Document Number: ICT-317669-METIS/D6.5

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

Deliverable D6.5

Report on simulation results and evaluations

Date of delivery:	01/03/2015	Version:	1
Start date of Project:	01/11/2012	Duration:	30 months

Deliverable D6.5
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Project Number:	ICT-317669
Project Name:	Mobile and wireless communications Enablers for the Twenty-twenty Information Society

Document Number:	ICT-317669-METIS/D6.5
Document Title:	Report on simulation results and evaluations
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Dissemination Level:	PU
Contractual Date of Delivery:	01/03/2015
Security:	Public
Status:	Final
Version:	1
File Name:	METIS_D6.5_v1

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 areas. First, in this deliverable the overall METIS 5G system concept and its generic services, namely, extreme mobile broadband (xMBB), massive machine-type communications (mMTC) and ultra-reliable machine-type communications (uMTC) are mapped and compared to the foreseen future technical objectives, known as the METIS goals. These goals are investigated on a detailed level where each of the twelve METIS test cases is evaluated separately. The solution of each test case is built on the integration of technology components developed within the project.

Keywords

System evaluation, System concept, System-level simulation, Simulation results, Test case, Technology components

Executive summary

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 areas. The METIS 5G concept has developed and matured during the course of the project into a system that supports three generic services envisaged for 2020 and beyond:

- Extreme mobile broadband, xMBB,
- Massive machine-type communications, mMTC,
- Ultra-reliable machine-type communications, uMTC.

These services map to the technical METIS goals:

- 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.

Note that the technical METIS goals are to be fulfilled at similar cost and energy consumption levels as today's system. However, all these technical objectives do not need to be met at the same time. The envisioned system is therefore adaptable with diverse capabilities that can be configured into utilizing the different system features when needed.

In this document, the METIS 5G system concept is being evaluated on each of the twelve METIS test cases. Some of the main findings and results are described below:

- D2D communications reduce the latency to the order of the TTI length (e.g. 1-2 ms) and can increase the average system capacity by a factor of two.
- New waveform and multiple access technologies can reduce the access time down to 1.5 ms if new air interfaces are coupled with efficient access procedures. In uplink SCMA can improve the connectivity by a factor of two to ten times.
- In an indoor Ultra Dense Network with ISD of 10 m the capacity scales as 0.73 times the number of nodes (provided centralized interference coordination).
- Traffic concentration in machine-type communications improves range of coverage and sensors' throughput between two and three times. In addition, the traffic concentration reduces signalling overhead and battery consumption.
- For Moving Networks the link budget for end users can improve up to 24 dB within a car and 9 dB outside given merely two access points (one for inside transmission/reception and the other for the outside).
- Localized traffic flows can be used to offload the cellular system. With a dedicated bandwidth of 80 MHz, the end-to-end latency is reduced to 60 % of current LTE-A systems.
- Massive MIMO is enabled by smaller antennas and can increase the spectral efficiency by a factor of 20 when the number of both transmitter and receiver antennas are 256 instead of four.
- Spectrum at higher frequencies are crucial as the foreseen demands on 5G is that it will require much larger bandwidths than available today. The antenna size reduces as the frequency increase allowing advanced multiantenna solutions.

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List of Abbreviations

1D	One dimensional
2D	Two dimensional
3D	Three dimensional
3GPP	Third Generation Partnership Project
5G	Fifth-Generation
AgN	Aggregation Node
AN	Access Node
AP	Access Point
ARQ	Automatic Repeat Request
B	Byte
BAD	Bursty Application-Driven traffic
BF	BeamForming
BLER	Block Error Rate
bps	bits per second
BS	Base Station
BUD	Bursty User-Driven traffic
BW	BandWidth
C-ITS	Cooperative active Intelligent Traffic System
C-plane	Control plane
CA	Carrier Aggregation
CB	Codebook Based
CDF	Cumulative Distribution Function
CH	Cluster-Head
CIPE	Central Image Processing Entity
CL	Closed Loop
Cmode	Cellular mode
CO_2	CarbondiOxide
CoMP	Coordinated Multi-Point
CP	Cyclic Prefix
CQI	Channel Quality Indicator
CRC	Cyclic Redundancy Code
CSG	Closed Subscriber Group
CSI	Channel State Information
D	Deliverable
D2D	Device-to-Device
DFT	Discrete Fourier Transform
DL	Downlink
DMS	D2D Mode Selection
DRX	Discontinuous Reception
DTX	Discontinuous Transmission
E2E	End-to-End
eICIC	Enhanced ICIC
EIRP	Equivalent Isotropically Radiated Power
EMF	ElectroMagnetic Field
eNodeB	eNode Base station
f.o.	fiber optics
FA	Frame Alignment
FBMC	Filter Bank MultiCarrier
FDD	Frequency Division Duplex
FTP	File Transfer Protocol
fps	files per second
HARQ	Hybrid Automatic Repeat Request

HetNet	Heterogeneous Network
HMS	Harmonic Mode Selection
IAT	Inter-Arrival Time
ICIC	Inter-Cell Interference Coordination
IMF-A	Interference Mitigation Filter-Advance
IoT	Internet of Things
IP	Internet Protocol
IR	Incremental Redundancy
IRC	Interference Rejection Combining
ISD	Inter Site Distance
ITU	International Telecommunication Union
ITU-T	ITU Telecommunication Standardization Sector
KPI	Key Performance Indicator
L2S	Link-to-System
LIPA	Local IP Access
LOS	Line Of Sight
LTE	Long Term Evolution
LTE-A	LTE-Advanced
M2M	Machine-to-Machine
MAC	Medium-access Control
MBB	Mobile BroadBand
MCS	Modulation and Coding Scheme
METIS	Mobile and wireless communications Enablers for the Twenty-twenty Information Society
MIMO	Multiple-Input Multiple-Output
MLD	Maximum Likelihood Detection
MMC	Massive Machine Communication
MME	Mobility Management Entity
mMTC	massive Machine-Type Communications
mmW	millimetre Waves
MN	Moving Networks
MN-M	Moving Networks Mobility
MNO	Mobile Network Operator
MPA	Message Passing Algorithm
MRC	Maximum Ratio Combining
MRT	Maximum Ratio Transmission
MU-MIMO	Multi-User MIMO
MU-SCMA	Multi-User SCMA
N.A.	Not Applicable
NACK	Negative-Acknowledge Character
NFV	Network Function Virtualization
NLOS	Non LOS
NRT	Non RT
NW	NetWork
O2I	Outdoor-to-Indoor
O2O	Outdoor-to-Outdoor
OAM	Operation, Accounting and

	Maintenance
OFDM	Orthogonal Frequency-Division Multiplexing
OFDMA	Orthogonal Frequency-Division Multiple Access
OL	Open Loop
PC	Personal Computer
PDF	Probability Density Function
perc.	percentile
PHY	PHYsical layer
PRACH	Physical RACH
PRB	Physical Resource Block
PS	Propagation Scenario
QAM	Quadrature Amplitude Modulation
QoE	Quality of Experience
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
R	Room
R11	Release 11
RA	Random Access
RACH	Random Access CHannel
RAN	Radio Access Network
RAT	Radio Access Technology
RB	Resource Block
RE	Resource Element
RPD	Receiver Processing Delay
RRC	Radio Resource Control
RRM	Radio Resource Management
RT	Real Time
RTT	Round Trip Time
RX	Receiver
SCMA	Sparse Code Multiple Access
SD	Scheduling Delay
SDMA	Space-Division Multiple Access
SeGW	Security GateWay
SFBC	Space-Frequency Block Coding
SIMO	Single-Input Multiple-Output
SINR	Signal to Interference plus Noise Ratio
SM	Single-Mode
SNR	Signal to Noise Ratio
SON	Self-Organizing Network
SU-MIMO	Single-User MIMO
SUMO	Simulation of Urban MObility
TC	Test Case
TDD	Time Division Duplex
TeC	Technology Components
TeCC	TeC Cluster
TES	Traffic Efficiency and Safty
TP	TTI per Package
TTI	Transmission Time Interval
TV	TeleVision
TX	Transmitter
UDN	Ultra-Dense Networks
UDP	User Datagram Protocol
UE	User Equipment
UFMC	Universal Filtered MultiCarrier
UL	Uplink
UM	Utility Maximization
uMTC	ultra-reliable Machine-Type Communications
UMi	Urban Micro model
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Device/Infrastructure/Vehicle
VT	Video Traffic
wAN	wireless Aggregation Node
WP	Work Package
x	times
xMBB	extreme Mobile BroadBand

1 Introduction

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 areas. In the METIS work, new technology components and paradigms are investigated. The most promising components are to be integrated into the METIS 5G system concept. This 5G system concept was initially introduced in [MET14-D62] and further elaborated in [MET14-D63], where also the intermediate system evaluation results were given. In [MET15-D64] the METIS 5G system architecture is presented. The proposed concept is to 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.

Following the simulation guidelines specified in [MET13-D61], the METIS technical objectives are investigated in detail in this deliverable for each of the twelve METIS test cases that were defined in [MET13-D11].

The overall insights on the performance of the METIS 5G system shall be given in the final deliverable D6.6.

1.1 Objective of the document

The objective of this document is to show whether the METIS 5G system concept is able to achieve the METIS technical objectives or not. In order to learn this, the METIS 5G system concept is being evaluated on each of the twelve METIS test cases. The simulation results are reported for each of the test cases.

1.2 Structure of the document

In Section 2, the METIS 5G system features and enablers are presented. Section 3 describes the evaluation settings and performance criteria for each of the test cases, while Section 4 provides the corresponding simulation results. Section 5 contains conclusions of the attained results and on the performance evaluation of the METIS 5G system.

In addition, this document contains two annexes. Annex A provides the simulation setting details and results for each test case. Annex B briefly describes each technology component that has been used in at least one of the evaluations.

2 METIS System Features and Enablers

2.1 Introduction

The METIS system concept will support three generic services envisaged for 2020 and beyond: extreme mobile broadband (xMBB), massive machine-type communications (mMTC) and ultra-reliable machine-type communications (uMTC) [MET14-D63].

- **xMBB** covers three of the scenarios defined in D1.1 [MET13-D11], namely, “amazingly fast”, “great service in a crowd” and “best experience follows you”. This service provides extreme high data rates and low latency communications, and a uniform and ubiquitous quality of minimum broadband experience, even in crowded areas. xMBB can be used for reliable communications.
- **mMTC** covers the “ubiquitous things communicating” scenario defined in D1.1 [MET13-D11]. This service provides wireless connectivity for tens of billions of network-enabled devices. Scalable connectivity for increasing number of devices, wide area coverage and deep penetration are prioritized over peak rates as compared to xMBB.
- **uMTC** covers the “super real-time and reliable connections” scenario defined in D1.1 [MET13-D11]. This service 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.

Table 2-1 maps the generic services to the most relevant METIS technical goals. From the Table, it is clear that not all technical objectives need to be met at the same time by different services. Thus, METIS foresees an adaptable system with diverse capabilities, which can be configured on demand to utilize different system features and technical capabilities in order to address different use cases and scenarios.

Table 2-1: Mapping of 5G services to the most significant METIS technical goals.

METIS technical goals	5G services		
	xMBB	mMTC	uMTC
1000x data volume	X		
10 – 100x data rate	X		
10 – 100x number of devices	X	x	
10x longer battery life		x	
5x reduced E2E latency			x

2.2 METIS System Features

The METIS 5G system concept as described in [MET13-D62] comprises three types of features, namely:

- Mature features transferred from the previous generations of wireless systems, but enhanced to fit the 5G requirements. Those include, e.g., efficient mobility support and energy-efficient operation of the terminals.

- Emerging system features, some already deployed, but expected to mature when implemented with the 5G architecture. Examples include cloud RAN, offloading through local connections and NFV.
- Novel 5G-specific features, such as nomadic nodes, ultra-reliable connections for critical control, D2D for relaying and aggregation of machine-type traffic, massive machine-type communications, as well as flexibility and configurability capabilities needed to meet the diverse 5G requirements.

An overview of some of the novel METIS 5G-specific features is given below (see future deliverable D6.6 for a complete description):

- **Dual role of the mobile wireless devices** eliminates the traditional distinction between infrastructure nodes and terminal nodes that exists in current networks. Thanks to advances in processing/computing capability, devices will be able to act as terminals and/ or as access nodes, facilitating use cases such as nomadic cells, ubiquitous caching, range extension and local traffic flows.
- **Ultra-reliable links with low latency** makes it possible to support applications such as road safety, autonomic mobile systems, industrial automation, and e-health services.
- **Guaranteed moderate rates and very high peak rates** sustain a consistent basic broadband experience, regardless of network conditions, user location, user density and user mobility alongside the ability to provide extremely high data rates where desired. This feature is a key differentiator from networks engineered for peak throughput.
- **Resilience to the lack of infrastructure support** provides reliable communications, even in the absence or damage to traditional network infrastructure, thanks to the dual role of the mobile wireless devices.
- **Increased cooperation among operators** efficiently supports new applications such as V2X communications, as well as, efficient use of network and spectrum resources.
- **Network follows the crowd** to ensure consistent end-user experience, anywhere and anytime. This relies on new advanced capabilities for dynamic network deployment to meet capacity, coverage and energy efficiency demands.
- **Localized traffic offloading** reduces the signalling and traffic burden on the backhaul and core networks and seamlessly facilitates high rate data transfers, latency-critical applications, as well as, massive device connectivity.
- **Unprecedented spectrum flexibility** allows all spectrum usage opportunities, including both exclusive and shared usage, as well as both licensed and unlicensed usage, to be exploited to consistently meet end-user requirements. Multiple spectrum usage schemes can be applied simultaneously for matching the dynamic requirements in different locations and time.
- **Flexibility and configurability** at all layers in the architecture, as well as network functions enable the same network to adapt to meet the needs of different services with diverse requirements.

2.3 METIS Enablers

Technologies and concepts developed within the METIS project enable the novel 5G features to be realized for the three 5G services and help to achieve the overall technical goals. Twelve test cases derived from the METIS scenarios (see [MET13-D11]) and spanning all the three 5G services, provide concrete examples of 5G usage against which these enablers are evaluated. The technology enablers that help in significant ways the METIS 5G system concept to meet the technical goals are briefly described below. More details are provided in Section 4 and Appendix A.

2.3.1 Enablers for xMBB

The enablers for xMBB contribute to meeting the METIS technical goals ‘1000x higher mobile data volume per area’, ‘10 to 100x higher typical user data rate’ and ‘10 – 100 x number of connected devices’ – see Table 2-1.

1000x higher mobile data volume per area

In general, more spectrum, higher spectral efficiency and reducing the communication distance (network densification) are all enablers to realize higher system capacity. The ability to use chunks of 100 MHz or more bandwidth is essential to realize capacity requirements for many foreseen use cases. In this regard, spectrum discovery and aggregation techniques for lower frequency bands and the use of higher frequency bands (centimetre and millimetre waves) are essential. When combined with new duplexing and transmission access technologies, such as dynamic TDD and massive MIMO respectively, the gains in capacity can be improved further. In particular, massive MIMO is well-suited to the use of higher frequencies, where beamforming gains can mitigate the challenging propagation properties at higher frequency bands.

Ultra-dense deployment of access nodes has two effects, namely, reducing the communication distance between terminals and access nodes and reducing the number of terminals served by each access node. This, in turn, enables the system to support many communicating links, each capable of high throughput performance, given the availability of proper interference management schemes and low-latency, high-capacity backhaul. In this regard, enablers like centralized RAN, where a centralized baseband unit controls multiple remote radio units can facilitate the creation of a favourable interference environment. This can help the system to realize even higher capacities, compared to the case where nodes are deployed in a decentralized manner. Evaluations suggest that a very high data volume per area, enough to meet the requirements of several test cases (e.g., TC1 - virtual reality office, TC2 - dense urban society), can be realized by using a combination of larger bandwidths, dense deployments, centralized coordination, MIMO techniques, multi-user transmission, as well as improved processing and routing in the core network.

Another means of reducing the communication distance is the use of D2D communications. In particular, network-controlled D2D, where the network plays an active role in selecting D2D communicating pairs and the communication resources, can significantly increase system capacity (see e.g., Chapter 4, TC2, TC4, TC6 and the Annex). Network-controlled D2D makes it possible not only to support many communicating links at higher throughputs, but also reduces the load on the backhaul and the core network, which improves the capacity of the overlay network as well. System level simulations show that up to 15 percent of traffic in a stadium can be offloaded via D2D, alleviating congestion on the macro network. Similarly, it is possible to use D2D to offload up to 25 percent of end user traffic in a traffic jam and free up resources on the macro network to serve more users (see Section 4 and Appendix A for more details). Local offloading (e.g., using other RATs) could also achieve a similar effect, given tight control plane integration, interference management and appropriate mode selection algorithms.

Finally, system intelligence, especially in the form of context awareness and prediction is also an important enabler. For instance, caching in the network can help to reduce the communication distance, reducing the load on the backhaul/core and at the same time facilitating many high-throughput communication links at the edge. In particular, the dual role of mobile terminals, as both access nodes and terminals can magnify the effect of caching in the network to improve system capacity. Awareness and ability to predict other context information such as movement can also help to optimize handovers and transmission parameters to improve overall system capacity.

10 – 100x higher typical user data rate

Most of the enablers highlighted in the previous section also help to achieve higher typical user data rate. In particular, larger bandwidth is a very important enabler. Larger bandwidths also make it easier to reduce the transmission time interval (TTI), which can help to achieve higher throughputs through faster scheduling and transmission of available data, as well as the possibility for faster retransmissions of erroneously received data. In system evaluations, reducing the TTI from 1 ms to 0.25 ms has been shown to improve the average throughput by around 20 percent (see Section 4 and Appendix A).

In addition, techniques that improve the spectral efficiency, e.g., higher modulation and coding schemes, new waveforms, new numerology and non-orthogonal multiple access, when combined with larger bandwidths can help to realize higher data rates. However, some of these techniques rely on high signal-to-interference and noise ratio (SINR) environment to achieve these gains. Thus, enablers that help to improve the SINR throughout the network are vital. For example, network densification, in combination with proper interference management (e.g., interference coordination, cooperative transmission, centralized RAN, interference cancellation with advanced receivers) reduces the communication distance and improves the SINR, which allows such advanced techniques to be applied. Network-controlled D2D also has a similar effect. In addition, massive MIMO, through precise beamforming, isolates the communication links of different users and thus achieve higher SINR over a wider range, which again helps to realize gains from using more advanced techniques. Besides, resource-efficient waveforms, such as FBMC and SCMA, robust to user and environment dynamics (e.g., mobility), make it possible to maintain high data rates. For instance, throughput gains of up to 13 percent can be realized with the use of FBMC in a situation with a high user density (e.g., traffic jam). Similarly, using SCMA could improve the cell edge throughput by as much as 65 percent (see Section 4 and Appendix A).

10 – 100x number of connected devices

An important feature of xMBB is the ability to provide a consistent broadband experience, even in extremely crowded scenarios, like an open air festival, a stadium or in a traffic jam. Several enablers make it possible to realize this feature.

The availability of larger bandwidth is naturally an important enabler. Nevertheless, a key bottleneck of current systems in such scenarios, besides the lack of capacity, is usually the inability to deal with the huge signalling load on the system, which may bring the entire network to a complete standstill. Techniques that reduce all types of signalling, as well as, the context stored in the network are important enablers. In particular, network-controlled D2D can reduce the data load, which can free up backhaul capacity and core network resources to handle the signalling. Grant-free contention based mechanisms can also reduce the dynamic signalling overhead.

Local routing and other offloading approaches also help in this regard. Separation of data and control plane is necessary for efficient local offloading, while ensuring independent mobility of control and data planes. The latter is important for the ability to independently scale different parts of the network, depending on the actual bottleneck (control plane or data plane). Coverage improvement techniques, such as beamforming realized with massive MIMO, are also important enablers.

2.3.2 Enablers for mMTC

The enablers for mMTC make it possible to support ‘10 to 100x the number of connected devices’ and ’10x longer battery life’ - see the METIS technical goals in Table 2-1. Unlike xMBB, the use case for high device density in mMTC mainly concentrates on low-end devices with limited resources and low data rate transmission requirements, e.g., sensors.

10 – 100x number of connected devices

Supporting a huge number of devices requires scalable connectivity, wide area coverage, including deep penetration and capacity improvement.

Several enablers help to realize scalable connectivity. Techniques that reduce control signalling are important in this regard. One example is efficient connection procedures realized through contention-based access combined with waveforms that do not require uplink synchronization (e.g., FBMC) and can tolerate more collisions (e.g., SCMA). Another enabler for scalable connectivity is hierarchical routing, achieved through the use of aggregators that accumulate the communications from several devices before forwarding to the nearest access node with a backhaul to the core network. In addition, context-aware mechanisms (e.g., context-aware grouping) enable further reduction in control signalling (see Section 4 and Appendix A).

Coverage improvement techniques also make it possible to support many devices, even those located deeply indoors. D2D, can help to extend the network range, especially in places with minimal or no network coverage. In addition, capacity improvement, especially in the uplink, is essential. In this regard, new waveforms which can be optimized for small packet transmissions (e.g., SCMA) can help to improve coverage as well as the uplink capacity. Evaluations show that up to tenfold improvement in the number of devices supported is possible (see Section 4 and Appendix A).

10x longer battery life

With fast network synchronization and reduced control and data plane latency, it is possible to enable quick transitions between device’s sleep and active modes, which reduces total energy consumption and prolongs battery life. Narrow-band transmissions also help to save energy. Thus, waveforms that are able to achieve efficient small packet transmission in such narrow bands play an important role. Furthermore, contention-based access schemes together with reliable multi-user detection techniques can reduce the time a device spends in active mode, thus helping to conserve energy. In addition, reducing the transmission distance, as well as, transmission times help to reduce energy consumption. D2D, as well as hierarchical network topologies with aggregators help to reduce the transmission distance. In addition, well-designed sleeping cycles reduce the transmission times and help to conserve device battery.

