance optimization);
- Frame structure (dynamic IP traffic optimization with reduced control signalling overhead and flexible UL / DL resource utilization);
- Flexible selection and use of spectrum (typically from 3.5 GHz up to 90 GHz).

The UDN AI is also designed to be feasible for D2D and MMC applications.

In addition to device access (end user UEs, machines/sensors, etc.) the UDN AI also supports wireless self-backhauling/relaying functionalities between the UDN radio nodes in the same frequency bands (in-band, out-of-band) in case of missing wireline backhaul links (due to deployment and/or cost reasons) with following characteristics:

- Self-configurable wireless backhaul, adaptive to changes in network topology and network load;
- High link capacity for traffic aggregation from several radio nodes;

- Low latency on physical layer to allow multi-hop connectivity.

The UDN concept foresees a potentially tight collaboration of radio nodes with respect to coordination of resource allocation for interference reduction and fast (de-)activation of cells due to energy performance reasons.

- The interaction and coordination among UDN cells allows an optimal selection of candidates for collaboration groups through smart and dynamic node clustering, based on advanced neighbourhood discovery. It provides enhanced network performance through short and long term resource/interference management, RAT selection, and inter-operator spectrum sharing algorithms. The latter avoids in-band/out-of-band coexistence problems through spectrum coordination configured via the on-top spectrum management procedures. These features described here with special emphasis to UDN are in principle common to other HT concepts.
- The (de-)activation of UDN radio nodes allows a fast response for rapid changes in network topology or network failures, reduces the number of Hand-Over (HO) failures in dense deployment (optimized mobility, solving problem of holes in the UDN coverage), a power safety optimization of radio nodes depending on the traffic load in the area. Together with self-backhaul functionalities the network maintenance cost will be reduced via simplified network planning and automated tuning of parameters.

The extended UDN concept offers additional performance improvements by application of following BBs:

- Context awareness for UDN mobility, resource and network management (especially to support the URC-L concept) which is integrable into a common BB for Context Management.
- Inter-RAT/ inter-operator collaboration via common novel network interfaces;
- Tight interaction of a UDN layer with a macro layer holding superior role in control and management functions over common area (split of C- and U-Plane between macro and UDN layer);
- Macro-layer based wireless backhaul for flexible and low-cost UDN deployments.

From UDN perspective the Spectrum Management BB has to enable:

- Operation on different frequencies within a wide range of spectrum bands incl. mmW.
- Fast spectrum aggregation and switching between available resources.
- Efficient spectrum sharing techniques, including
    - Inter-operator spectrum sharing with novel inter-network interfaces for flexible network management;
    - Communication with a LSA manager/database to obtain regulatory operational requirements.

C.2.5 Main building blocks and functionalities for URC

Similar to "Architecture" URC can be characterised as an overarching HT. In order to enable the generic mechanisms described in [MET14-D62] the following main BBs can be identified:

- *Reliable Service Decomposition*.
- *Air Interface* consisting of
  - Framework for URC (URC-L (long term),URC-S (short term)),
  - D2D (Multi-hop),
  - Channel Access for Ad-Hoc Mobile D2D (MN),
  - Framework for MN,
  - UDN Flexible Air Interface.
- *Radio Node Management* consisting of
  - RAT Selection,
  - Long and Short Term RRM and Interference Management,
  - Radio Node Clustering & Dynamic (De-)Activation,
  - Nomadic Node Management,
  - Interference Identification & Prediction,
  - Mobility Management.
- Network Management consisting of
  - Context Management,
  - Spectrum Management,
  - Novel Network Interfaces.

The interrelations between the BBs are shown in Figure C.6 with BBs to be commonly applied by other HT concepts shown with red frames.