2.3.3 Enablers for uMTC

The enablers for uMTC help to provide 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 like the METIS technical goal '5 x reduced E2E latency' – see Table 2-1.

5x reduced E2E latency

Given the availability of sufficient bandwidth, lower E2E latency can be realized through a combination of several techniques such as efficient and reliable control plane (e.g., efficient signalling, discovery and link setup procedures), waveforms that provide high reliability through their ability to deal with environment dynamics (e.g., mobility, varying channel conditions), reduction in transmission distance and transmission time interval.

D2D communications, in particular the network-controlled variant, is also an important enabler since it reduces the transmission distance for the data plane. In combination with efficient control signalling, this helps to reduce latency through sheer proximity, as well as, reliable communications (enabled by higher SINRs) which reduces the need for retransmissions. Similarly, reducing the TTI also helps to improve E2E latency, primarily due to faster transmissions and retransmissions. Evaluations show that by combining a resource coordination scheme with smart retransmission schemes and reduced TTI interval, it is possible to achieve 5 ms E2E latency for V2X communications with a reliability of ≈98% compared to a reliability of ≈85% for the baseline system without such enablers (see Chapter 4 and Annex for TC6).

2.3.4 Energy efficiency enablers and cost rationalization enablers

Though energy efficiency is not novel in 5G per se, the difference is that in the 5G development energy efficiency is a KPI that will be considered from the start of the system development, e.g. thought the Lean System Control Plane and activation and deactivation of nodes in the Dynamic RAN. Since energy efficiency is a KPI on par with communication performance, it is sometimes referred to as Energy Performance to highlight this. Energy efficiency throughout the network is vital in the METIS system concept. Thus, techniques to dynamically activate and deactivate nodes, based on network status, play an important role. Context awareness enables the network to meet end-user requirements while achieving energy efficiency at the same time. Enablers such as wireless backhaul solutions, operating in different frequency bands (lower frequency bands, millimetre waves) also contribute to realize flexible and dynamic network deployments to meet dynamic network needs in a cost-efficient manner. Flexible integration and adaptation of Operation, Accounting and Maintenance (OAM) and self-organizing/automation functionalities (Enhanced SON), are also enablers to implement "green" and "affordable" network operation.

3 Evaluation Scenarios and Performance Criteria

This section offers a short overview of the simulation assumptions in the twelve test cases (TC) analysed in this deliverable. For more details on the simulation assumptions, please refer to Annex A, where full explanation is available. The list of Technology Components (TeCs) that have been evaluated can be also found in Annex B. For each TC, the specific list of TeCs used is also included.

3.1 TC1: Virtual Reality Office

This test case consists of an indoor scenario in which the work involves interaction with high-resolution 3D scenes where a team of 20 individuals is simultaneously interacting. The challenge is to support the huge traffic flow of 5 Gbps per user interacting in the scene, both in uplink and downlink, while keeping packet round trip time at the application layer below 10 ms in average. Details on the used metrics can be found in Section A.1.2.

The realistic modelling of the office is attained by explicitly considering walls, screens, desks, chairs and people. We assume the existence of fibre optics connections to all access points. Deployment comprises one main base station ceiling-mounted operating at 3.5 GHz and five additional access points operating at 60 GHz. For propagation characterization, we used Propagation Scenario number 7 (PS#7) for the transmitter at 3.5 GHz [MET13-D61] and a ray-tracing characterization for the remaining 5 access points (see [MET14-Web] for more details on the ray-tracing files).

Every user (users in office and users out of office) sends/receives a traffic flow to/from a central image processing entity (CIPE) located in the same office. This flow can be sent/received to/from the central processing entity through the local routing entity or through D2D links. The CIPE collects all uplink flows, which include the video of each particular user, and bounces back the combined scene in the downlink.

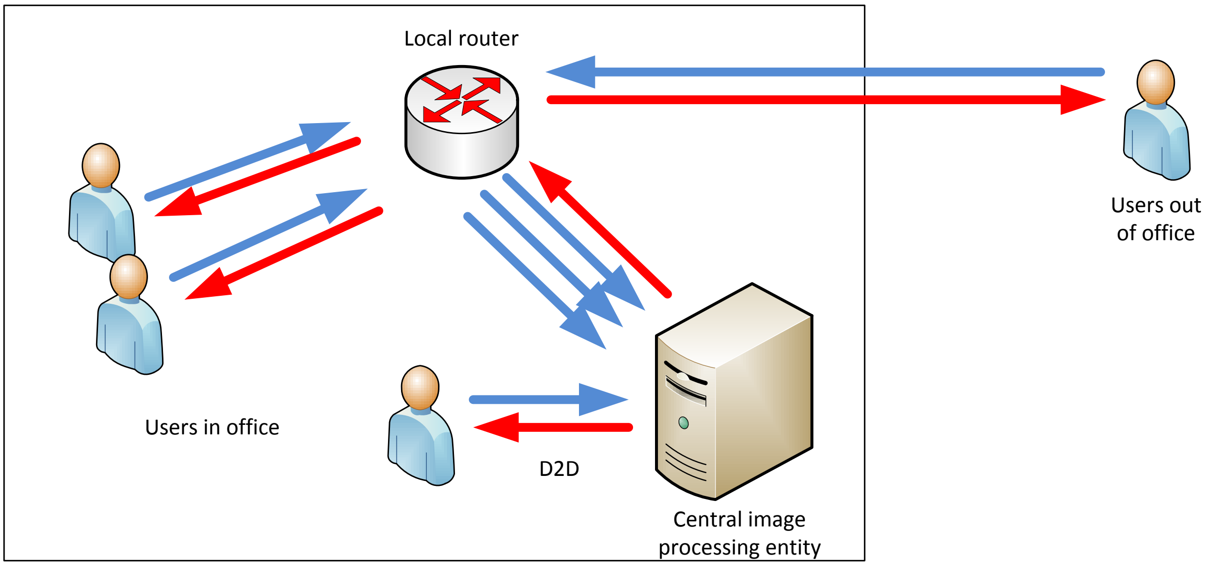

Figure 3-1: Data flows in TC1 and the role of the CIPE.

All transmitters and users are equipped with 8 antennas (4 cross-polarized antennas). In the baseline, 60 MHz are allocated for main base station at 3.5 GHz, whereas 140 MHz are given to access points operating at 60 GHz.

Regarding users' location, according to mean user density and area, 20 users in average should be generated in the office. In our simulations, 18 users are placed in the office rooms and 2 users are located in outer locations. All rooms are occupied by one user except rooms R4 (2 users), R8 (4 users), and R12 (2 users). See Figure A-2 for more details on the room distribution. There are no users explicitly placed in outer positions but 2 users in the office (not those in R8) are in a video call different to that of the other 18 users. They are consuming radio resources and latency is artificially increased to account for the real performance of those actual outer users.

Traffic is modelled with FTP at 1 Gbps in each direction. We assume that packet size is 20 Mbits, and time between packets is 20 ms (50 fps). Latency for a fibre optics link is assumed to be 1 ms. Processing in routers and gateways is assumed to be also 1 ms. Latency between gateways for users in outer locations is assumed to be 1 ms. These values will be added to the radio access network delays, which will depend on congestion, scheduling and system capacity. More details on the simulation assumptions in this TC can be found in Section A.1.

3.2 TC2: Dense urban information society

The Dense urban information society, TC2, is a future urban setting where the need to handle high traffic volumes and high experienced data rates are necessary in order to fulfil the foreseen requirements at a reasonable cost in these urban regions. The main requirements and KPIs are:

- Traffic volume per subscriber: 500 [Gbyte/month/subscriber] in DL and UL
- Device density: 200’000 per km^2
- Traffic volume per area: 700 [$Gbps/km^2$] DL and UL,
- Experienced user data rate: 60 / 300 [Mbps], UL / DL, with 95% availability (max rates up to 1 [Gbps])

The urban environmental model of this test case is made realistic by e.g. considering the different environments of buildings (with entrances), roads, park, bus stops, metro entrances, sidewalks and crossing lanes. These different aspects are captured within, what is referred to as the Madrid grid environmental model. This model has been developed within the METIS consortium and is based on observations regarding the city structure of Madrid. It is an example of typical European city environment capturing way more aspects then Manhattan grid. The TC2 environmental model, the Madrid grid, is given in Figure 3-2, and is described in more detail in [MET13-D61].

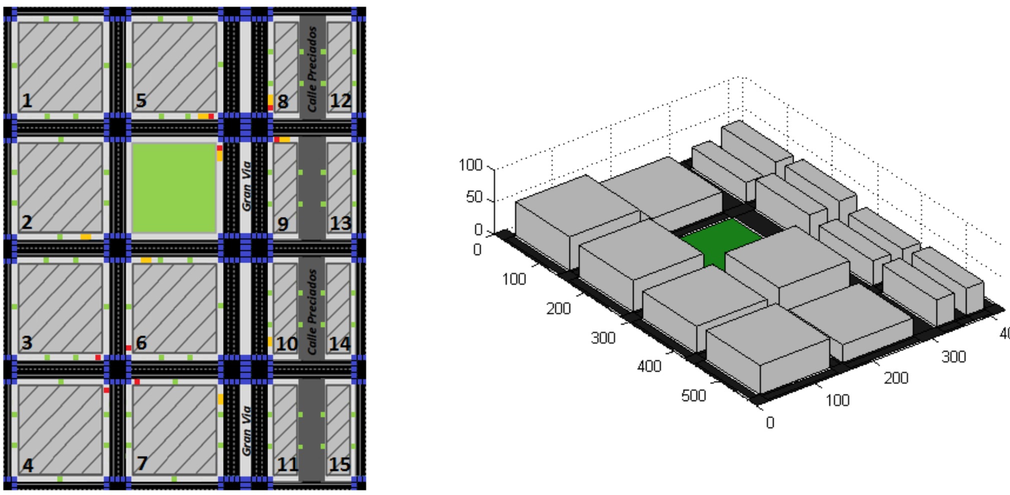

Figure 3-2: A 2D visualization (left) and a 3D visualization (right) of the Madrid grid.

The key evaluation criterion is a user experienced data rate at 95th percentile of CDF that can be calculated directly from experienced packet delay under the assumption of fixed packet size. The other criteria used in evaluation are a percentage of packets delivered on time below 0.5 second and user rate vs. traffic volume in area.

To fulfil the specified KPIs and requirements some of the technology components developed within METIS are being used. The WP2-TeCC1 is a cluster of technology components that enables a flexible OFDM air interface for dense deployment in terms of frame structure, dynamic TDD and harmonized OFDM. The centralization and coordination of fast uplink downlink resource allocation was enabled by T4.1-TeC6-A1 and verified in high and low interference isolation scenarios. T4.2-TeC17 on downlink multiuser SCMA for high data rate looked for performance gains in pico outdoor deployments. In TC2 macro deployment we check potential of new 5GMBB with further use of cmW. Details on these technology components are provided in Section B.

The evaluation of this TC has been divided into three different parts, assessing different aspects in the indoor areas and in the outdoor area. More details on the different assumptions in the different scenarios can be found in the Annex A.2.6 for indoor UDN deployments, Annex A.2.7 and A2.8 for outdoor TC2 pico and macro deployments respectively.

3.3 TC3: Shopping mall

Test case three, TC3, focuses on challenging traffic demands in a Shopping mall. The main requirements and KPIs are:

- Traffic volume per area: 170 (67) Gbps/km^2 DL (UL),
- Traffic volume per subscriber: 1.07 Gbyte DL+UL,
- Experienced user data rate: 300 (60) Mbps DL (UL),

together with high availability and reliability [MET-D11].

A shopping mall environment model was specified in [MET-D61] with shops, walls, corridors and a food court. That environment model is used in this study, and a graphical illustration of the shopping mall is given in Annex A.3. The propagation behaviours in the mall have been attained via ray-tracing computations that were based on the specified simulation guidelines [MET13-D61] and [MET14-D63]. In this TC3 evaluation the food court is assumed to be a boosting area for wireless data traffic and hence the stage of the simulations. The propagation results of the entire shopping mall can be found at [MET14-Web]. In this TC3 study the propagation results of the food court were refined. In Figure 3-3 the ray-trace generated geographical locations of AP positions (blue-stars) and UE positions (red-crosses) are given, together with the aggregation node (fibre backhaul) positions and wireless aggregation node positions (self backhauling nodes) used in the performance evaluations. An Aggregation Node (AgN) have direct access to the network while a wireless Aggregation Node (wAN) have a wireless backhaul that needs to go through an AgN first. The left part of Figure 3-3 represents the AgN topology with its six aggregation nodes, 6 AgN (in orange). The right part depicts the wireless topology with its 6 AgN (in orange) and its four wireless aggregation nodes, 4 wAN (in green).

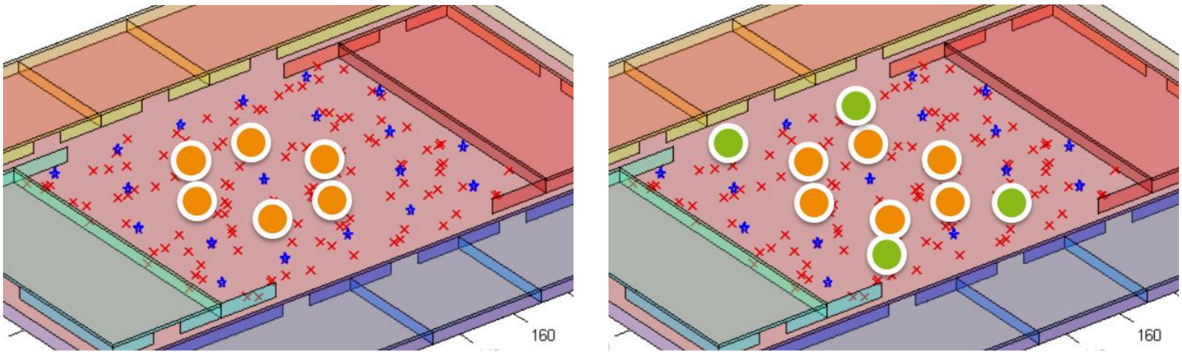

Figure 3-3: TC3 simulation topologies.

To fulfil the specified KPIs and requirements some of the technology components developed within METIS are being used. The WP2-TeCC1 is a cluster of technology components that enables a flexible OFDM air interface for dense deployment in terms of frame structure, dynamic TDD and harmonized OFDM. Contention based MAC is enabled by WP2-TeC12.3 and T3.3-TeC2. The T3.3-TeC2 also enables wireless self-backhauling. Details on these technology components are provided in Section B.

The total throughput target is 5.6 TB per hour. This is modelled as 82 files (each with the size 20 MB) per second (Poisson arrival) with one file per user. The traffic split is 70% in downlink and 30% in uplink. The file transfer is User Datagram Protocol (UDP). MAC ensures the transmissions.

The users are deployed as they have a file. Only static users are considered (i.e. the UE is assumed to remain static during the download/upload which typically is less than a second). The UE positions are randomly selected from 128 available locations, i.e. the red-crosses in Figure 3-3.

The technology components and simulation assumptions are evaluated with metrics as:

- CDF of experienced user throughput,
- CDF of total file delay,
- RX SNR comparison between the two specified topologies,

More details on the simulation set up and assumptions are given in Annex A.3.

3.4 TC4: Stadium

The stadium use case relies on an existing market, where operators experience today a “difficulty” in providing a service with good quality of experience. From a technical point of view, the general challenge is to offer a reliable and extremely huge bandwidth service to a multitude of users temporarily located in a single cell already deployed area. The main parameters to be analysed in this scenarios are capacity, since the system must carry up to 20 Mbps per user, and latency, with a target of 5 ms for the radio access network.

There is a dense network of small cells antennas deployed at the rooftop of the stadium and directed toward the audience. Thirty small cells access points are connected with optical fibre to a common baseband unit. To limit intercell interferences small cells antennas are highly directive. In this work, the simulations only focus on below 6 GHz spectrum, more specifically on the 2.6 GHz band. 180 MHz is allocated to cellular communications at 2.6 GHz, and 20 MHz (UL+DL) for D2D communication at 60 GHz. Stations and users have 8 antennas (4 cross polarized pairs) and antennas at base stations have 17 dBi gain.

Given the relevance of confining transmitted signal to the area of interest, we are working on the following customized configuration of antennas:

- Antennas at x=10 → tilt=95º, θ_{3dB}=10º, ϕ_{3dB}=15º
- Antennas at x=25 → tilt=85º, θ_{3dB}=15º, ϕ_{3dB}=20º
- Antennas at x=40 → tilt=65º, θ_{3dB}=20º, ϕ_{3dB}=35º

being θ_{3dB} the beamwidth in the horizontal plane and ϕ_{3dB} the beamwidth in the vertical plane. A proper explanation of these assumptions are given in Section A.4.

This scenario is assumed to be isolated from outside interferences. By default, small cells are deployed on out band frequency with respect to macro layer.

In the stand area under study there are 9751 users distributed uniformly in the considered area. Antennas of different cells are all deployed at the height of 33 m, with horizontal plane separation of 10 m along the major stadium axis and 15 m along minor stadium axis. To avoid intercell interferences the antennas are directive and all of them are 60º angled with respect to the roof plane orientation. The total output power for small cell is limited to 30 dBm.

The propagation model for TC4 is the UMi LOS model defined in [ITU08]. Additionally, for D2D traffic PS#9 is proposed [MET13-D61]. Concerning propagation, the FTP-traffic model described in [METIS13-D61] is used, where users are downloading 50 Mbytes files every 20 s.

We consider the next delays in the latency budget:

- delay in the link from the central baseband unit to the remote radio unit: 1ms.
- subframe alignment in the remote radio unit: a value between 0 and the subframe length.
- processing time in the remote radio unit and the user equipment: 0.5 ms each.
- transmission time over the air: multiple of the subframe length, depending on the packet size and the transmission opportunities.

Final delay is calculated with the summation of all those components. Note that more details on the assumptions of this test case can be found in Section A.4.

3.5 TC5: Teleprotection in smart grid network

This test case focuses on the efficient distribution of wireless messages between electric substations after a failure in the energy distribution system. A prompt reaction in terms of a reconfiguration of the network is needed and therefore the message must reach the surrounding substations in less than 8 ms.

In this test case the only requirement is to be able to forward a control message of 1521 bytes from one substation to a set of neighbour substations in less than 8 ms with 99.999 % reliability.

Concerning the evaluation scenario, the environment of TC5 is the same as TC2, that is, the Madrid grid. In this urban area 42 substation are randomly deployed in outdoor locations, close to the building edges. A set of macro and pico-cells are available in this area, exactly in the same positions as explained in TC2. The propagation models used in TC5 are PS#1 (pico-cells outdoor coverage), PS#3 (macro-cells outdoor coverage) and PS#9 (direct substation-to-substation communication) as proposed in [MET13-D61].

Substations are wirelessly connected to the base stations. In case of sharing the base station Local IP Access (LIPA) is used, that is, routing happens directly in the base station, without the need to go to core network entities. Substations may also use D2D links for redundancy transmission. Discovery is assumed to already exist, since substations are static and can be made with very low frequency. If in D2D coverage, direct communication between substations will happen in parallel with infrastructure-based traffic. In case of transmission between two substations without direct coverage and not connected to the same base station, conventional routing is used. 200 MHz bandwidth is available in the cellular links while only 20 MHz are used for D2D links.

Substations are assumed to have 8 antennas. With them we assume that in OFDM (LTE-A like) and FBMC (WP2-TeCC8.1) spatial multiplexing allows us to multiplex up to 4 layers in parallel without mutual interference. In SCMA (WP2TeCC11), up to 6 layers are code-multiplexed using a code of length 4, while spatial multiplexing increases multiplexing capability 4 times, up to 24 layers. We are also investigating the effect of reduced subframe lengths. In this sense, we have considered a subframe length of 1, 0.5 and 0.25 ms.

In order to reduce latency, an improved procedure for random access channel and resource allocation is used. This procedure is agnostic with respect to the waveform, but has been only tested with FBMC and SCMA options. It is worth noting that the same improvement could have been applied to an OFDMA system, but the other two waveforms are more appropriate for the coexistence of machines transmitting small packets and this is why we have only focused on these two alternatives.

The use of FBMC as compared with OFDMA, like in LTE-Advanced, has several implications in our study (see [MET14-D23] for more details):

- The SINR required to obtain a given throughput is lower in FBMC. In average, this gain is about 0.3 dB.
- Substation access to uplink channel is faster than in LTE-Advanced since no contention and scheduling process is needed.

On the other hand, the use of SCMA this technique instead of OFDMA has several implications in our study (see [MET14-D23] for more details):

- The SINR required to obtain a given throughput is lower in SCMA than in OFDM. In average, this gain is about 3.3 dB. This SINR offset is a simple abstraction methodology to, in general, model the aggregated impact of SCMA codebooks, SCMA overloading, and the MPA joint detector.
- Substation access to uplink channel is faster than in LTE-Advanced since no contention and scheduling process is needed.
- Multiple layers can be code-multiplexed even with only 1 transmitting antenna. Up to 6 layers can be multiplexed without mutual interference.

In simulations, each substation transmits packets to its closest substations. The number of neighbours ranges from 1 to 10. For each number of target neighbours the maximum time needed for the packet to reach all the neighbours is recorded. With these values we show three kinds of results:

- CDF of the time to reach a substation considering all the targeted substations, and all the possible numbers of target neighbours.

- For the entire set of substations we get the maximum value needed to reach 1 neighbour, 2 neighbours and up to 10 neighbours. These new values represent the performance of the worst-case user.
- For the entire set of substations we get the mean value needed to reach 1 neighbour, 2 neighbours and up to 10 neighbours. These new values represent the performance of the mean case user.

More details on the simulations set up and assumptions can be found in Annex A.4.

3.6 TC6: Traffic jam

The high popularity of smartphones and Tablet PCs, is expected to increase the consumption of public cloud services on the move. As a result, users travelling inside cars or buses will be used to enjoy services such as web browsing or file download with their personal devices as well as with the vehicle's infotainment systems. Together with those traditional services, a significant increase in the consumption of high-definition video is expected as a result of larger and better quality screens. In the future, the provision of public cloud services inside vehicles will be challenged during the occurrence of traffic jams due to the sudden increase in the capacity demand. In this case, it is important that the QoE of public cloud services is maintained regardless of the number of vehicles that might become trapped in the traffic jam. This is especially challenging in motorways and rural areas, in which the deployment of network infrastructure might not be dense enough to satisfy the capacity needs of a large number of users.

The requirements in this test case focus mainly on throughput, latency, and availability and reliability. A high data rate connectivity is expected that allows each user in a car to experience a data rate of at least 100 Mbps in downlink and 20 Mbps in uplink. Assuming four users in one car and a vehicle density of 1000 cars per squared kilometre that leads to a total data volume of 400 Gbps/km² for downlink and 80 Gbps/km² for uplink. The end-to-end latency has to be less than 100 ms. An availability of 95 % is necessary in order to satisfy user QoE.

The TC2 evaluation scenario, Madrid Grid, is used in this work to simulate this test case. In addition to the deployment model described in TC2, 13 new small cells are considered here also to provide higher system throughput. Further, it is also assumed that four antennas are equipped on top of each vehicle and therefore a communication link in between each vehicle and base station can be established. In this manner, passengers inside each vehicle are served by their attached vehicle, and vehicles act as relay nodes in between their carried passengers and base stations. Since the local serving in between each vehicle and its carried passengers is relatively simple and can be solved by legacy technology, the main challenge for this TC focus on the links in between vehicles and base stations. In case where D2D communication is available, a link can be established in between any two vehicles to exchange local information.

To simulate the path loss between transmitter and receiver, the following propagation models [MET13-D61] are used in TC6:

- PS#1 for micro-cell outdoor coverage
- PS#3 for macro-cell outdoor coverage
- PS#9 for direct device-to-device communication

In order to achieve the requirement on throughput, the following technology components were evaluated to improve throughput of cellular network, as illustrated in A.6.5,

- Filter Bank MultiCarrier (FBMC)
- Sparse Code Multiple Access (SCMA)
- Time-sharing approach to interference mitigation using resource auctioning and regret-matching learning

Since some traffic needs to be offloaded to D2D communication, the following TeCs are evaluated for D2D communications.

- FBMC
- Further enhanced ICIC in D2D enabled HetNets
- Spectrum sharing and mode selection for overlay D2D communication

In this work, we evaluate D2D communications in both underlay and dedicated modes. In underlay mode, D2D tries to reuse the resource of cellular network and therefore mutual interference is a big concern. Besides, due to the high density of network nodes experienced in our scenario, the interference from D2D transmitter to base station has to be controlled carefully in order to protect link quality of cellular users. When D2D operates in dedicated mode, a dedicated spectrum band is explicitly given to D2D communication. Thus, interference exists in between different D2D links in case of dedicated mode.

To evaluate system performance of above selected technology components, following metrics are applied to show our results:

- CDF of end-to-end delay
- PDF of connected user (availability)
- CDF of overall throughput

More details on the simulations set up and assumptions can be found in Annex A.6.

3.7 TC7: Blind Spot

This scenario is to characterize the behaviour of METIS proposal to deal with situations in which coverage is not as good as expected. This could happen in rural areas or in urban areas where the deployment density is not enough. The performance criteria in this case is the experienced user data rate, which must be at least of 100 Mbps in the downlink and 20 Mbps in the uplink, and the service latency. For the reduction in the end-to-end latency we should improve the total radio access network transmission time, which include all hops in the mobile relay concept evaluated in this TC, where mobile relays are mounted on the cars. For the evaluation of mobile relaying and caching, it is assumed that the car has two independent interfaces: one to communicate with out-of-car users, e.g., pedestrians, as in case of nomadic nodes, 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 best serving cell of the user and its wideband SINR.
- Find the closest cars (within a range of 85 m)
- If caching is active,
    - get for each neighbour vehicle not serving cached content to other users, in ascending order of distance, the wideband SINR of the vehicle-

to-pedestrian link. If the SINR is higher than 20 dB the vehicle is candidate to serve the user. Randomly determine if the vehicle has the content requested by the pedestrian, according to probability in Table 3-1. If content is cached in the vehicle, it is selected to serve the user.

- If relaying is active and no vehicles were selected in the previous step,
  - get for each vehicle the best serving cell and its wideband .
  - if the vehicle-to-cell SINR is such that throughput achievable in this link would be higher than two times the throughput achievable through direct link from cell to pedestrian, the vehicle is selected to serve the user.

Range of 85 m is calculated assuming PS#1, a target SNR of 20 dB and 20 dBm EIRP in the car. Note also that mobile relaying can be applicable to outside users or to the car passengers.

Table 3-1: 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

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 3-2.

Table 3-2: 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 AT&T 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.

Concerning the environment, TC2 layout is proposed also for the evaluation of the blind spot effect, assuming that only the macro-transmitter is active in the area. Moreover, 50 % of users are randomly distributed near the vehicles, within a radius of 50 m from each vehicle. Vehicles are randomly distributed along the streets or parking areas avoiding the park area to make a more uniform distribution among users.

The propagation models used in TC7 are PS#3 for the macro-cell outdoor coverage and PS#9 for vehicle-to-pedestrian communication, as proposed in [MET13-D61]. Only outdoor traffic is considered. In order to obtain general conclusions, traffic model is assumed to be a constant bit rate model characterized by fixed packet size and time between packets.

Finally, concerning mobility, in this assessment, users are static, i.e., static snapshots of the system are studied. In these snapshots short term channel parameters change according to an assumed mobility for each user, but long term channel parameters (shadowing, path losses, etc.) do not change. More details on the assumptions and performance metrics in TC7 can be found in Section A.7.

3.8 TC8: Real-time remote computing for mobile terminals

It is expected that in the 2020 and beyond, people will extend their expectations on the quality of a mobile connection from the stationary use cases (such as at home or in the office) to the scenarios when users are on the move – travelling or commuting. Therefore TC8, Real-time remote computing for mobile terminals focuses on provision of a broadband access for the users travelling at high velocities, e.g., in cars, buses, trams or trains.

The main challenge of this TC is how to provide a fast and reliable broadband connection at the velocities up to 350 km/h. Fast connection is defined as 100 Mbps of experienced user's throughput in the DL and 20 Mbps in the UL, while the reliability level should guarantee to transmit successfully 95% of packets within a maximum E2E latency of 10 ms (e.g., for real-time processing services). Provided solutions should boost currently experienced QoS, limited due to the channel aging, insufficient antenna capabilities and the penetration loss of the vehicle shells which can be as high as 20 dB.

Two approaches were exploited and evaluated, both targeting at this TC. First one (we refer to it in TC8 related sections as an OFDMA approach) focus on utilization of OFDMA in combination with the new frame structure proposed for UDN in METIS WP2-TeCC1.1 [MET15-D24]. Evaluated frame structure allows for a dynamic UL/DL transmission switching in TDD mode, depending on the instantaneous channel conditions and traffic demands. Such approach enables data transfers with high spectral efficiency, which is an absolute necessity in order to provide a cost efficient solution for TC8. Another advantage of a new frame structure is its short TTI length (0.25 ms) that helps to reduce the E2E delay, and control plane signalling for both UL and DL in each transmission slot, regardless of the orientation of the data flow in the user plane. Apart from the new frame structure, this approach exploits also the concept of moving relay nodes, where vehicles are equipped with two sets of antennas. First set, mounted on the rooftop of the vehicle is responsible for providing an efficient wireless backhaul connection and can be implemented as a higher order MIMO, with limited concerns about the footprint (comparing to the personal handheld devices case). Second set of antennas is mounted inside the vehicle, which allows circumventing vehicular penetration losses and provision of a broadband access to the travellers. With this setup user's devices experience almost a stationary channel conditions and no additional solutions at their equipment are needed. Channel aging of the wireless backhaul link is combated using predictor antenna concept as proposed in T3.1-TeC6 [MET15-D33]. Predictor antennas are used to help selecting optimal antennas from the pool of candidate antennas located on the rooftop. Such solutions were proved to work up to the speed of 350 km/h [MET15-D33]. Finally, a decentralized RRM scheme as proposed in [MET15-D43] is used to efficiently distribute available radio resources.

This approach is evaluated in the urban scenario, which comprise of TC2 environment of a Madrid grid (outdoor part) enhanced with vehicles (420 cars with 1 to 5 users and 8 buses with 1 to 50 users) that are moving according to the mobility traces available in [MET-Web] with velocities up to 50 km/h. A number of small cells are deployed in the facades of the buildings, 5 m about the ground level, with ISD of 20 m. 4x4 MIMO transmission and IRC receivers are used to evaluate both UL and DL data transfers.

We assume a control/user plane decoupling where control plane is handled via macro layer and user plane is transmitted via small cells. This heavily reduces the number of handovers, as small cells are treated as transmission points and handover occur only when connection point for control plane is changed. In this approach only the performance of wireless backhaul is evaluated, as it is a bottle neck of the transmission.

Second of the evaluated approaches, focus on utilization of SCMA for high velocities scenarios (we refer to it in TC8 related sections as an SCMA approach). SCMA as described in WP2-TeC11 [MET15-D24] is based on multiplexing of different users in code domain using limited channel knowledge in terms of CQI. In this modulation, as a non-orthogonal access scheme, coded bits are directly mapped to multi-dimensional sparse codewords. This allows overloading of the system (when number of overlaid users is higher than the length of multiplexed codewords), but users can be still detected and separated using MPA receivers with a moderate complexity. This approach is also suitable for users moving at high velocities as it also allows operating multi-user multiplexing in a high performing open loop mode as described in T4.2-TeC17 [MET15-D43]. In the same time, at high velocities, LTE-A legacy closed loop schemes (such as MU-MIMO) achieve low performance due to the detrimental effects of the channel aging and mismatch between the feedback information and instantaneous channel conditions.

The suitability of this approach is tested in a simplified Madrid grid. In this setup 9 micro access nodes are equipped with 2 sector antennas and each sector is operating in an open loop 2x2 spatial multiplexing mode. 560 users are dropped uniformly on streets and FTP2 bursty traffic model is used. Both, SCMA and OFDMA are simulated using this setup and comparison of both methods at velocities of 3 and 120 km/h is shown. SCMA uses codewords with length of 4 OFDMA tones and MPA receivers. Multiple codewords of a user are spanned over 50 RBs of a 10 MHz system. Also, OFDMA operates with 50 RBs wideband scheduling and MLD receivers. In both cases a proportional fair scheduler is used.

More details on simulations set up and assumptions can be found in Annex A.7.

3.9 TC9: Open air festival

Test Case 9 “Open Area Festival” models a small rural area, less than 1 km^2, which is visited by at least 100 000 visitors during a multi-stage open air music festival. For example, the visitors want to be able to locate interactively, share real-time or recorded high definition video clips from the simultaneous ten stages, and to access the Internet at a high-speed that is greater than 30 Mbps, especially during the breaks between the performances. Furthermore, there are sensors and IoT devices on the area, sending small uplink packets. Motivation for this test case is to enhance the user experience of an extremely high density of active users/devices with a huge amount of aggregated traffic in terms of user throughput, availability, and reliability in an area where normally the mobile access network nodes are sparsely deployed, i.e. the normal network is highly under-dimensioned.

Main KPIs for this Test Case are:

- 100 000 users and 10000 sensors per one square kilometre area
- 30 Mbps user data rate for 95% of the users (downlink and uplink)
- Latency less than 1s with 99% probability for machine traffic

For simulation purposes, a square field, with an area of 1 km by 1 km is used. A total of ten stages for the festival with equal dimensions should be placed in the field, with the following constraints:

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

On average, up to 10 000 people can be assumed per stage with a density of up to four people per square meter. In addition, up to 10 000 machines and sensor devices are assumed to be randomly distributed in the festival area. No mobility is assumed.

In the results, we analyse following performance metrics:

- End user throughput distributions
- Effective SINR distributions or the users/sensors
- Latency for the machine traffic packets

The main Technology Components used in the simulations were WP2 components TeCC1.1 and TeCC1.3 for new frame structure and higher frequency bands and T3.1 components TeC7 and TeC11 for massive MIMO and beamforming on higher frequency bands. For energy efficiency (not simulated) on both uplink and downlink, WP2-TeC11.1.2 (SCMA) and T3.2-TeC3 (Distributed Precoding) could be useful.

More details on simulations set up and assumptions can be found in Annex A.9.

3.10 TC10: Emergency communications

TC10, Emergency communications, is a test case where a disaster just has taken place. The focus is on discover and to communicate with the survivors. The main KPIs and requirements are:

- Discovery rate of 99.9%,
- Reliable setup time of less than 10 s with a reliable call establishment after 1 s,
- Five days of operations to be supported in “emergency mode”,

which was specified in [MET13-D11].

The environmental model is the Madrid grid, defined in [MET13-D61], after a natural disaster with ISD up to 5 km and out of coverage UEs. Temporary emergency base stations can be used to improve coverage. The indoor to outdoor propagation conditions are specified in [MET13-D61], where the propagation model of cellular UEs is the O2I model (PS#2) and the propagation model of D2D UEs is the O2I model (PS#10). Note that the density of users is 20 to 500 UEs/cell area in this evaluation, which is significantly lower density of UEs (approximately 0.077 UEs per 10 m^2) than the 1 UE per 10 m^2 which was proposed in [MET13-D11].

Discovery aspects of this test case may be addressed by a unified resource allocation framework for D2D discovery, the T4.1-TeC2. The communication aspects, with energy efficiency focus, can make use of T4.1-TeC3-A1 and T4.1-TeC5-A1/A2. The T4.1-TeC3-A1 is a distributed Channel State Information (CSI) based mode selection for D2D communications and T4.1-TeC5-A1/A2 are joint methods for SINR target setting and power control for D2D communications.

The technology components and simulation assumptions are evaluated with metrics as:

- Out-of-coverage UE percentage
- Discovery time average

- SINR D2D to Power D2D for different mode selection algorithms
- Average throughput to average power consumption trade-off

More details on the simulation set up and assumptions are given in Annex A.10.

3.11 TC11: Massive deployment of sensors and actuators

The focus of TC11, “Massive deployment of sensors and actuators”, is on the expected massive increase in number of cheap-set devices, such as sensors and actuators. These devices are typically only transmitting data occasionally, e.g. in order of every minute, hour or day. In addition, the payload is typically small, e.g. 20 to 125 byte per message [MET13-D11], and the latency requirements are often very moderate, in the range of several seconds. They also need to be low cost devices and energy efficient, i.e. low battery consumption.

The main requirements and KPIs were defined in [MET13-D11] and are: high energy efficiency, 0.015 µJ/bit for a data rate in the order of 1 kbps; 80% protocol efficiency at 300 000 devices per access node; and 99.9% of coverage. Further, the overall METIS goals of 10x battery life and 10x-100x capacity are most relevant for TC11.

Depending on e.g. environment and targeted data rates the best approach to address this test case may vary. In this evaluation of TC11 various aspects have been investigated in separate studies. A narrow bandwidth transmission and radio link efficiency evaluation lifts the potential of using a transmission bandwidth of 15 kHz instead of 180 kHz (i.e. comparing a resource element to a physical resource block of the R11 LTE baseline). The single-cell evaluation is based on the theoretical upper limit that the Shannon capacity provides, and evaluates uplink capacity gains and scheduling efficiency gains for MMC. Another aspect is the context-based device grouping and signalling where the R11 LTE baseline is compared with a system that is able to exclude redundant messages, coordinate PRACH resources in a configured group, and use compression for the control signalling part. Another important aspect of TC11 is new waveforms. As this test case typically addresses rather small packet sizes it may not be advantageous to spend a lot of resources to set up a great communication link but rather to use schemes that are less costly in terms of resources needed to set up the communication. This is called contention-based transmission of data and is compared to the LTE baseline in the SCMA evaluations, which further overloads physical resources to increase capacity. Another key aspect to realize MMC is to prolong the battery lifetime of the devices. In a theoretical study the energy consumption of R11 LTE baseline with RRC connection setup is compared to the corresponding system with contention-based transmission without any uplink synchronization, and to a system where both the contention resolution phase is skipped and random access is transmitted with a fixed timing such that DRX/DTX can be applied. In this setting, the battery life as a function of sleeping cycle length for various inter-arrival times is compared. Finally, a M2M relaying evaluation is made in the environmental setting of the Madrid grid, defined in [MET13-D61], in which machine devices can act as relays to other devices. This improves coverage; battery consumption and capacity simultaneously, both in uplink and downlink.

The general narrow bandwidth transmission and radio link efficiency do improve coverage, capacity and the spectral efficiency. Waveform related components that improve the system performance are e.g. the WP2-TeCC1 components that do enable flexible OFDM, the context-based device grouping and signalling component, T4.2-TeC12, and the SCMA components WP2-TeC11.1.2, T4.2-TeC16 that are used to attain scalable MMC solutions. M2M relaying is a general solution that is enabled by WP2-TeC2.3, T4.1-TeC2, T4.1-TeC3-A1, T4.1-TeC4-A1, T4.1-TeC5-A1/A2.

The technology components and simulation assumptions are evaluated with metrics as:

- Capacity and coverage limits for different transmission bandwidth.
- Scheduling efficiency for small MMC payloads.
- Control signal overhead reductions as a function of number of MMC devices.
- Capacity in terms of the number of devices per MHz.
- Battery life as a function of sleeping cycle lengths and signalling overhead.
- Battery life, coverage, and capacity improvement when assisted by sensor-relays.

More details on the simulation set up and assumptions are given in Annex A.11.

3.12 TC12: Traffic efficiency and safety

In this test case, information exchange between vehicles is exploited to enable cooperative driving. Since each vehicle can communicate with other vehicles, accidents can be actively avoided. Besides providing a safer driving environment, information exchange between vehicles can also enhance traffic efficiency by increasing traffic flows and reducing fuel consumption and emissions.

In order to improve traffic efficiency and safety in this test case, a strict requirement on package end-to-end (E2E) latency of 5ms should be achieved with a reliability of 99.999 %.

This test case should work in any road environment, independent from whether it is urban, rural, or highway scenario. However, special consideration is given to urban dense scenario in this work, which is the same as TC2 scenario. This scenario is selected for our evaluation since it has more complicated user distribution and channel propagation models, compared with other cases. The channel propagation models in between vehicles used in this TC include PS#9 for LOS propagation and another model existed in literature [TOH11] for NLOS propagation.

As a key technology enabler, network controlled direct V2V communication is exploited in this work for information exchange. It is assumed that vehicles are connected to network in C-plane and packages are transmitted in a direct V2V manner without involvement of network infrastructure in U-plane. Further, a new server is deployed in the core network of a mobile operator as a central entity and used for controlling V2V communication. With help of this new server, location information reported by each vehicle can be collected and used for efficient resource allocation for V2V communication.

100 MHz and 200 MHz are used as two bandwidth options in this work and V2V communication operates with a carrier frequency of 5.9 GHz. More assumptions related with this work are given in Annex A.12.

Some TeCs developed in METIS are considered as key technology enablers for this test case. FBMC cooperating with advanced coding and decoding scheme can improve the link performance in high mobility scenario. Context awareness through prediction of next cell and context aware mobility handover optimization using Fuzzy Q-learning cooperating with signalling for trajectory prediction can provide seamless connection to vehicles in C-plane. Besides, new management interfaces between the operator and the service provider and new management interfaces for information exchange and action enforcement can provide necessary interfaces between network and the new server used for controlling V2V communication.

In the simulation, two important metrics are used for evaluation:

- Successful package transmission ratio: it represents ratio of overall packages successfully received by receiver with any latency value.
- 5 ms E2E latency ratio: it represents ratio of packages successfully received by receiver within a 5ms end-to-end latency value.

These metrics are used to inspect system performance of different technologies:

- A scheme with coordination between neighbour BSs is evaluated. It can be seen from the result shown in Annex A.12. A coordination scheme can contribute to mitigating interference and avoiding package collision. Therefore, system performance can be improved.
- Due to high reliability requirement, all packages failed in previous transmission should be retransmitted. In case where V2V communication requires a large communication range, a large amount of packages fail in first transmission and therefore consume a large amount of resource for retransmission. Thus, an adaptive retransmission scheme and additional spectrum resource are exploited to evaluate the influence of retransmission.
- In legacy LTE network, RRM operates on a TTI level, which has a duration time of 1ms. With this frame structure, any package successfully received in retransmission exceeds the 5ms package end-to-end latency. Therefore, a different value of 0.5 ms is considered here as one TTI duration and system result shows that retransmitted packages can have E2E latency within 5ms. Therefore, this decreased value of TTI duration can improve system performance.

4 Simulation Results

This section presents the results of the evaluation of the METIS system concept in each one of the twelve test cases defined in METIS. Note that this analysis is partial, since only selected Technology Components (TeC) have been used in this simulation work. The subset of evaluated TeCs is listed in Annex B.

4.1 TC1: Virtual Reality Office

Wideband SINR in TC1 is in general low, mostly in the rooms without an access point. It is worth noting that median SINR is below 10 dB being cell-edge users below 0 dB. Therefore, the expected bandwidth required to fulfil TC1 requirements is 4.5 GHz [MET14-D53]. This interference-limited scenario limits the set of techniques to be employed and impose the need for mechanism to reduce the impact of these interferences.