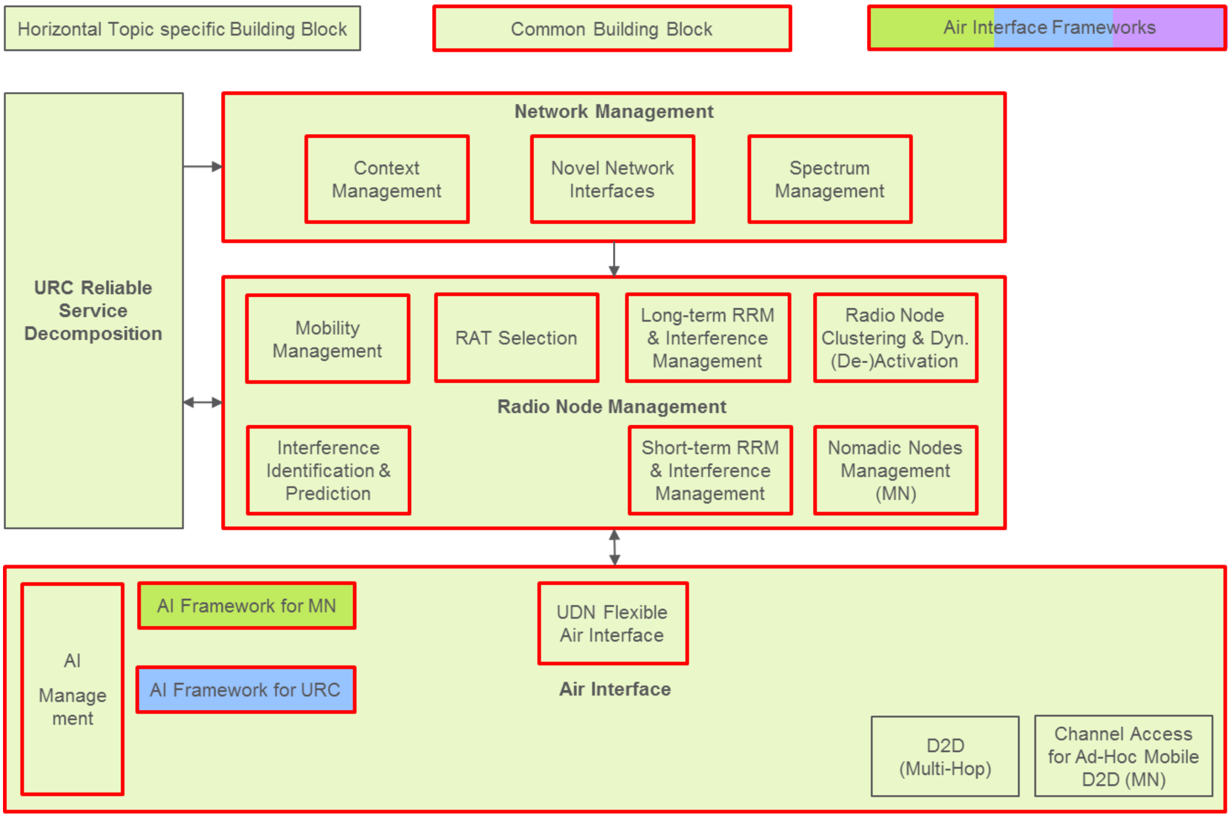

Figure C.6: HT URC building blocks (HT common BBs marked by red frames).

Reliable Service Decomposition represents the central BB for URC. It processes all information on abilities available from the lower layers, transforming it into respective actions that enable provisioning of ultra-reliable links in the network:

- Evaluation of AI information on abilities and actual QoS/QoE resulting in respective control of AIs or Multi-RAT functionalities.
- Evaluation of context information resulting in appropriate control messages.
- Decision on opportunities for providing reduced grade of service (graceful degradation).

With respect to URC the most important functional element of the AI is the AI Management. It controls:

- Signalling of AI abilities to higher layers (reliable service decomposition);
- Proper settings for robust PHY mechanisms;
- Signalling of actual QoS/QoE to higher layers.

Abilities of the AI consist of

- Framework for URC (URC-L and URC-S):
  - Application of QoS/QoE in order to guarantee minimal rates for a given probability in time.

  - Application of deadline driven operations in order to guarantee maximal latencies for a given probability in time.
  - Counters that documents actual service provisioning parameters.
- Functional Elements enabling URC-E:
  - D2D (Multi-hop);
  - Channel Access for Ad-Hoc Mobile D2D (MN).
- Framework for MN, especially provisioning of robust PHY transmissions.
- UDN Flexible Air Interface; as also designed to be feasible for D2D applications.

Following BBs for the URC *Radio Node Management* have to be mentioned:

- RAT Selection functionalities will enable:
  - Load balancing between cells of different RATs;
  - Smart device /service to RAT mapping;
  - Smart signalling using context information.
- Long and Short Term RRM & Interference management:
  - May contribute in collaboration with user/service prioritisation especially to control RLA2 related topics [MET14-D62].

The URC *Network Management* BBs have to support:

- Context Management:
  - To collect relevant information from different parts of the network and to provide it wherever needed.
- Spectrum Management shall be capable to flexibly reallocate spectrum in order to achieve:
  - Offloading to another frequency band, when the number of users increase and adherence of reliability is threatened (RLA3) [MET14-D62].
  - Operation in a less-interfered spectrum chunk, when there is a significant interference and reliability is threatened (RLA2) [MET14-D62].
  - Operation in a dedicated spectrum chunk to attain a specific KPI: for example, low-latency D2D operation or operation at a lower frequency in order to achieve a larger coverage range (RLA1) [MET14-D62].

C.3 METIS 5G architecture: How to cope with wide spread service provisioning

The METIS 5G architecture development is driven by three key aspects, namely, flexibility, scalability, and service-oriented management. All of these three aspects are complementary to each other such that the diverse set of TeCs accompanied with the broad range of service requirements can be efficiently supported. Flexibility is the core aspect to enable dynamic configuration of the necessary network functionalities for the realization of a given HT. In this sense, flexibility may span a multi-dimensional space comprising time, frequency, and devices – to be referred to as Network Elements (NEs) as of now. A certain network functionality may be necessary at a given time for a target frequency band in certain NEs, e.g. mmW support on the radio access link of a small cell during peak time of 5-7 p.m. during summer time.

The flexible architecture will enable the efficient cooperation among HT concepts. This can necessitate new or tailored functionalities that will be made available on-demand. Furthermore, scalability will be assisted by flexibility to fulfill the requirements of extremely contradicting use cases, e.g. low data rate MMC versus multi-user Ultra-High Definition (UHD) tele-presence. The anticipated flexibility and scalability will enable a future-proof architecture that can adapt to the requirements of the possibly emerging use cases that are unknown up to date. Accordingly, the service-oriented management will make use of scalability and flexibility to provide the utmost quality for a targeted service. In addition, METIS 5G architecture shall enable cost- and energy-efficient operation of mobile and wireless communications networks.

The architectural trends such as Software Defined Networking (SDN) and Network Function Virtualization (NFV) will be taken into account to define the final METIS 5G architecture. Implementation of radio network and service functions in C-RAN environments in a localized and/or centralized way (dependent on infrastructure availability of the Mobile Network Operator (MNO) and line delay limitations set, e.g. by CoMP schemes) will simplify the mapping of SDN and NFV features onto the RAN. NFV [ETSI12; ETSI13] can be seen as highly complementary to SDN [SSC+13; JP13], as it is relying on techniques currently in use in many data centers. However, applying NFV together with the SDN approach of service-adaptive separation of control and data planes can enhance the final performance and reduce the CapEx and OpEx of 5G networks. A set of advantages of the application of Wireless SDN (WSDN) with NFV (noted here as Radio Network Function Virtualization (RNFV) and Radio Function Virtualization (RFV), respectively) [PWH13; CSG+13; DGK+13] can be outlined as:

- Extension of cloud service offerings, noted as Infrastructure as a Service (IaaS) or Platform as a Service (PaaS), from fixed/mobile core to RAN area, noted as RAN as a Service (RANaaS).
- Flexibility with respect to integration of decentralized core functions in C-RAN processing units like joint scheduling as well as Content Delivery Networks (CDNs) with caching capabilities [WCT+14].
- Increased flexibility in E2E service offerings by on-demand adaptation of data transport on radio and back-/fronthaul layers according to service content and available resources (content and resource awareness).
- Simplified clustering of cells for joint RRM (including carrier aggregation), interference coordination (including CoMP procedures) and context-/service-aware mobility management due to centralized processing and minimum delay among baseband processing units (realizable via virtual machines on general purpose processors, probably with support of HW accelerators for dedicated PHY computing tasks).

- Multi-operator network infrastructure and resource sharing, including also Fixed Network Operators (FNO) with respect to back-/fronthaul usage, realizable in an optimal manner.
- Flexible integration and adaptation of Operation, Accounting and Maintenance (OAM) and self-organizing/automation functionalities (Enhanced SON), also to implement "green" network operation (e.g. energy management for on-demand (de-)activation of radio nodes).

The provisioning of suitable backhaul and – in case of C-RANs – fronthaul is a very important aspect especially for UDN. Even in mid-term future, it cannot be expected that fiber- or copper-based wired solutions (e.g. GPON or G.Fast) will be available everywhere. To avoid expensive cable construction, wireless back-/fronthaul solutions will play an important role in future mobile networks and will ideally be integrated into the radio nodes with access link provisioning based on the proposed flexible air interface (e.g. in-band and/or out-of-band solutions).

The main functional building blocks to appear in the METIS 5G architecture – from a logical point of view – are shown in Figure C.7 (except of "classical" core functions like for example AAA). The envisioned architecture will provide the necessary flexibility so that HT concepts can be realized with efficient integration and cooperation of functional blocks according to the individual service and network function needs of the HT concepts. The functions can be flexibly modified, tailored and created by the Function Coordinator according to the service flows and moved to the relevant network nodes on-demand. Function agents will embed the functions inside the NEs and, hence, execute the '*function re-configurations*' that are managed by the Function Coordinator. It is based on Wireless SDN (WSDN) approach to enable on-demand creation of customized Virtual Networks (VNs) using shared resource pools and allowing effective service-adaptive decoupling of control and data plane (to be reviewed for some MMC applications on the air interface link to keep the overhead low) in order to optimize routing and mobility management across the whole service transport chain. The NEs comprise BaseBand Elements (BBEs) on the RAN side and Core Network Elements (CNEs) on the core network side. From the perspective of the E2E flow, even protocol stacks will be optimized and customized via software according to the required services and the network topology, i.e. the protocol stack becomes more and more a set of functional BBs flexibly/dynamically combined on-demand to fulfill the very specific tasks for a certain service. On this basis, BBEs comprise flexible protocol stack, flexible air interface, and function agent.