The goal is to experience 1 Gbps in 95% locations (for cell-edge users) and 5 Gbps in 20% locations, which is equivalent to have this value in percentile 80-th of the user-throughput CDF. Moreover, we need to have less than 10 ms of mean packet latency, and less than 5% of packet loss rate. In this scenario, with 200 MHz allocated to the system it is impossible to handle the amount of data to be delivered between the different recording units and the central processing entity. In fact, even with the best configuration, 200 MHz system reach congestion and the quality of service is far from the requirements specified for TC1 in [MET13-D11]. Therefore, simulations have included a range of simulations, from 200 MHz up to 4.5 GHz, to check the required bandwidth for the different configurations of the system.

Different TTI values have been used in this scenario including legacy assumption of 1ms, 0.5ms and 0.25ms. Moreover, several transmission schemes have been tested: SIMO, SU-MIMO codebook based (CB), non-CB MU-MIMO and non-CB MU-MIMO with COMP. For CoMP, all access points are supposed to participate in the same cluster, in such a way that scheduling and resource allocation is made in collaboration with the other transmitters. In these simulations, we have not checked joint transmission solutions.

We first analyse the influence of bandwidth in the system performance for SU-MIMO (8x8). As represented in Figure 4-1, with a bandwidth of 4.5 GHz all requirements are met unless maximum packet latency of 10 ms, which is satisfied in around 85%. However, other techniques can be added to increase efficiency and reduce packet latency. Note that the figure represents to which extend the required KPI is fulfilled. In this sense, 100% means that the target is totally achieved.

We first evaluate, for 1.5 GHz, the effect of increasing complexity of MIMO transmission and coordination. As shown in Figure 4-2, the use of MU-MIMO and coordinated transmission and reception, as compared with SU-MIMO, increase by a factor of almost three cell-edge user performance but degrades (-24 %) average performance. When reducing TTI time to half a millisecond, the cell-edge user performance is affected, but we improve the use of spectrum, which finally results in a better average cell performance. This trend is again observed for a TTI value of 0.25 ms. In this case, average throughput improves (+21 %) and target is almost fulfilled. However, mean packet round trip time is far from reaching the objective and cannot be improved even reducing the TTI value.

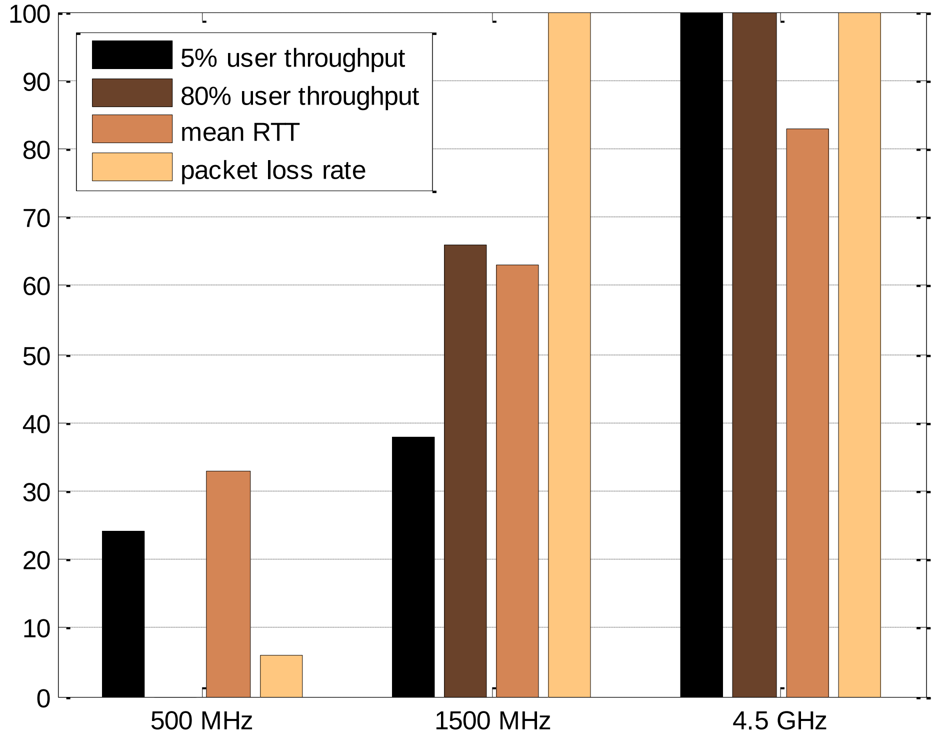

Figure 4-1: Level of satisfaction of KPI for TC1.

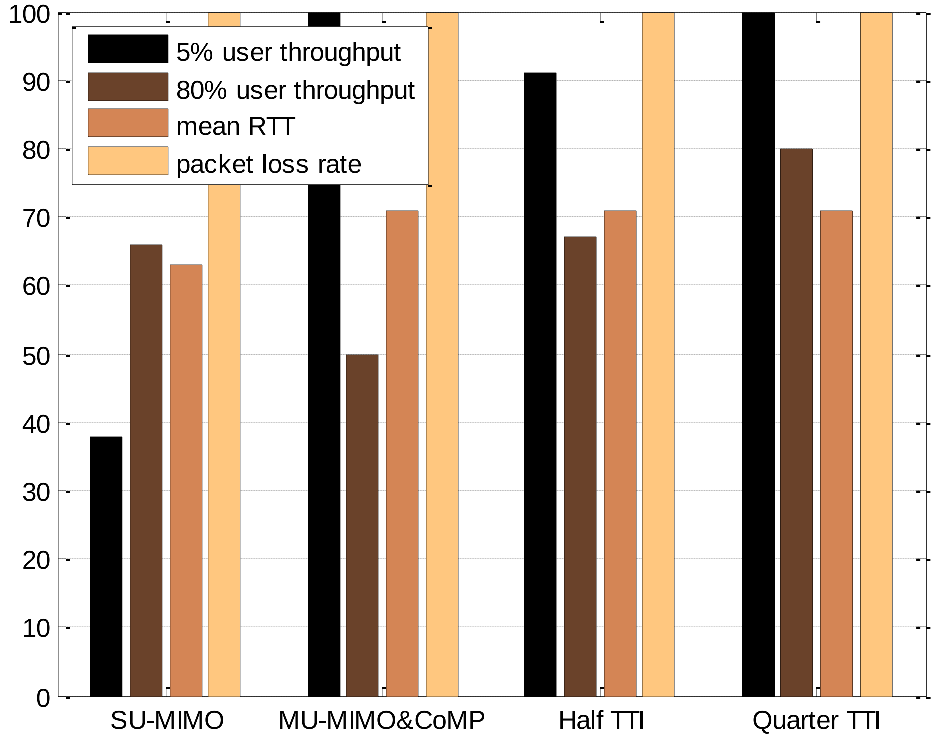

Figure 4-2: Level of satisfaction for different transmission schemes and 1500 MHz bandwidth.

After several trials increasing bandwidth we found out that the fibre optics and processing time is around 6 ms (time per fibre optic link is assumed to be 1 ms, and processing time in routers is also assumed to be 1 ms) and radio time cannot be less than 2.2 ms per direction, that is 4.4 ms in total. Therefore, the only way of reaching the goal is to improve fibre optics or routing time around 10% to have less than 10 ms in RTT time. If this is possible, with 1.875 GHz the system will be able to fulfil all system requirements. Given this huge amount of spectrum needed, we highlight here the interest of techniques for spectrum sharing as the one defined in WP5-TeC04. This concept might be relevant in xMBB especially below 6 GHz bands.

4.2 TC2: Dense urban information society

This test case is evaluated with three different approaches, depending on the focus of the research.

4.2.1 Approach 1

Approach 1 is defined by WP2-TeC1.1.3 and T4.1-TeC6-A1 and is based on flexible air interface and centralized resource allocation studies. This approach intends to answer to what level of improvement can be expected by applying the dynamic TDD with distributed/local resource allocation /user scheduling. As expected, the highest gains are indicated by UL results (30-80% delay reduction) The gain comes from the full utilisation of the resources in case of dynamic TDD while in the fixed TDD proportions are set 1:4 accordingly to expected differences in averaged traffic load in UL&DL. In DL gains are moderate (0-30% of delay reduction). An interesting observation is that gains decline proportionally to the packet size or higher AI utilisation. Second interesting observation is that introduction of the dynamic TDD to already centralised network result in very similar performance improvement.

The Dynamic TDD results for high and low cell isolation indicate similar performance improvement. This confirms that these gains are not sensitive to the different deployments and/or environments.

The gain from introduction of the centralised resource allocation and interference management is visible for fixed and flexible TDD in similar level. Gains increase with the increase of the offered load (PHY layer utilization) and vary between (20-60%). Analysing results for high and low cell isolation we conclude that for similar PHY layer utilisation, gains are slightly higher for LowIS (40-60%) than HighIS (20-40%). Gains in both links are in general on the same level.

In general, studies show that an introduction of the flexible TDD resource allocation can result in ≈20% gain over optimised but fixed switching between UL/DL phase. Another 20% gain can be achieved on top by introducing fully centralized scheduling that includes extensive search of the optimal transmission/muting decision in considered coordination area (up to 9 nodes considered is in this case).

The scenario requirement the traffic volume per area according to TC2 definition is defined as 0.7 Tbps/km^2. However, in this evaluation we are capable to fulfil user experience rates with data volume equal to 4-6 Gbps in an area of 0.0012 km^2 (40 meters x 30 meters) and that correspond to 3.3 to 5 Tbps/km^2 on 200 MHz in open space area (assuming 10 meters ISD). With similar ISD but with 5 dB isolation between APs and locating APs every room, we can achieve even higher rates between 7-9 Gbps on 200 MHz. With decrease of the nodes density we observe acceptable load level decrease proportional to ≈1/sqrt(2). However, we still fulfil requirement for TC2, where most of the traffic demand is located in indoor environment. Exemplary results are presented in the following table and figures. The full set of results available in Annex A.2.7.

Table 4-1: Total load per area fulfilling TC2 requirements on 200 MHz BW.

ISD	Nodes density	Open space total load [Gbps]		Isolated rooms total load [Gbps]	
10m	1	4	6	7	9
20m	0.5	2.7	3.5	4	5.5
37m	0.25	2.2	2.95	2.95	4

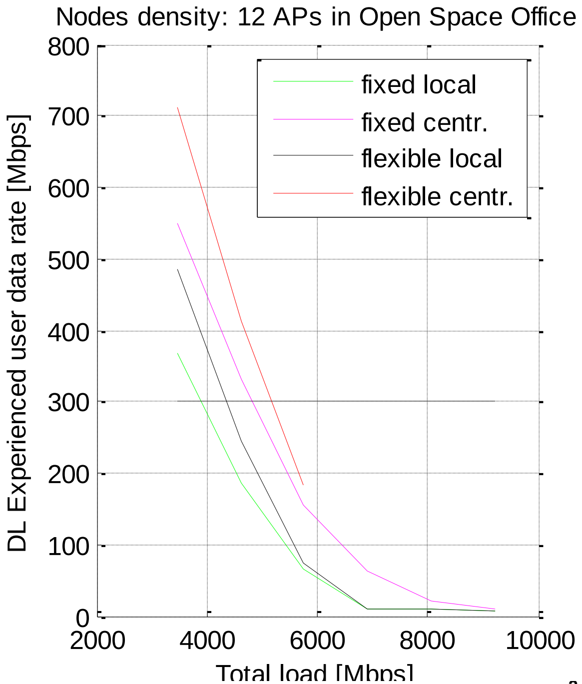

Figure 4-3: Low isolation scenario 1AP/100m^2 UL experienced user date rate vs. total load.

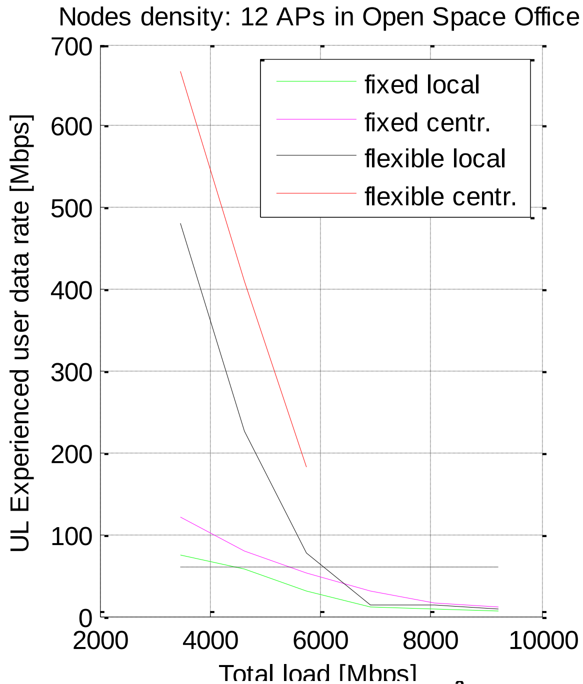

Figure 4-4: Low Isolation 1AP/100m^2 scenario DL experienced user date rate vs. total load.

4.2.2 Approach 2

Approach 2 is defined by T4.2-TeC17. This approach focuses on the application of open loop user multiplexing (MU-SCMA) scheme on top of OFDM modulation in case of CoMP and non-CoMP transmission modes. Ignoring the delay constraint, the cell average and cell-edge throughput gains over open-loop MIMO OFDMA in full-buffer scenario can be more than 50% independent of users' speed. It shows that MU-SCMA can provide better experience even for vehicular users with fast variation of their channel quality. The results of non-full buffer traffic also show the advantage and benefit of this technique. According to these results, for the same delay constraint (less than 0.5 sec delay) and outage (95% packet delivery), MU-SCMA-CoMP is able to improve the overall network load by up to 83% and 14% with respect to OFDMA non-CoMP and CoMP solutions, respectively. The full set of results available in Annex A.2.7.

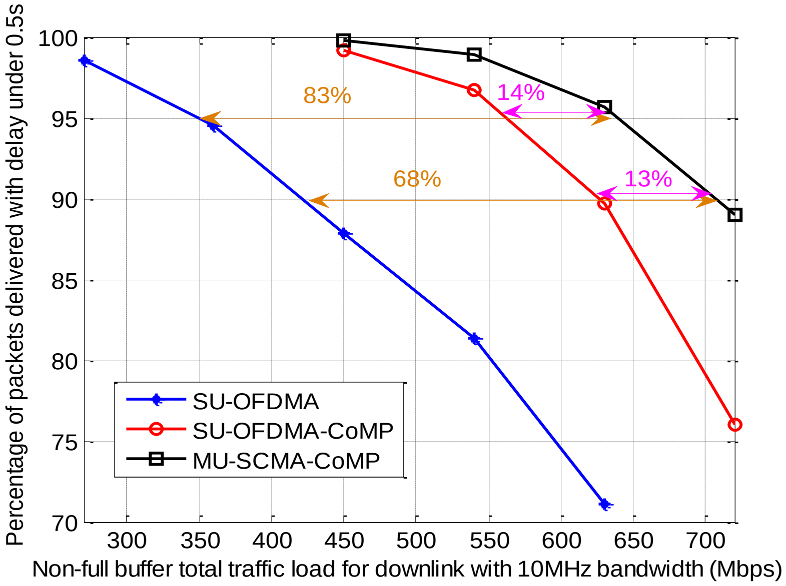

Figure 4-5: Percentage of packets delivered in due time (< 0.5 s) for different traffic and transmission techniques. The traffic model is FTP2 with 1 s inter-arrival time. Packet size is set according to the desired overall network load.

4.2.3 Approach 3

In this approach, the LTE baseline is compared to a possible 5G mobile broadband (5GMBB) solution with beamforming capabilities enabled. The user throughput is analysed both in a single RAT (standalone) setting and in a carrier aggregation (CA) setting. The evaluation is conducted at a higher cmW frequency and at 2.6 GHz carrier frequency for the LTE baseline. The fifth percentile downlink results are given in Figure 4-6.

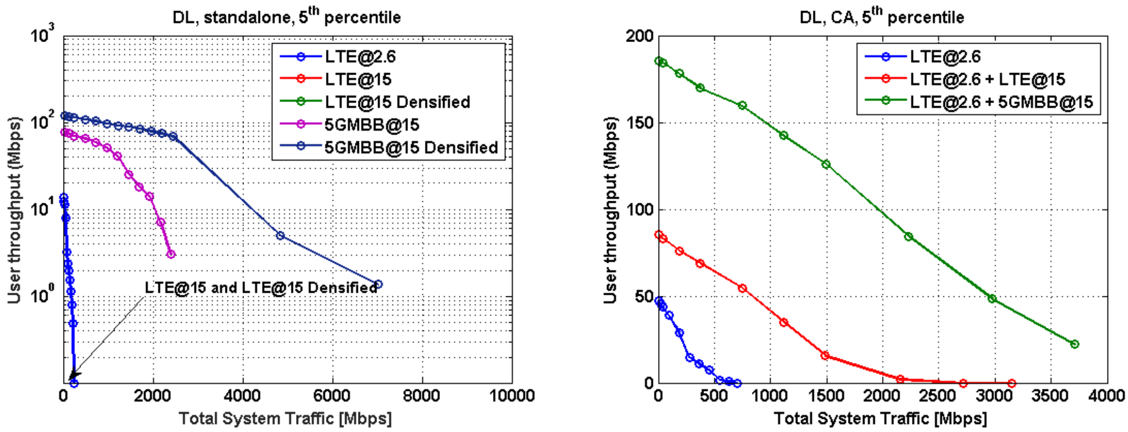

Figure 4-6: User throughput for increasing traffic and different solutions in cmW on 5th percentile.

With this approach, we have demonstrated that it is possible, from capacity point of view, to fulfil TC2 requirements with the use of cmW and additional 5G MBB features (for example 5x20 antenna arrays at 15 GHz are enabling high beamforming gains with use of max 800 beams).

Note that the evaluation above was performed on another city environment than the Madrid grid (Figure 3-2). The description and full set of results for this approach is available in Section A.2.8.

4.3 TC3: Shopping mall

The results include performance evaluations of a flexible OFDM, high-gain beamforming, contention based MAC, wireless self-backhauling system with a bandwidth of 2 GHz at 60 GHz. Two topologies are evaluated in a rather large line-of-sight food court environment. The first topology contains six aggregation nodes, and is referred to as 6 AgN. The second topology contains, in addition to the previous six aggregation nodes, four wireless self-backhauling aggregation nodes and is referred to as 6 AgN + 4 wAN. More details on the TC3 evaluation are given in Annex A.3.

In Figure 4-7 the experienced throughput[1] for the two topologies (6 AgN and 6 AgN + 4 wAN) are given in both downlink and uplink.

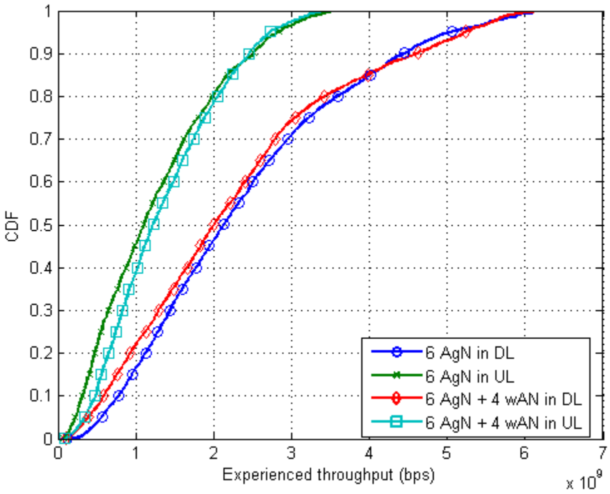

Figure 4-7: User experience CDF of average file transfer data rate, where the average is over the time between file demand and full reception.

Similarly, in Figure 4-8 the object delay for the two topologies are given in both downlink and uplink.

Based on the results in Figure 4-7 and Figure 4-8 a KPI summary of TC3 is given in Table 4-2. Both the throughput and file delay transfer KPIs are met with the mmW setting.

In Table 4-2 one can see that the main requirements and KPIs of TC3, defined in [MET13-D11], have been fulfilled. Based on the results in Table 4-2 the experienced throughput improves in uplink while it degrades in downlink when the wireless self-backhauling access nodes are introduced. In DL, the degradation comes from the multi hops transfers, while in UL, the contention access is eased by the addition of access nodes. However, the wAN performance is expected to be more efficient in other deployments, such as NLOS, coverage extension, etc. With wANs it is possible to easily deploy cheap APs. The proximity enables reduced competition for resources, such as reduced RAT latency and easier allocation.

[1] The experienced throughput is defined as the file size / total file transfer time.

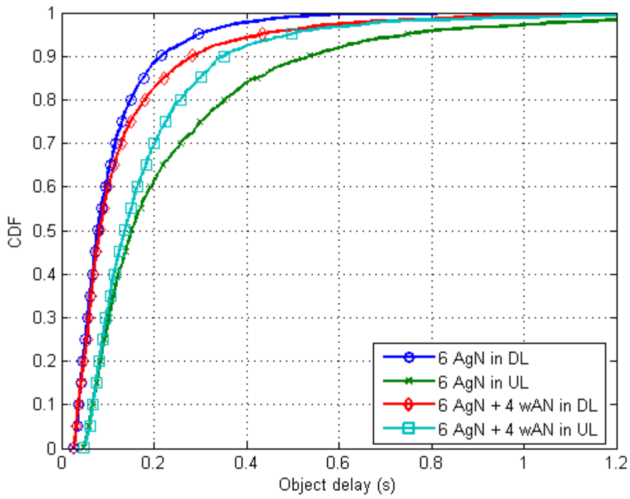

Figure 4-8: CDF of total file delay, where the time is between file demand and full reception of the 20 MB file.

Table 4-2: KPI summary of TC3.

Performance	Target value	Simulation results	
		6 AgN	**6 AgN + 4 wAN**
Experienced throughput*	300 Mbps in downlink	690 Mbps in downlink	565 Mbps in downlink
	60 Mbps in uplink	225 Mbps in uplink	339 Mbps in uplink
Traffic volume	5.6 TB/hour (70% in DL)	Ok**	Ok**
RAN latency*	5 ms	≈ 1 ms	≈ 1 ms
Availability	95% of the space	128 of 128	128 of 128
Reliability*	1 s file transfer	296 (475) ms	430 (495) ms
Cost		Simple beamforming	Simple beamforming + wireless self-backhauled AP

*Worst 5th percentile.

**Set as user/packet arrival setting.

4.4 TC4: Stadium

In our simulations a 20 Mbps traffic source generates one packet per millisecond (equivalent to 50 MByte packets each 20 s). We obtain the mean radio access latency of these packets and the mean experienced user data rate of each user. In order to calculate the latter, we average the data rate of each packet received by a user. The data rate is defined as the packet size divided by the time required to transmit the packet over the air, plus the time between retransmissions if needed. Additionally, we provide the packet loss percentage to have a complete picture of the system performance.

Table 4-3: TC4 results summary.

Configuration		Experienced user data rate	Latency in the radio access network	Packet loss
Requirement		0.3-20	< 5 ms	N.A.
1.8 GHz	MU-MIMO + MASSIVE MIMO	5% CDF: 4.4 Mbps 80% CDF: 20.0 Mbps	4.32 ms	2.2 %
	MU-MIMO + COMP + MASSIVE MIMO	5% CDF: 14.4 Mbps 80% CDF: 20.0 Mbps	3.84 ms	0.2 %

In the configuration labelled as “MU-MIMO + COMP” 8 antennas are placed at transmitter and receiver and coordination is implemented among preconfigured clusters of 9 cells. In configuration “MU-MIMO + COMP + MASSIVE MIMO”, base station has a 64-antenna elements array. It is assumed that this 64 elements array is equivalent to an 8 elements array with 9 dB antenna gain in each element.

Results show that with 3.6 GHz bandwidth all requirements of this TC are reached for any of the MIMO schemes studied. They also show that in this scenario there is a significant gain in using massive MIMO scheme. This means that using multiple antennas to have the same multiplexing gain as a smaller array is useful in this scenario. In fact, with 1.8 GHz and a combination of MU-MIMO and massive MIMO all the requirements are fulfilled, even without the use of COMP.

Figure 4-9 presents the CDF of user experienced data rate. As expected, the maximum value is the data rate of the traffic source, 20 Mbps. More than 20% of the users present this data rate for all the configurations. Figure 4-10 shows the packet latency CDF. More than 80% of packets are received in less than 5 ms using massive MIMO. Therefore, latency goal is clearly fulfilled, as shown in the figure and presented in Table 4-3, when massive MIMO is used.

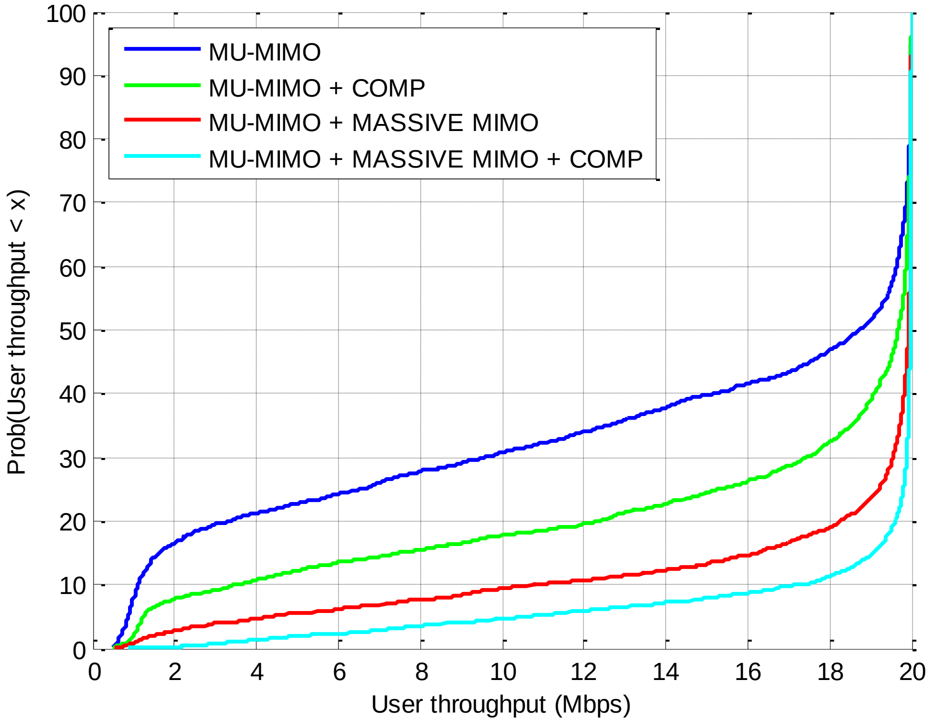

Figure 4-9: Experienced user data rate CDF with 1.8 GHz bandwidth.

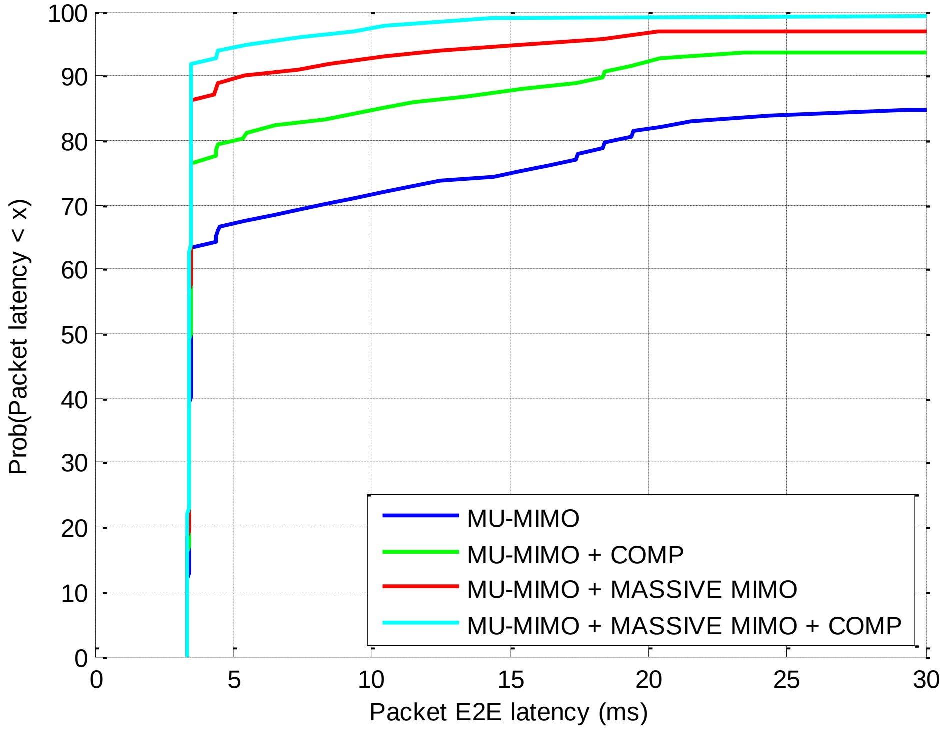

Figure 4-10: Packet latency CDF with 1.8 GHz.

4.5 TC5: Teleprotection in smart grid network

Results include the performance of the LTE-Advanced technology (OFDM-based), a FBMC-based METIS system, and a SCMA-based METIS system, all of them using spatial multiplexing capabilities according to the description in Section 3.5.

Results with 1 ms subframe length, 0.5 ms and 0.25 ms have been collected. With 1 ms, the maximum delays are 18.96 ms for OFDM, 8.96 ms for FBMC and 8.00 ms for SCMA. That is, the requirement is not fulfilled, but in SCMA it is almost fulfilled. With 0.5 ms the maximum delays are 12.48 ms for OFDM, 7.48 ms for FBMC and 6.50 ms for SCMA. That is, requirement is fulfilled by FBMC and SCMA. With 0.25 ms, the maximum delays are 9.24 ms for OFDM, 6.75 ms for FBMC and 5.75 ms for SCMA. That is, requirement is fulfilled by FBMC and SCMA, but not by OFDM.

For the sake of simplicity, we include below only the CDFs for the 0.5 ms case, considering the use of LTE-Advanced or the METIS solution with FBMC or SCMA. In LTE-Advanced we see that LIPA provides a marginal improvement in low percentiles of the CDF. The reason is that the probability of having multiple substations connected to the same cell (being capable of using LIPA) is low. D2D can be used with more probability, although still the number of cases in which it can be used is low. See in Figure 4-11 that it is beneficial in about 20% of cases. However, for those users using D2D the benefit is huge compared to that provided by LIPA. Finally, the combined effect of LIPA and D2D provides only a marginal gain compared to the scenario with only D2D. With the METIS system (new signalling and scheduling for machine-type communications) and FBMC or SCMA, the main difference with respect to LTE-Advanced is a shift of the curve to lower values. The main reason is the avoidance of the channel access procedure used in LTE-Advanced. Additionally, both technical solutions are more efficient than OFDM, and need a lower SINR to provide the same throughput. SCMA is more efficient than FBMC. This explains that SCMA provides lower latencies.

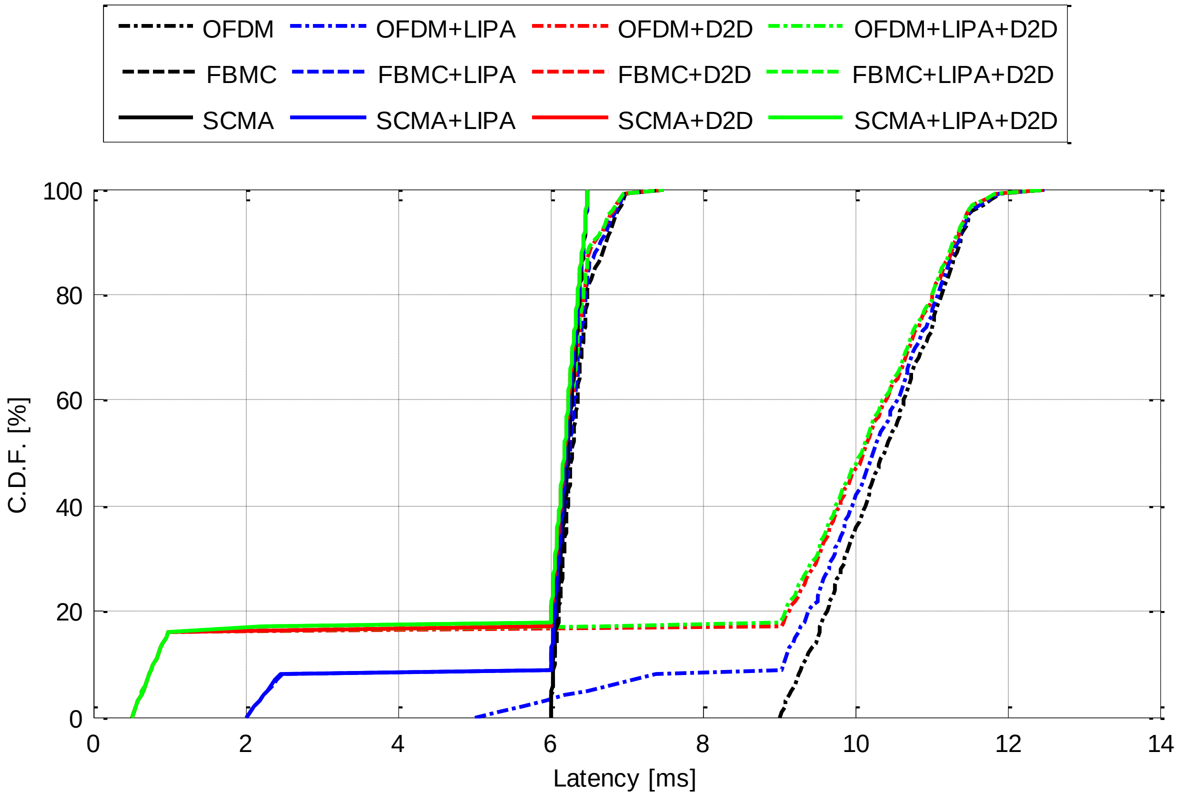

Figure 4-11: Latency CDF with spatial multiplexing and 0.5 ms subframe.

We provide in the table below the maximum latency needed to reach a number of neighbour stations for several system configurations. A small amount of users takes a benefit from LIPA and D2D. This has an effect on mean latencies but it does not improve the upper limit of the latency. More users can take a benefit from D2D while LIPA in combination with D2D only provides marginal benefit.

Table 4-4: Maximum latency (ms) needed to reach a number of neighbour substations with spatial multiplexing and 0.5 ms subframes.

Modulation	Config	1 neig.	2 neig.	5 neig.	10 neig.
OFDM	Cellular	11.50	11.98	12.48	12.48
	LIPA	11.50	11.98	12.48	12.48
	D2D	11.50	11.98	12.48	12.48
	LIPA+D2D	11.50	11.98	12.48	12.48
FBMC	Cellular	6.94	6.98	7.48	7.48
	LIPA	6.50	6.98	7.48	7.48
	D2D	6.50	6.98	7.48	7.48
	LIPA+D2D	6.50	6.98	7.48	7.48
SCMA	Cellular	6.50	6.50	6.50	6.50
	LIPA	6.50	6.50	6.50	6.50
	D2D	6.50	6.50	6.50	6.50
	LIPA+D2D	6.50	6.50	6.50	6.50

Finally, it is worth stressing that the METIS solution of signalling together with the use of FBMC or SCMA and a subframe reduction (0.5 ms) is valid to fulfil latency requirement of this test case.

4.6 TC6: Traffic jam

In order to generate the simulation results, 100 sets of simulations have been executed. In each set a mobility model with velocity in between 3 km/h and 10 km/h is used for every user. This model is described in [MET13-D61].

To simulate the end-to-end latency of a packet, SINR values were used in combination with BLER curves to compute an error probability for each packet. A packet will be counted as “lost” after 100ms or after three unsuccessful transmissions. To simulate failed packet transmission a random process is used taking into account the error probability. In this case a transmission takes 7.5 ms whereas a retransmission takes 5 ms. More details can be found in A.6.4.

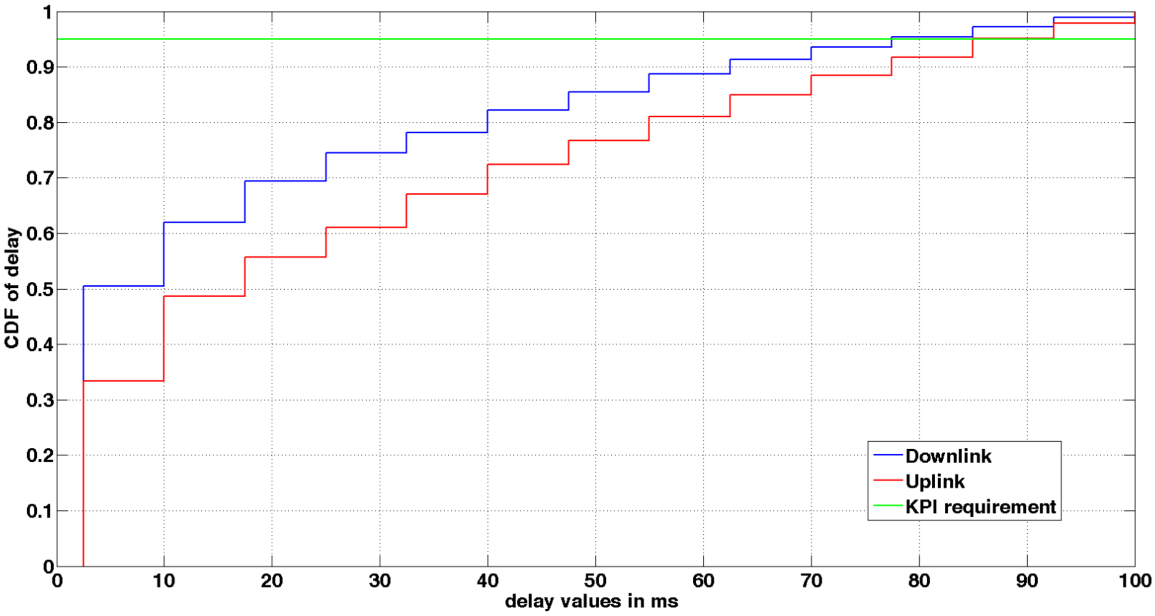

Figure 4-12: CDF of End-to-End Delay

By applying selected TeCs stated in Annex A.6, Figure 4-12 depicts the CDF of all transmitted packets during 100 simulation sets for downlink and for uplink. As can be seen here, the 100ms E2E delay can be achieved in our work with a reliability of 98% in downlink and 97% in uplink, which fulfils the KPI requirement of this TC.

Table 4-5 shows both the requirements for this TC and system performance of our evaluation. As mentioned before, requirement of E2E delay can be achieved in our case. By exploiting SCMA and FBMC the requirements regarding throughput can be achieved with reliabilities of 94.2% in downlink and 96.3% in uplink. In order to meet the 95% reliability in the downlink, certain traffic has to be offloaded to D2D. The D2D communication is further described in Annex A.6.

Table 4-5: Simulation requirements and results.

KPI	Requirement	Achieved in TC6
End-to-End Delay [DL]	<100 ms in more than 95 % of transmissions	<100 ms in 98 % of transmissions possible
End-to-End Delay [UL]	<100 ms in more than 95 % of transmissions	<100 ms in 97 % of transmissions possible
Traffic volume in TC6 scenario [DL]	85.2 Gbps/scenario in more than 95%	85.2 Gbps/scenario or more can be reached in 94.2 %
Traffic volume in TC6 scenario [UL]	17.04 Gbps/scenario in more than 95%	17.04 Gbps/scenario or more can be reached in 96.3 %
End user data rate [DL]	100 Mbps/user in more than 95 %	>100 Mbps/user can be reached in 96.1 % (cellular + D2D)
End user data rate [UL]	20 Mbps/user in more than 95 %	>20 Mbps/user can be reached in 95.7 % (cellular)
Availability	95 %	92.4 % (cellular) 97.2 % (cellular + D2D)

In summary, all KPIs can be met by using the technology components that are described in A.6.5. Since the main challenge of this test case is an extreme requirement of data volume due to the dense deployment of user devices, selected TeCs target to increase overall system throughput. The performance gain and main idea of selected TeCs are briefly described in the following:

- FBMC: Performance gain regarding system throughput of 13% compared to legacy network are achieved.
- SCMA: Cell average and edge throughput can be increased up to 65%. The increase of throughput can contribute to an overall lower latency value with a given system operating bandwidth.
- Offload cellular traffic to D2D: When resource of cellular network is reused, in order to protect cellular users and decrease interference coming from D2D communication, only a limited amount of traffic can be offloaded. When D2D communication operates with dedicated resource, a larger amount of traffic can be offloaded from cellular to D2D communication.
- Regret-matching learning: By decreasing transmit power, interference can be reduced and it is important in a scenario like this TC where high user density is experienced.

4.7 TC7: Blind Spot

In TC7, only experienced data rate has been specified: 100 Mbps in downlink, and 20 Mbps in uplink. These figures can be translated to average data rates of 1.7 Mbps in downlink and 0.3 Mbps in uplink, according to the relation provided for TC2.

In order to conduct our assessment, a 10 MHz bandwidth for macro-cells was assumed. A nominal data rate of 50 kbps was selected to study the performance of the system and calculate the bandwidth increase needed to fulfil the requirements.

Multiple configurations have been studied. For the sake of comparison a configuration without caching and relaying is the reference (blue line in figures). There is a configuration with layer 3 (L3) relays operating in FDD, where frequency used in relay-user link is different to the frequency used in the other links (green line in figures). Another configuration with layer 2 (L2) relays in FDD with outband backhaul link (red lines in figures) has also been considered. Concerning caching, a configuration with caching but without relaying is simulated (cyan lines), and a configuration with caching and L3 relays is also considered (magenta lines). Finally, two more L2 relay configurations have been assessed: with FDD inband half-duplex (yellow lines), and TDD inband half-duplex (black lines). The text “hd” in legends stands for “half-duplex”.

According to the results shown in Table 4-6, in order to have 100 Mbps of experienced throughput in downlink for 90% of users, bandwidth should be increased about 140 times for the configuration without relaying and without caching. That is, up to 1.4 GHz. Nevertheless, to achieve 95% availability, we need about 2.9 GHz. In fact, we need two times more bandwidth in FDD, However, in this study no multiplexing gain has been considered. Assuming a typical multiplexing gain of 6 (being conservative, we assume that with 8 antennas up to 6 users can be spatially multiplexed), it turns out that for the simpler configuration, in FDD, we would need about 0.97 GHz to fulfil the METIS objective for this TC.

In the configuration with caching, the cellular spectrum could be reduced 0.7 times, down to 0.68 GHz. However, additional bandwidth is required for links to perform caching. Users with cache present about 1.9 Mbps with 10 MHz. Therefore, about 526 MHz is needed in downlink. Considering a multiplexing gain of 4, more realistic for D2D, the required spectrum for uplink and downlink would be 258 MHz. The aggregate needed bandwidth would be 0.938 GHz .This value is quite similar to the bandwidth needed without caching. However, the configuration with caching achieves reduced latencies, above all for those users communicating with a cache server.

The analysed L2 relay configurations are not able to reduce even further the required bandwidth. Due to their high bandwidth consumption (L2 FDD outband) or low experienced throughput (L2 inband half-duplex configurations). T3.3-TeC1 solution proposes a coordinate multi-flow transmission in TDD mode that if generalized to this scenario could reduce even further the needed bandwidth. Results would be similar to those of L2 FDD outband, but with half the bandwidth needs. The needed bandwidth would be 0.88 times that of the simpler configuration, that is, 0.85 GHz. The lower bandwidth requirement comes at the cost of increasing transmission powers at base stations and user equipment, not being this increase valid for many scenarios.