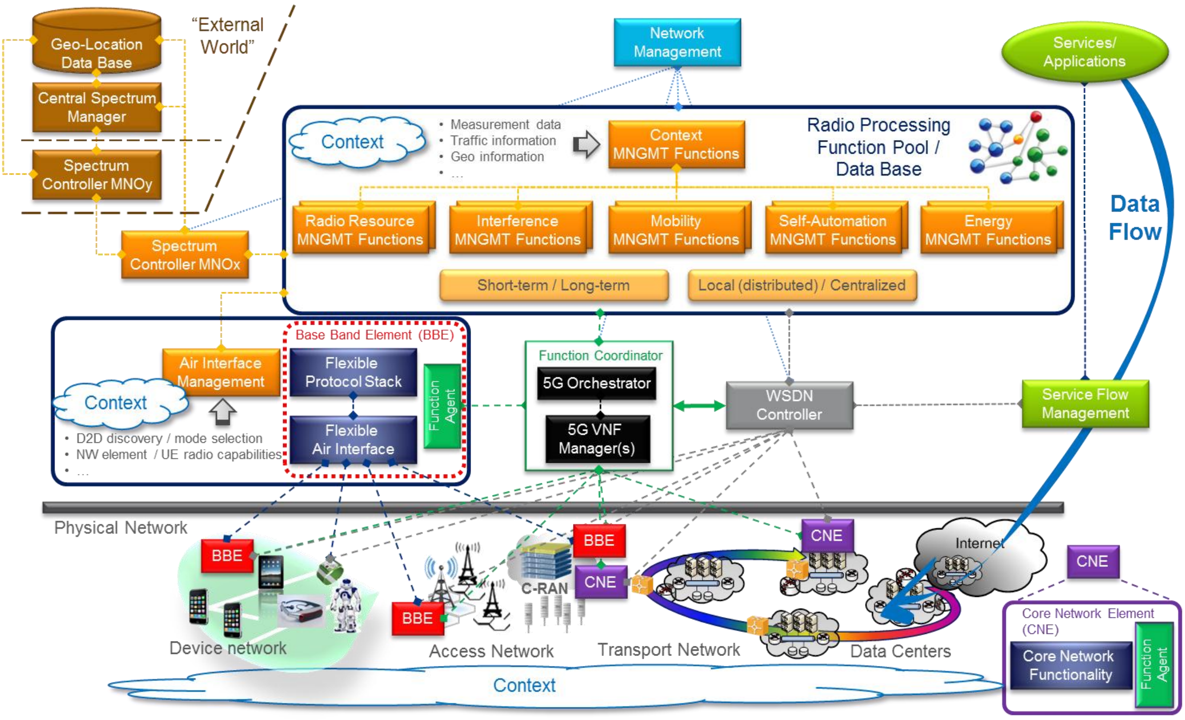

Figure C.7: METIS 5G architecture – logical view.

One of the targets of the 5G architecture development is to pinpoint possible limitations of such trends, i.e. boundaries, and the distinguishing features, i.e. key novelties, of the METIS 5G architecture. For instance, ETSI ISG NFV main area of activity is within the operator-owned resources [ETSI13]. Thus, a customer-owned device, e.g. a mobile phone, is kept outside the scope, as an operator cannot exercise its authority on it. Although, this is currently true, in the future within the time frame of 5G, certain functionalities of the user devices may be partially controlled by the operator, e.g. D2D relay. Furthermore, not only the user devices will be connected to the network, but also a wide range of other devices such as sensors and robots. All these devices will co-exist, and the operator may have further degrees of freedom to coordinate the functionalities of these devices. Subsequently, METIS 5G architecture considers the network as a whole which takes into account any connected or connectable NE. Therefore, the Function Coordinator consists of NFV Orchestrator and Virtual Network Function (VNF) Managers with extended features. The extended features needed for the METIS 5G architecture will be further elaborated throughout the project. Nevertheless, not all functions can be (or will be) virtualized. In this sense, the set of functions to be virtualized may create a certain limit on the flexibility. However, such a limitation of flexibility shall be considered for each network element individually. In addition, the flexibility may be limited by the capabilities of the network elements, such as sensors, which may not be updated with new functionalities, e.g. due to hardware limitations.