Table 4-6: Median of mean user E2E latency in legacy system.

Configuration	Experienced throughput	Mean E2E packet latency	Normalized bandwidth req.
no caching, no relaying	5% CDF: 340.4 kbps 80% CDF: 1.9 Mbps	21.6 ms	2
L3 relaying	5% CDF: 278.8 kbps 80% CDF: 1.9 Mbps	22.3 ms	4
L2 FDD outband relaying	5% CDF: 301.3 Mbps 80% CDF: 1.9 Mbps	21.9 ms	4
caching	5% CDF: 408.0 kbps 80% CDF: 1.9 Mbps	18.7 ms	<4 (2.5)*
caching + L3 relaying	5% CDF: 286.8 kbps 80% CDF: 1.9 Mbps	19.0 ms	< 6 (4.5)*
L2 FDD inband half-duplex relaying	5% CDF: 138.1 kbps 80% CDF: 1.5 Mbps	24.6 ms	2
L2 TDD inband half-duplex relaying	5% CDF: 64.4 kbps 80% CDF: 985.5 kbps	30.0 ms	1
* Exact value depends on the bandwidth allocated to cache link. Realistic values indicated in parenthesis.			

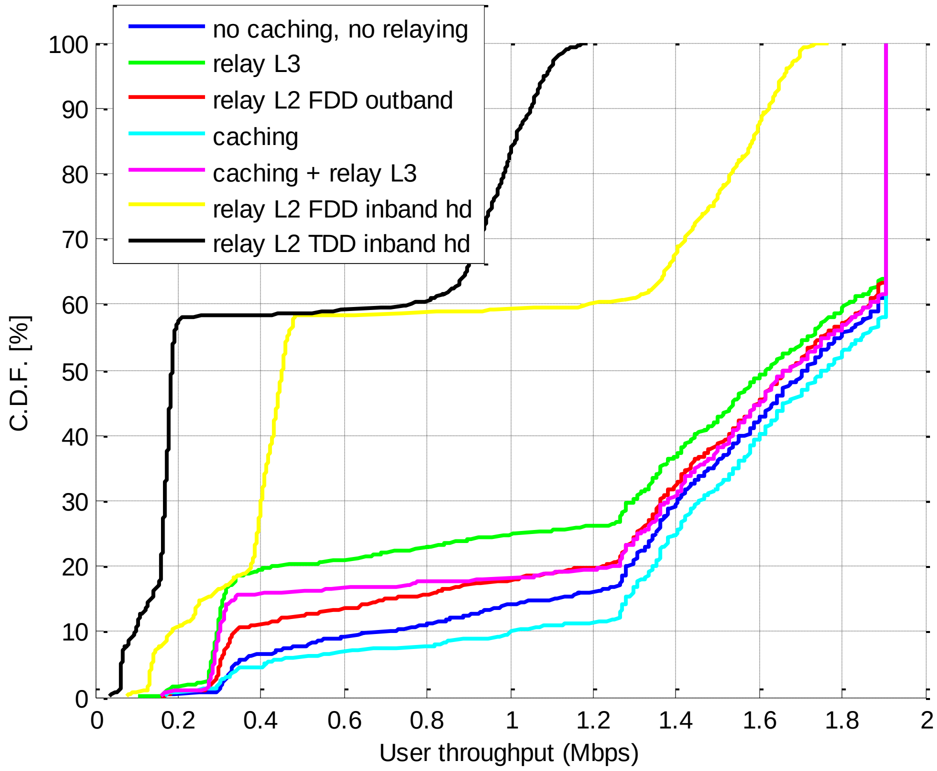

Figure 4-13: CDFs of experienced user throughput.

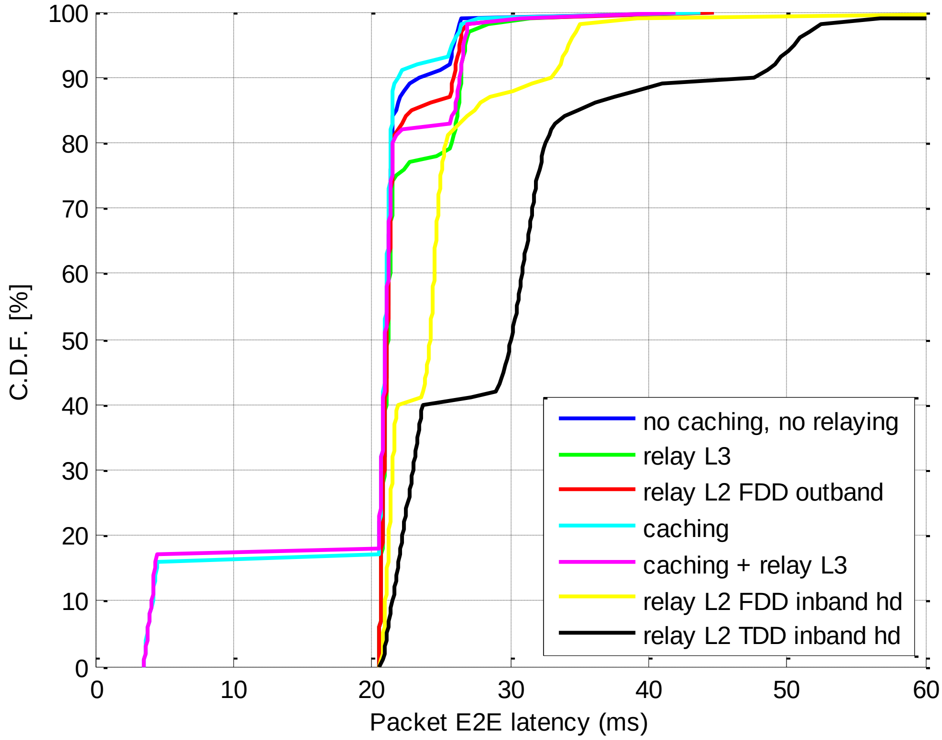

Figure 4-14: CDFs of E2E packet latency.

4.8 TC8: Real-time remote computing for mobile terminals

Evaluation of TC8 is based on the evaluation of OFDMA approach and SCMA approach (comprising of both SCMA and OFDMA, but using different assumptions and TeCs set as in the first, OFDMA-only approach). Details of simulation assumptions for both cases can be found in Section 3.8.

In the first approach results with small cells deployed in the streets with ISD of 20 m and 40 MHz in 2.6 GHz band configured in TDD mode. To guarantee a high performing solution, 4x4 MIMO and IRC receivers are used. In order to exploit benefits of closed loop spatial multiplexing (using optimal precoding matrix feedback instead of Cyclic Delay Diversity used in open loop mode) a concept of predictor and candidate antennas is employed. Using this setup, an instantaneous user throughput in the order of ≈300 Mbps in the DL and ≈25 Mbps in UL for the cell edge users at 5^{th}% tile of the user throughput CDF, was achieved. These results are captured in Table 4-7.

Table 4-7: Individual user's packet throughput for the cell edge users in OFDMA approach.

Perceived throughput [Mbps]	DL	UL
5^{th} %	303.4	24.3
10^{th} %	422.5	32.5

Experienced packet delay for the DL and UL is exemplified in Figure 4-15. It is visible that majority of the packets can be transmitted with the single-digit delay (in ms). UL packets are four times smaller than DL ones, therefore some of them (≈12%) could be transmitted with delay not greater than 1 ms. Delay aware scheduler prioritize transmission of different packets in order to reach the required KPIs for both transmission directions.

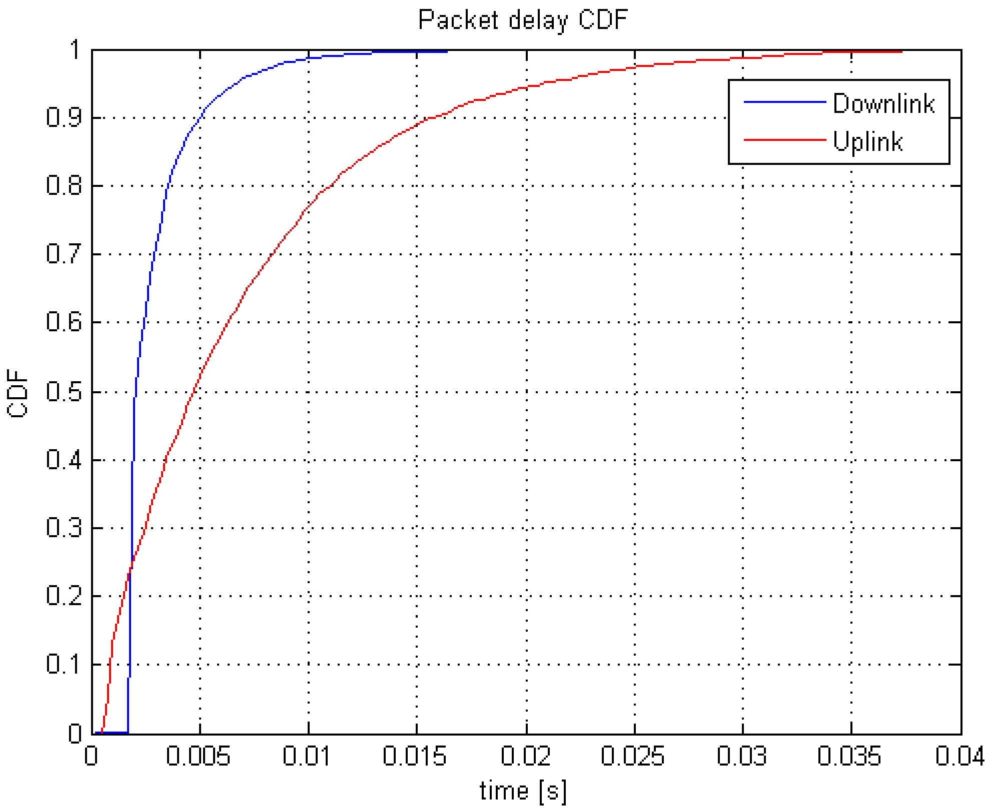

Figure 4-15: CDF of packet delay for OFDMA approach

Performance of MU-SCMA is summarized in Table 4-8. In considered scenario, MU-SCMA outperforms OFDMA. In both cases 2x2 OL SM MIMO mode was used. As depicted in Figure 4-16, in both cases packets of cell edge users are transmitted much slower comparing to the devices in the cell centre, but SCMA provides additional capacity and is able to transmit faster than its OFDMA counterpart. This difference is more visible at higher speed regimes (i.e. 120 km/h), where SCMA achieves 1.19 Mbps at the 5^{th} % tile, while legacy OFDMA transmits the packets at the speed of 0.2 Mbps. When users move with the speed of 3 km/h the performance is 1.69 Mbps and 0.53 Mbps for SCMA and OFDMA respectively.

Table 4-8: Throughput for the cell edge users in SCMA approach at the speed of 3 and 120 km/h.

Perceived throughput [Mbps]	10^{th} % 3 km/h	5^{th} % 3 km/h	10^{th} % 120 km/h	5^{th} % 120 km/h
OFDMA	2.17	0.53	0.92	0.2
MU-SCMA	2.86	1.69	2.25	1.19
Gain	31.8%	217%	145%	495%

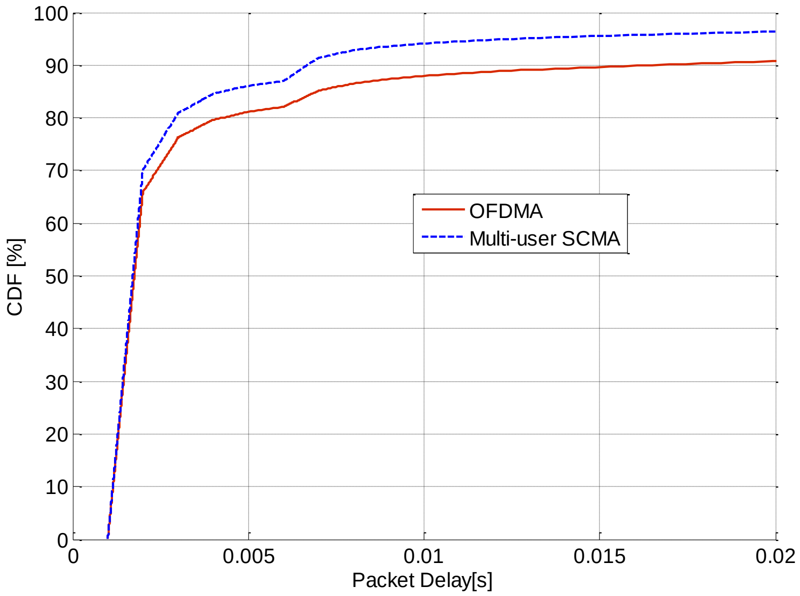

Figure 4-16: Packet delay distribution at the speed of 120 km/h for the total load of 84 Mbps for the SCMA approach.

Technology components developed in METIS are able to cater for the requirements of TC8. In order to circumvent vehicular penetration losses a dual antenna set seems a straightforward solution. This concept has additional advantage of enabling advanced antenna systems (e.g., higher order MIMO) mounted on the rooftop that can provide efficient wireless backhaul and shift the complexity of the solutions away from the users traveling in a vehicle. Predictor antennas are needed in order to enable well performing Closed Loop (CL) MIMO scheme, which otherwise fails at higher speed in legacy solutions due to detrimental effects of channel aging. In the cases that predictor antennas are not available or CSI feedback overhead is not affordable, open loop user multiplexing such as MU-SCMA seems as a promising technology to enable a high performing and mobility-robust solution. In addition, if CL MIMO is affordable, MU-SCMA can be applied on top of MIMO layers to further improve the throughput and latency of the network.

4.9 TC9: Open Area Festival

In TC9 we study user and machine traffic on lower 2.6 GHz band and on higher 20GHz band, although machine traffic uses only the lower band. Furthermore, we study the use of opportunistic network assisted D2D as a means to offload the data from the network. Our main technical solution is the access to large amount of new higher centimetre wave band combined with Massive MIMO technologies, especially beamforming. Simulation results show that the machine traffic KPIs can be fulfilled with traditional lower band spectrum and with affordable non-MIMO radios, as can be seen in Figure 4-17.

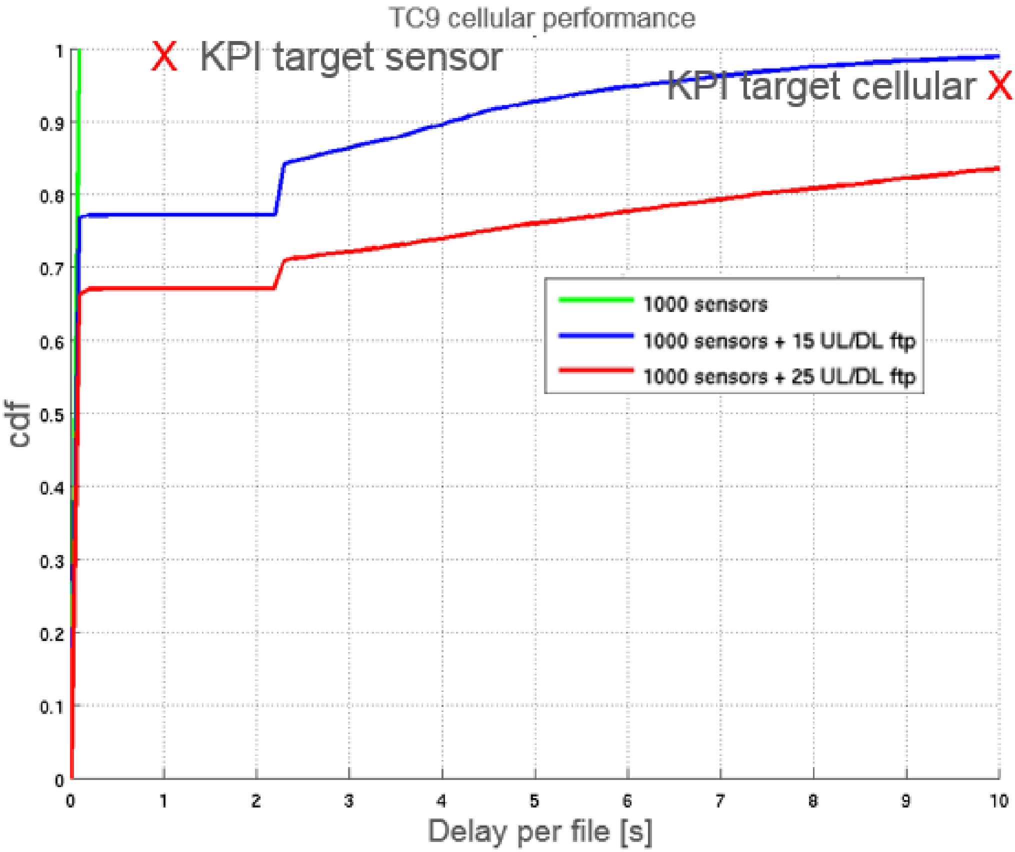

Figure 4-17: Machine traffic KPI on 2.6 GHz band (with some user traffic).

On the high cmWave band, we assume 256x16 beamforming using 800 MHz of spectrum. An example of SINR and file delay (10 seconds correspond to target throughput KPI) are shown in Figure 4-18. We can support more than 5000 uses per stage area.

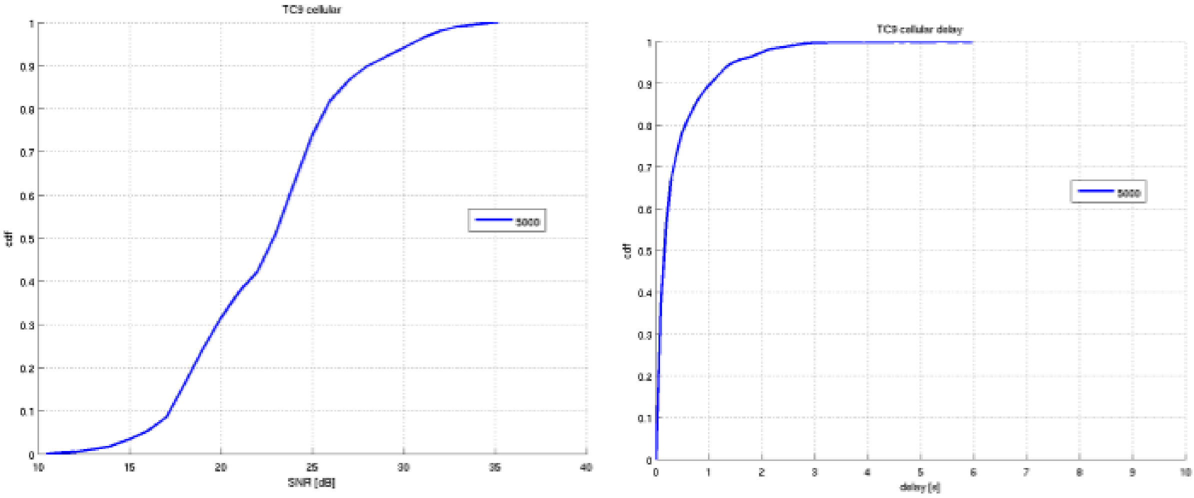

Figure 4-18: User traffic SINR (left) and file delay (right) on 20 GHz band, 5000 users/stage.

Furthermore, we study the usage of D2D using the higher 20 GHz band and 400 MHz of total spectrum. In these simulations, we assume that the devices can find a pair within 12 meters radius in the crowd and that 50% of the users can offload the data opportunistically via network assisted D2D. The SINR and file delay distributions are shown in Figure 4-19.

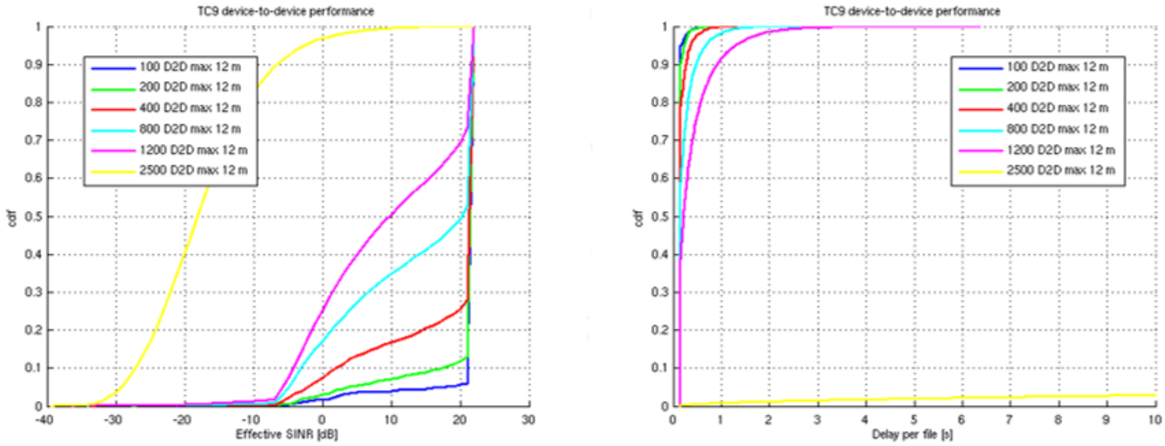

Figure 4-19: D2D SINR (left) and file delay (right) on 20 GHz band, discovery range 12 m.

As a summary, Table 4-9 shows the capacity estimate for the different cases.

Table 4-9: Summary of simulated capacity estimates.

Traffic	Spectrum needed (max)	Capacity/target (# devices)
Sensor traffic	200 MHz at 2.6 GHz	1000/1000 = 100%
Cellular traffic	800 MHz at 20 GHz	5000/10000 = 50%
D2D traffic, range {8, 12, 16} m	400 MHz at 20 GHz	{>2500, ≈2000, ≈1000}
Sum: Cellular + D2D		(5000+2000)/10000 = 70%

For D2D, we take 12 m reference for the capacity, which is roughly 2000 users. When adding the cellular and D2D capacity, we can support roughly 70 % of the target.

4.10 TC10: Emergency communications

Discovery and low energy consumption of the devices to the users in need are crucial in emergency communications. The device discovery algorithm was evaluated using a Monte Carlo simulation for different device loads using a simplified link-to-system (L2S) interface: according to which a discovery beacon will be detected if SINR is larger than 0 dB. For each user density we simulated 10 drops of users and run the simulation for 25 s time length for each drop. The right cluster-head (CH) for each device is pre-defined based on the path-loss, SINR threshold and the UE metric and this information is used at the end of simulation to indicate if a user is discovered or not: a UE is considered discovered if it has connected to the right CH and is considered out of coverage if at the end of simulation it is not able to detect a discovery beacon from the right CH. Based on this the discovery ration is calculated as the percentage of the users that connect to at least one CH. The CH itself can be some remaining base station after a natural disaster, temporary emergency BS or the device carried by first responders.

In Figure 4-20 the discovery ratio is given for three different approaches. The Cluster-based approach only has a few CHs, which imply that a lower number of UEs can be covered. In the Hybrid-based approach all CHs-capable transmit their beacons, which enable coverage of more UEs but at a cost of higher collision rate .The Threshold-based approach is based on trade-offs between the number of CHs and coverage.

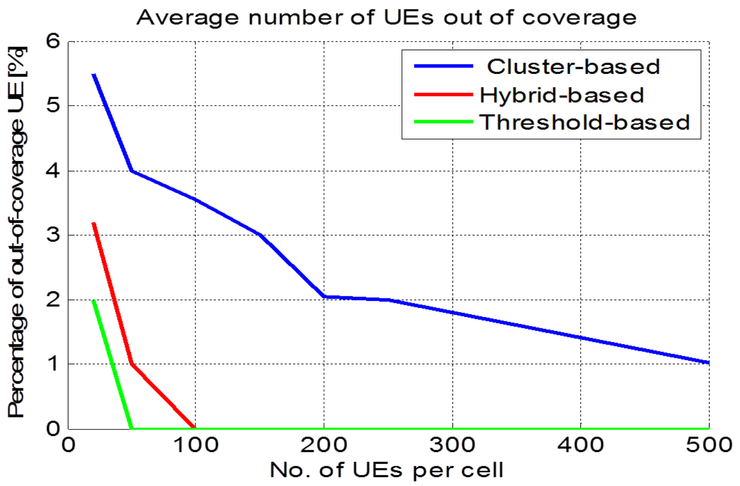

Figure 4-20: The percentage of under coverage UEs, i.e. UEs that connect to one CH), as a function of the number of UEs per cell.

The discovery time is defined as the time needed for the device to connect to a CH. With a sufficient number of CHs (e.g. more than 50) the goal of 99.9% discovery rate is fulfilled for both the Hybrid-based and Threshold-based approaches. Figure 4-21 shows the discovery time for the three discovery approaches with the increase of the number of users.

The results show that the goal of having an infrastructure setup time of less than 10 s are fulfilled for all three approaches when considering the number UEs in Figure 4-21 (i.e. for up to 500 UEs per cell).

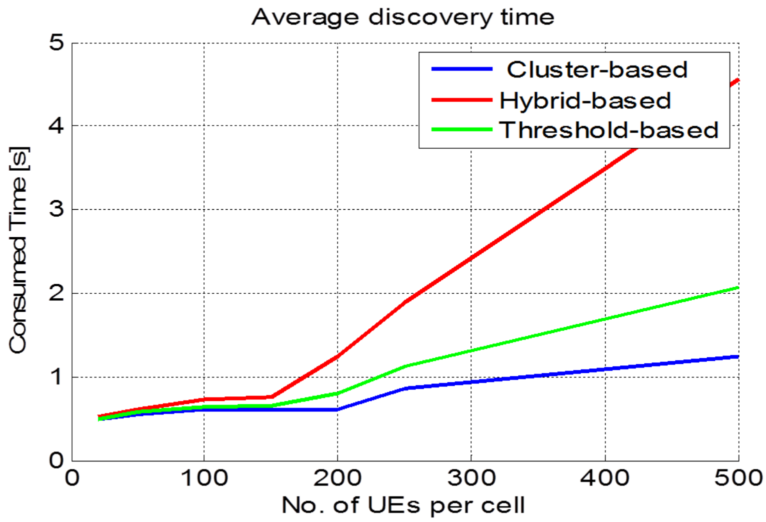

Figure 4-21: The average consumed time to discover a UE as a function of the number of UEs per cell.

To reduce the energy consumption a trade-off between energy efficiency and spectral efficiency is formulated, by using different power control algorithms. The LTE baseline approach is open loop (OL), whereas Fix is a simplified version of OL. Another approach is the Utility Maximization (UM) approach where there is a parameter one can vary to trade-off between energy consumption and throughput. The results are presented in Figure 4-22. With the parameter equal to 100 (i.e. UM100) one makes a 90% energy saving compared to the LTE baseline (i.e. OL) while still maintaining a decent throughput. In such “emergency mode” setting (e.g. UM100) the UE battery would last much longer than in the regular mode currently used (OL).

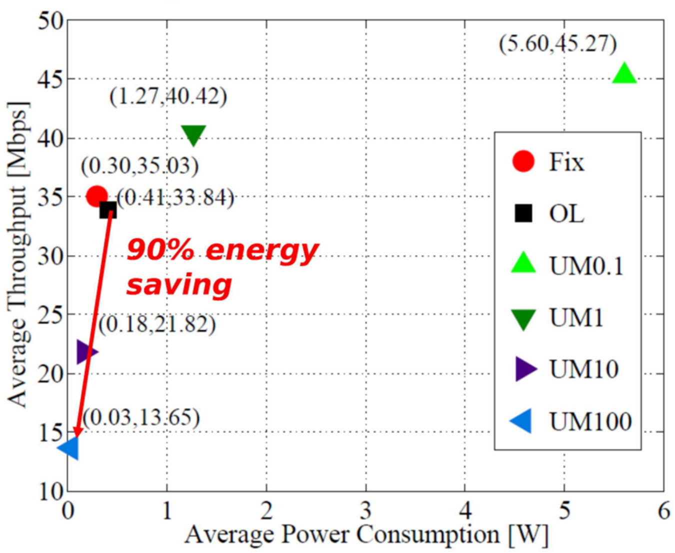

Figure 4-22: Scatter plot of the total power consumption and average throughput achieved by the examined power control algorithms.

The main KPIs and requirements of TC10, Emergency communications, can thereby be fulfilled with this improved system (in the considered reduced UE-density setting), as it provides:

- a discovery rate of 99.9%,
- a discovery time of below 5 s with a sufficient number of CH capable devices,
- an “emergency mode” approach is able to save significant amount of power.

Also, at the end of the discovery procedure a cellular-like structure is in place which allows reusing the network-assisted D2D mechanisms, such as RRM and power control, multi-hop communications, etc.

4.11 TC11: Massive deployment of sensors and actuators

In Figure 4-23 the narrow bandwidth transmission and radio link efficiency is being investigated in uplink for the transmission bandwidth 15 kHz as compared to the baseline of 180 kHz (in this figure with a QPSK upper rate limitation).

It is found that 1.4 MHz system bandwidth will meet the TC11 capacity requirements (intercell-interference not considered). That is, the capacity is more than $3.6 \cdot 10^6$ messages of 125 Bytes per hour, which is indicated by the horizontal dotted black line. Focusing on indoor MMC devices (+20 dB path loss curve), using a narrow bandwidth transmission of 15 kHz allocation would at a cell radius of 1.1 km give an absolute increase in capacity of $2.8 \cdot 10^6$ messages per hour (indicated by the vertical orange arrow in Figure 4-23). That is 78% of the traffic requirement of TC11. Alternatively, at the traffic requirement of $3.6 \cdot 10^6$ messages/h, the 15 kHz narrow bandwidth transmission would increase the cell radius by 98% (as indicated by the green horizontal line in the figure). In terms of area that means 290% larger cell sizes for the narrow-band transmissions.

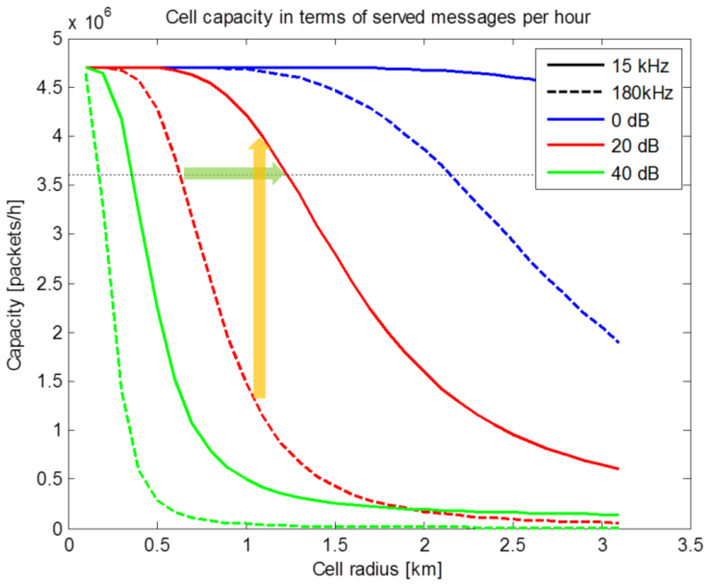

Figure 4-23: UL capacity with 1.4 MHz system bandwidth and QPSK rate limitation (solid lines indicate transmission bandwidth of 15 kHz whereas dashed lines indicate 180 kHz).

In Table 4-10 the non-delay-sensitive applications, where up to three retransmissions are allowed for failed packets, of LTE baseline and SCMA are compared. For SCMA the gains are a combination of those from contention-based transmission and from the SCMA overloading of the physical resources. The gain depends on packet sizes, ranging from around 2x for 125 bytes payload to 10x for 20 bytes payload. In general, packet size is larger if current LTE connection setup control signaling overhead is included for every packet transmission. However, packet size can be smaller in the future when such overhead is not sent in every contention-based transmission for machine type applications.

Table 4-10: MMC capacity in terms of the number of devices per MHz at 1% packet failure rate.

	Packet size 20 bytes	Packet size 125 bytes
LTE baseline	95 000	80 000
SCMA	1 010 000	168 000

The battery lifetime improvements for the devices are illustrated in Figure 4-24 and for the M2M relaying associated gains in Table 4-11. In Figure 4-24 the battery life gains associated with connectionless approaches, i.e. omitting UL synchronization and parts of connection setup, is illustrated relative to the baseline case with a DRX cycle of 2.56 s as a function of the sleeping cycle length for various inter-arrival times. It is seen that the majority of the gains is achieved by using a DRX sleeping cycle longer than 2.56 s. At the TC11 reference case of UL payload every 5 min, using a 300 s DRX cycle improves the battery life by x20. This can be further increased by contention-based approaches, either by x25 from omitting the UL sync, or by x24 from still getting synchronized but with an optimized procedure.

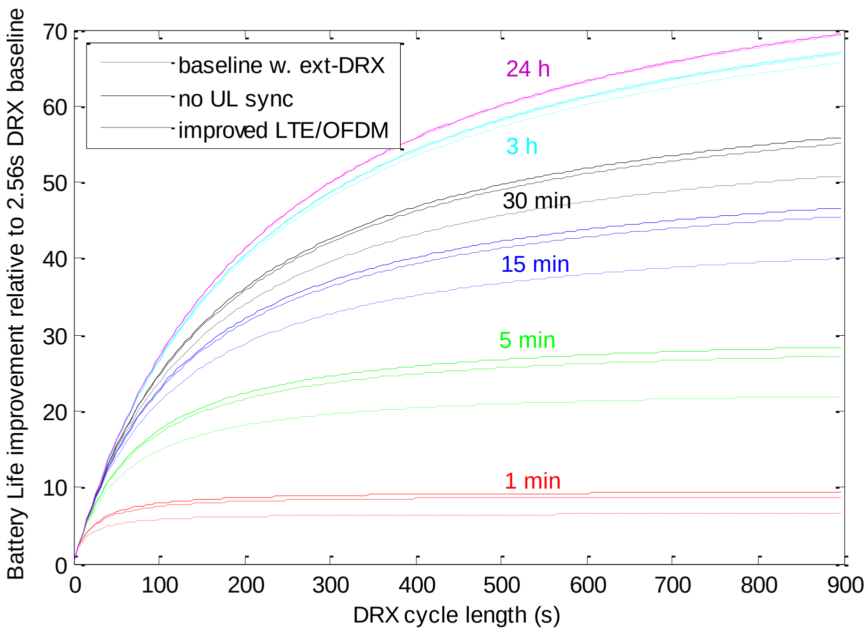

Figure 4-24: Battery-life gain (as a factor) plotted as a function of sleeping cycle length for various inter-arrival times of periodic UL traffic relative to the case with DRX cycle of 2.56 s.

In Table 4-11 the gains of M2M relaying, in which devices can act as relays to other devices in poor coverage, is compared to the LTE baseline. The battery life stated is the average improvement for the devices which gets served by a relay device and the capacity improvement is stated as the maximal total served throughput with a highest acceptable user drop rate of 4%.

Table 4-11: Results at 300 000 devices/cell with 125 Byte payload with 50% overhead every 5 min.

		Baseline:	M2M Relay:
Battery life:	DL:	16 years	27 years
	UL:	12 years	26 years
Drop rate:	DL:	18 %	0 %
	UL:	17 %	0 %
Capacity (4%):	DL:	1 Mbps	16 Mbps
	UL:	1 Mbps	5 Mbps

For an overview the gains from individual solutions are summarized in the following table (note that the combination of solutions has not been considered and could give even higher gains).

Table 4-12: Summary of TC11 results.

	Narrow Band	Group based signalling	SCMA	Battery opt.	M2M Relaying
Coverage	3x	-	-	-	18% to 0% drop rate
Capacity	12x	(*)	2.1x – 10x	(*)	5x-217x
Battery life	(*)	-	(*)	20-24x	2.2x
Protocol eff.	-	76% increase (**)	(*)	-	-

where (*) indicates that there could potentially be gains, but that it has not been studied in the evaluation. (**) the increase depends on the traffic model – see more details in annex, Section A.11.5.

The goals can be met in terms of capacity, and potentially narrow-band transmissions using SCMA with sensor relays could even be combined to obtain very large capacity improvements. The coverage goal is met by M2M relaying, obtaining 100% coverage in the studied scenario and by narrow-band transmission giving x3 larger cells (uplink). Moreover, the battery life improvements meet the targets, mainly by longer sleeping cycles and secondly by contention-based transmissions and optimized procedures. Protocol efficiency however falls short of the 80% target. In the evaluations, the control signalling was reduced to ½ but to reach the target, at 125 Byte payload with a 50% overhead, it would have to be reduced to ¼, which is very challenging for already small payloads. Potentially this target could be reached by further combination with contention-based transmission of data.

4.12 TC12: Traffic efficiency and safety

Table 4-13 demonstrates the system performance w.r.t. different communication range requirements of 50 m, 100 m and 200 m. Besides, successful package transmission ratio and 5ms E2E latency ratio defined in Section 3.12 are used to inspect on system performance of different technologies.

Table 4-13: System performance w.r.t. different schemes.

Row		R=50m		R=100m		R=200m	
	system parameters	successful ratio	5 ms E2E	successful ratio	5ms E2E	successful ratio	5 ms E2E
1	1,3,5,7	99.93%	99.1%	97.71%	96.82%	86.26%	85.59%
2	2,3,5,7	99.99%	99.83%	99.56%	99.18%	94.73%	94.45%
3	2,3,6,7	100%	99.83%	99.98%	99.18%	97.25%	94.45%
4	2,4,6,7	100%	99.83%	100%	99.18%	98.5%	94.45%
5	2,4,6,8	100%	100%	100%	99.98%	98.5%	97.98%

System parameters in Table 4-13:

1. No coordi. between neighbouring BSs
2. Coordi. between neighbouring BSs
3. Retransmission with spectral efficiency of 0.1523 bits/Hz
4. Retransmission with spectral efficiency of 0.377 bits/Hz
5. Bandwidth=100MHz
6. Bandwidth=200MHz
7. Duration time of per TTI = 1ms
8. Duration time of per TTI = 0.5ms

As can be seen from this table, system performance of larger communication range is more sensitive to exploited technologies. Thus, we focus on the numbers where communication range is up to 200 meters ($R = 200m$) for analysis.

In row 1, a system without any coordination between neighbouring BSs with 100MHz bandwidth is exploited. Besides, modulation and coding scheme (MCS) used here for retransmission has a spectral efficiency of 0.1523 bits/Hz and LTE frame structure is applied where per TTI has time duration of 1ms. It can be seen there, 85.59% of overall packets are received successfully with E2E latency with 5ms requirement and 86.26% of overall packets are successfully received with any E2E latency value. In row 2, a coordination scheme is applied where location information of vehicles connected to neighbouring cells is available in the central entity in order to mitigate interference and avoid packet collision. As can be seen here, system performance has been improved compared with the previous case and 94.45% of packets can be received with E2E latency within 5ms. However, the successful ratio of 94.73% in this case is not very much different from the value of 5ms E2E latency ratio. Actually, in the case where per TTI has duration of 1ms, the difference between these two metrics represents the contribution from successful retransmitted. Therefore, the reason why retransmission does not contribute much in this case is due to the fact that 100MHz bandwidth does not provide enough resource for retransmission and therefore a large ratio of unsuccessfully received packages cannot be scheduled for retransmission.

In row 3 and row 4, we increased system bandwidth to 200 MHz and two different retransmission schemes are used where one has spectral efficiency of 0.1523 bits/Hz and the other of 0.377 bits/Hz. As can be seen here, since additional bandwidth is available for retransmission, more retransmission packages can be scheduled and contribute to a higher ratio of overall successful transmission ratio. Moreover, by comparing two cases shown in row 3 and row 4, though MCS with spectral efficiency of 0.1523 bits/Hz has a lower modulation and coding rate and provides a better link robustness compared with the other case, it has a successful ratio of 97.25% which is lower than 98.5% of the other case where MCS with higher spectral efficiency is exploited. The reason here is that a MCS with lower spectral efficiency requires more resource compared with a MCS with higher spectral efficiency. Therefore, a compromise in between the link robustness and available resource should always be made by central entity in order to achieve a better performance. Regarding the 5ms E2E latency ratio, we can see that there is no change compared with previous case where 100MHz bandwidth is used. This demonstrates that legacy LTE frame structure where per TTI has duration of 1ms is not an optimal solution for network controlled V2V communication since retransmitted packages have E2E latency larger than 5ms.

In the last row, the TTI duration is decreased to 0.5 ms. Due to this change, retransmitted packages can have E2E latency lower than 5 ms and therefore contribute to 5ms E2E latency ratio. Comparing with the previous case, 5ms E2E latency ratio can be improved from 94.45% to 97.98%.

Though above analysis is done w.r.t. the case where V2V communication range is up to 200 meters, it also applies to other cases where shorter communication range is required. With the results shown above, a procedure is demonstrated about how we tried to approach METIS goal and fulfil the requirement for traffic efficiency and safety. Based on our evaluation work, it can be seen that all related TeCs should add on top of each other to approach required KPI value and enable traffic safety and efficiency.

5 Conclusions

This deliverable has presented the current view on the 5G system concept from the METIS project together with some system-level results aimed at providing a clear view on the impact of some of the most promising technology components (TeCs) in the 5G system performance.

Simulation results have proven the potential of some of the techniques discussed along the METIS project. Table 5-1 summarizes the impact of most significant techniques together with some comments concerning the pros and cons of their use in 5G systems. Note that the quantitative analysis provided in Table 5-1 is derived from all simulations in the twelve different test cases evaluated.

Of significant relevance is the use of D2D communications, which could increase average system capacity by a factor of 2 (with high density of users and common interests in the consumed contents), and moving networks, in which vehicles can operate in relaying mode for other users, e.g., out-vehicle users in case of nomadic node operation. Moreover, the collaboration of vehicles allows for a feasible implementation of universal caching, by which vehicles forward cached content directly to interested user.

Table 5-1: Summary of the system-level simulation results in METIS.

Technique	Pros	Cons
D2D communications	System capacity can be increased by a factor of 2 using the same bandwidth when some RRM mechanisms are used for opportunistic access and there exists full cooperation among devices. Latency is also reduced to the order of the TTI length (e.g. 1-2 ms). With properly selected safety distance, D2D communication can use the spectrum allocated to small cells (mostly uplink band) without affecting the small cell performance.	How to motivate cooperation of users is an open issue. Battery consumption is critical in current systems and D2D communication model is only accepted by the users for their own benefit. Moreover, D2D increase complexity in the terminal side. Specification is far from being ready for D2D integration. Opposition from some MNO is also an important barrier to overcome.
New waveform and multiple access technologies	Access time can be reduced down to 1.5 ms if new air interfaces are coupled with efficient access procedures (as shown by FBMC evaluations). Due to the very good frequency localization, the transmit power can be concentrated on only very few subcarriers to eventually enhance significantly the expected coverage or to reduce battery consumption. This is of special relevance for machine-type communications, in which payload is very small. SCMA, in which multiple users can transmit data with sparse codebooks, can	Changing the waveform impacts the signal structures, implying a revolutionary step towards a new radio generation. Backward compatibility thus cannot be guaranteed, however, for a new radio generation this should not be crucial requirement. Extension to MIMO systems is not yet fully understood.

	enable DL open-loop multi-user transmission and CoMP that is mobility robust with improve downlink cell edge throughput by up to 65%. UL SCMA, on the other hand, supports massive connectivity with moderate complexity receiver due to SCMA codebook design. It has been shown by evaluations to improve uplink connectivity by 2 to 10 times. Moreover, the reliable multi-user detection can reduce the time a device spends in active mode, thus helping to conserve energy. 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.	
Ultra Dense Network	Capacity is directly proportional with the number of nodes, provided centralized interference coordination. For indoor cases, the coefficient of proportionality could be as high as 0.73 with ISD of 10 m. Together with increasing the bandwidth, the use of more nodes is a straightforward means to achieve desired levels of capacity.	Cost is the main issue of this approach, together with the need for interference coordination. In case of certain isolation between cells, this need for coordination is relaxed.
Traffic concentration	The use of accumulators or concentrators for machine-type communications improves range of coverage and sensors' throughput. The improvement factor is between two and three thanks to those relays. For the same throughput and coverage needs, traffic concentration reduces battery consumption. Concentrators also reduce signalling overhead thanks to the coupling of parallel signalling flows.	Performance heavily depends upon the appropriate relay selection. Delay will be increased due to the multiple-hop operation.
Moving Networks	In vehicles equipped with two access points, one for outside transmission/reception and another for inside users, their best reception chain improve the link budget for the end user up to 9 dB, in cases where the user is outside the car, and up to 24 dB, when the user is within the car. This results in better coverage or higher user throughput, mostly in the cell-edge. Battery is not a big issue for vehicles, which opens the door for more active collaboration between cars and end-	Mobility of access points increases management complexity mostly due to the higher dynamicity of the network.

	users. Moreover, the number of antennas integrated in vehicles can be much higher than in the handheld devices. This allows for massive-MIMO solutions mostly at high frequencies.	
Localized traffic flows	With a dedicated bandwidth of 80 MHz, the end-to-end latency is reduced to 60 %, as compared with current LTE-A system. Moreover, half of the traffic can be offloaded from the cellular system. Use of localized traffic flows is simple to implement and can be easily integrated into current networks.	Universal caching requires storage resources as well as the design of specific signalling mechanisms.
Massive MIMO	Spectral efficiency can be increased by a factor of 20 when using 256 antennas in the transmitter and receiver side as compared with 4 antenna systems. For the same spatial multiplexing capability as legacy systems (8 streams), beamforming gain reaches 15 dB. Straightforward way of increasing cell efficiency mostly for small cell deployments. Fits together with the use of higher frequencies above 6 GHz due to the reduced antenna size.	Pilot contamination is one of the main showstoppers of the use of massive MIMO. Moreover, TDD mode seems to be a must to reduce signalling overhead thanks to the use of channel reciprocity principle. Form factor forces the use of cmW or mmW to compact massive antennas. Finally, performance is sensitive to mobility and computation burden could make Multi-User MIMO solutions unrealistic.
Spectrum above 6 GHz	Since 5G will serve a wide variety of use cases with different technical requirements, which needs different characteristics of the spectrum employed. Thus, 5G will need allocations in several spectrum ranges. Meeting the 5G user expectations for extreme MBB use case will require much larger bandwidths as today, in the order of 500 MHz - 2 GHz, which is only available at frequencies above 6 GHz in the current regulatory framework. No restrictions on previous allocations of paired FDD spectrum allows for the use of TDD mode, which is much more efficient for channel estimation. Higher frequencies also reduce antenna size, thus permitting massive MIMO.	Higher order beamforming is required to provide good coverage at higher frequencies.

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Annex A

A. Complementary Simulation Results

Annex A comprises all details on the simulation work presented in this deliverable. The intention with this material is to allow other researchers to reproduce this simulation activity for calibration and crosscheck.

A.1 TC1: Virtual Reality Office

A.1.1 Description of the test case

Today's tele-presence services will evolve into high-resolution 3D versions, which will allow friends and relatives to have the amazing experience "as if you were there". An inexpensive and flexible wireless communication system, able to exchange the huge amount of data generated during the process, will be an essential part of the technical solution.

This test case consists of a top-modern office space located in a refurbished 19th century building classified as cultural heritage. The building is rented by a company working with 3D tele-presence and virtual reality. The work involves interaction with high resolution 3D scenes and is typically performed in teams of some 5 to 10 individuals simultaneously interacting with a scene. Some of the team members are sited within the building; others are working remotely from other office buildings. Each scene may include the virtual representation of the team members or computer generated characters and items. The high-resolution quality of the scene provides an as-if-you-were here feeling. Since each team member may affect the scene, all must continuously update the scene by streaming data to the others. In order to provide the real-time interaction, the work is supported by bi-directional streams with very high data-rates and low latencies.

A.1.2 Main KPI and requirements

Main KPIs of TC1 are summarized in the table below. More details on the definition of these KPIs can be found in [MET13-D11].

Table A-1: Main KPIs defined for TC1 [MET13-D11].

KPI	Requirement
Traffic volume per subscriber	36 [Tbyte/month/subscriber] in DL and UL, respectively
Average user data rate during busy period	0.5 [Gbps] DL and UL, respectively
Traffic volume per area	100 [Mbps/m^2] DL and UL, respectively
Experienced user data rate	1 [Gbps], UL and DL, with 95% availability (5 [Gbps] with 20% availability)
Latency	10 [ms] round trip time

A.1.3 Simulation models

Simulations follow simulation details included in [MET13-D61]. In the following, we include a short description of these models and deviations.

Environmental model

A realistic office environmental model for this test case is attained by explicitly considering walls, screens, desks, chairs and people. We assume the existence of fibre optics connection to all access points, which does not strictly follow recommendations in [MET13-D61].

Deployment considerations

The deployment baseline is one main base station ceiling-mounted with fibre backhaul with UEs in either a sitting or standing position. This coverage base station works at frequencies below 6 GHz and is located in the centre of the office whereas other five access points are deployed and operate above 6 GHz to give further capacity to the system.

This scenario is assumed to be isolated from outside interferences.

Propagation model

For the coverage small cell we use METIS model described in [METIS13-D61] as Propagation Scenario number 7 (PS#7). For the propagation at mmW band we use the ray-tracing material available at [MET14-Web].

Traffic model

The FTP-traffic model described in [METIS13-D61] is used, adapting the reading time to achieve the desired data rates.

Mobility model

The users are stationary for the duration of the simulation.

A.1.4 Assumptions

As depicted in Figure A-1, in the performance evaluation of TC1 we assume that the main base station and the access points are connected to a local routing entity through fibre optics. This local routing entity is connected again through fibre optics to a Security Gateway that provides access to the Mobile Network Operator (MNO) core network. Every user (users in office and users out of office) sends/receives a traffic flow to/from a central image processing entity (CIPE) located in the same office. This flow can be sent/received to/from the central processing entity through the local routing entity or through D2D links.

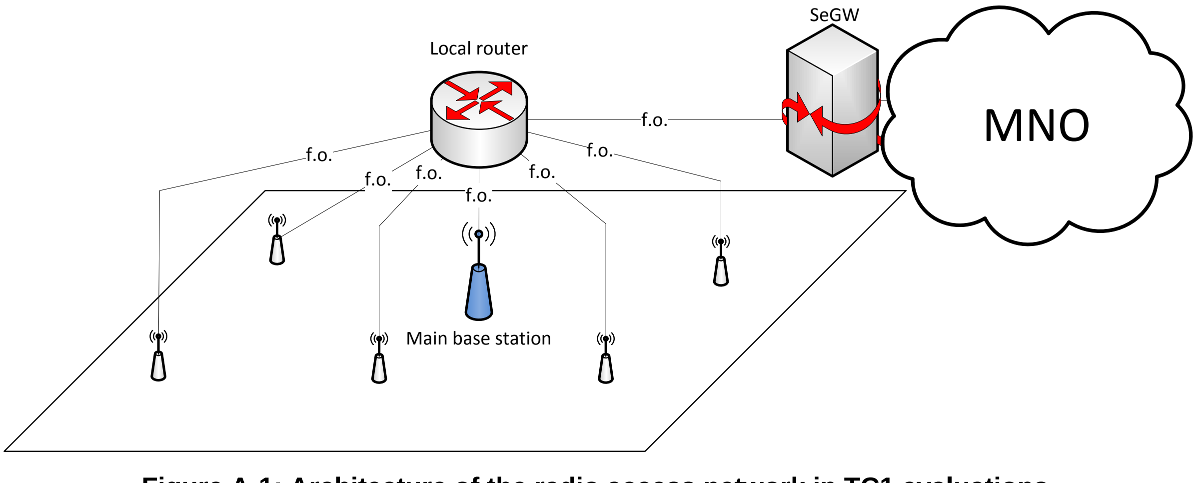

Figure A-1: Architecture of the radio access network in TC1 evaluations.

Due to the need for a specific layout in the ray-tracing calculation, we have defined a set of offices, corridors and desks, following the main descriptors in [MET13-D11]. In particular, the scenario includes fifteen offices, one small cell station (blue cross) and five mmW access points (red circles). The central image processing entity is located in room 8 (yellow star). All transmitters and users are equipped with 8 antennas (4 cross-polarized antennas). In the baseline 60 MHz are allocated for main base station at 3.5 GHz, whereas 140 MHz are given to access points operating at 60 GHz. Simulations will include multiples of this allocated bandwidth (200 MHz).

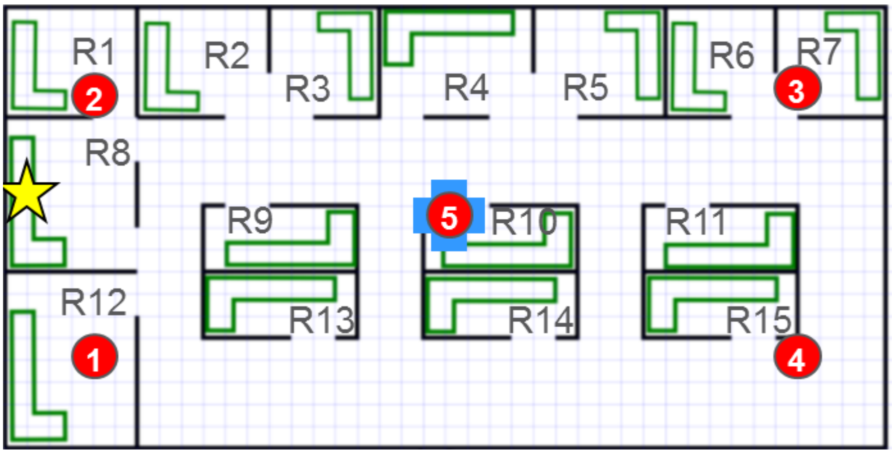

Figure A-2: Office layout and deployment.

Regarding users location, according to mean user density and area, 20 users in average should be generated in the office. In our simulations, 18 users are placed in the office rooms and 2 users are located in outer locations. All rooms are occupied by one user except rooms R4 (2 users), R8 (4 users), and R12 (2 users). There are no users explicitly placed in outer positions but 2 users in the office (not those in R8) are in a video call different to that of the other 18 users.

Traffic is modelled with FTP at 1 Gbps in each direction. We assume that packet size is 20 Mbits, and time between packets is 20 ms (50 fps). Latency for a fibre optics link is assumed to be 1 ms. Processing in routers and gateways is assumed to be also 1 ms. Latency between gateways for users in outer locations is assumed to be 1 ms. These values will be added to the radio access network delays, which will depend on congestion, scheduling and system capacity.

As commented above, path loss maps for this scenario can be found at [MET14-Web].

A.1.5 Technology components

The main characteristic of this TC is the huge amount of data, which bring the system to a congested state. In this situation RTT latency of 10 ms forces the system to be highly efficient in the management of retransmissions, since otherwise, the delay in the radio interface would prevent users from having an appropriate experience. However, interferences are huge, and therefore coordination among access points is mandatory. Given that there is a central entity in the area, centralized coordination will be investigated here (distributed coordination will be investigated in TC2). In this sense, evaluations will be progressively investigating the performance of the system with SU-MIMO, MU-MIMO and coordinated MU-MIMO (CoMP).

On the other hand, todays TTI of 1 ms seems not to be appropriate in this scenario of tight latency requirements, and therefore we should adapt the frame structure to reduced TTI, also paying attention to the specific requirements on the signalling and frame structure when increasing the carrier frequency up to mmW (WP2-TeCC1). Other subsidiary techniques will be used, to reduce interferences (T3.2-TeC11) and to facilitate D2D communications (T4.1-TeC3-A1).

Table A-2: Main technology components evaluated in TC1 simulations.

WP/Task	TeC	Name
WP2	TeCC1.1	Air interface in dense deployments – Frame structure
WP2	TeCC1.2	Air interface in dense deployments – Dynamic TDD
WP2	TeCC1.3	Air interface in dense deployments – Harmonized OFDM
T3.2	TeC11	Decentralized Interference Aware Scheduling
T4.1	TeC3-A1	Distributed CSI-based Mode Selection for D2D Communications

A.1.6 Results

First analysis is the SINR characterization of the scenario. Figure A-3 depicts the pathgain in dB for the five mmW access points plus the small cell. The lack of complete walls reaching the ceil increases the influence range of each access point. Consequently, wideband SINR is in general low, mostly in the rooms without an access point. As represented in Figure A-5, median SINR is below 10 dB being cell-edge users below 0 dB. It is worth recalling that with a median below 10 dB, the expected bandwidth required to fulfil TC1 requirements is 4.5 GHz [MET14-D53]. This interference-limited scenario will limit the set of techniques to be employed and we are forced to make use of appropriate tools to reduce the impact of these interferences.

The goal is to experience 1 Gbps in 95% locations (for cell-edge users) and 5 Gbps in 20% locations, which is equivalent to have this value in percentile 80-th of the user-throughput CDF. Moreover, we need to have less than 10 ms of mean packet latency, and less than 5% of packet loss rate. In this scenario, with 200 MHz allocated to the system it is impossible to handle the amount of data to be delivered between the different recording units and the central processing entity. In fact, even with the best configuration, 200 MHz system reach congestion and the quality of service is far from the requirements specified for TC1 in [MET13-D11]. Therefore, we will include a range of simulations to check the required bandwidth for the different configurations of the system.

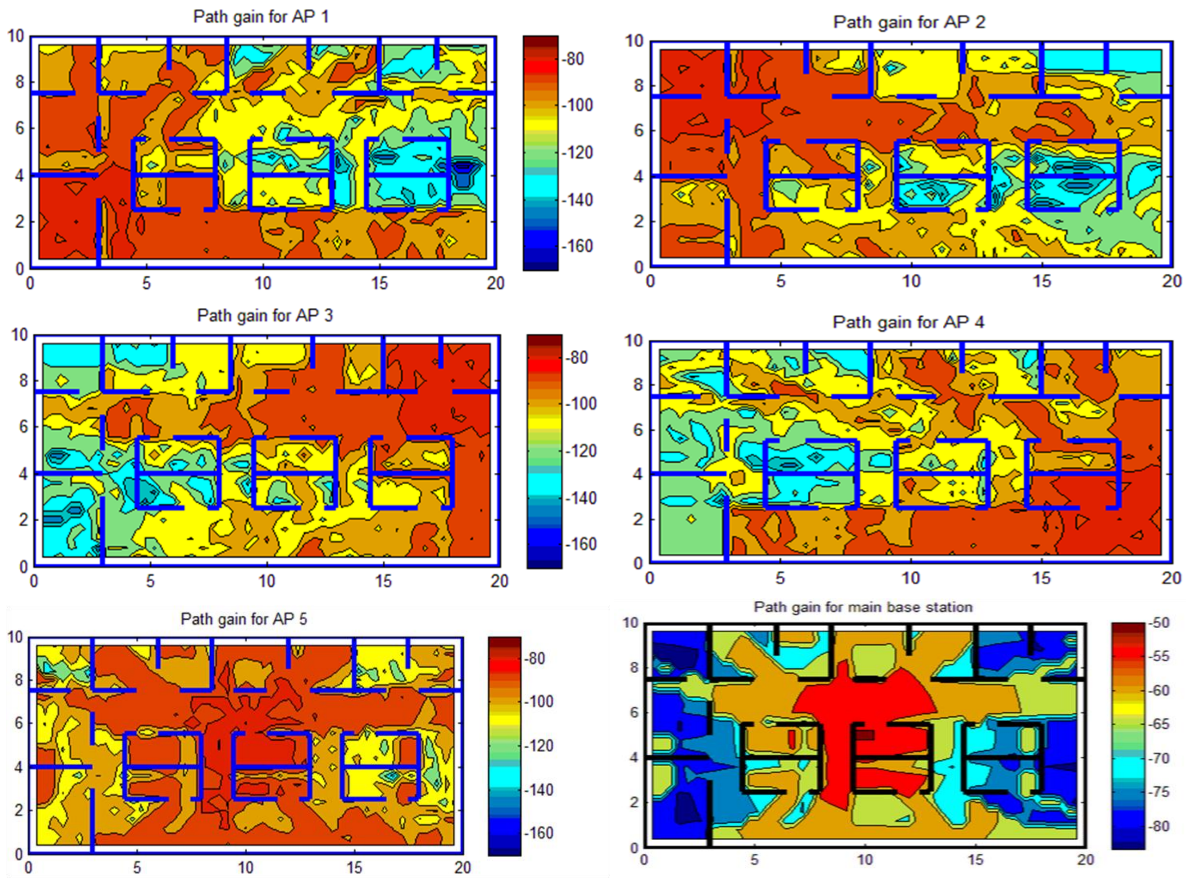

Figure A-3: Path gain for the different access points and the main base station.

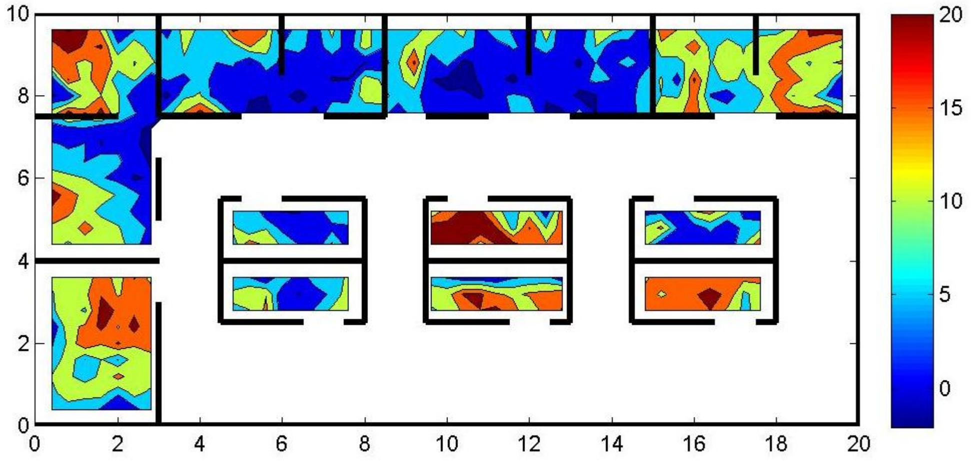

Figure A-4: Wideband SINR in the scenario under study.

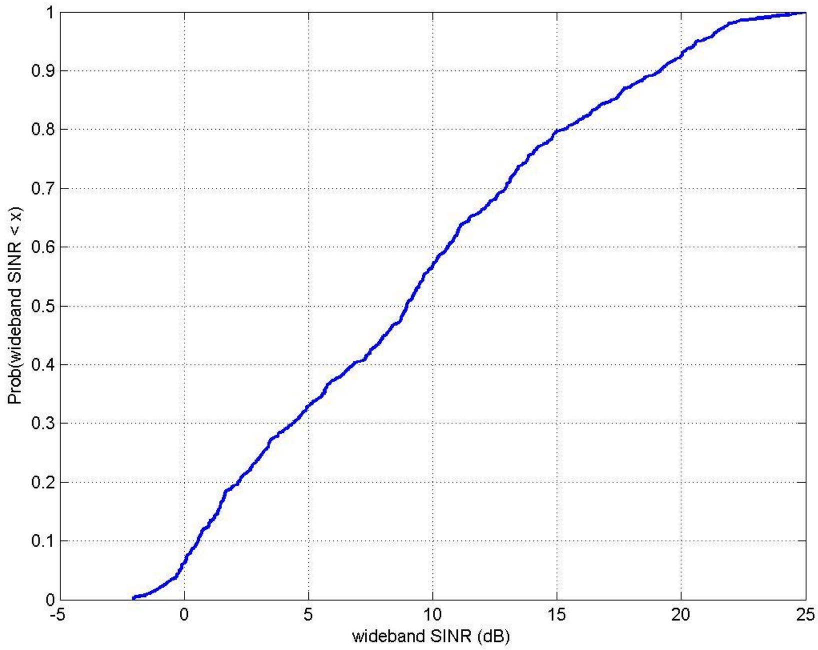

Figure A-5: CDF of the wideband SINR in TC1.

Different TTI values have been used in this scenario including legacy assumption of 1 ms, 0.5 ms and 0.25 ms. Moreover, several transmission schemes have been tested: SIMO, SU-MIMO codebook based, non-CB MU-MIMO and non-CB MU-MIMO with COMP. For CoMP, all access points are supposed to participate in the same cluster, in such a way that scheduling and resource allocation is made in collaboration with the other transmitters. In these simulations, we have not checked joint transmission solutions.

We first analyse the influence of bandwidth in the system performance for SU-MIMO (8x8). As represented in Figure A-6, with a bandwidth of 4.5 GHz all requirements are met unless maximum packet latency of 10 ms, which is satisfied in around 85%. However, other techniques can be added to increase efficiency and reduce packet latency.

We first evaluate, for 1.5 GHz, the effect of increasing complexity of MIMO transmission and coordination. As shown in Figure A-7, the use of MU-MIMO and coordinated transmission and reception, as compared with SU-MIMO, increase by a factor of almost three cell-edge user performance but degrades (-24 %) average performance. When reducing TTI time to half a millisecond, the cell-edge user performance is affected, but we improve the use of spectrum, which finally results in a better cell performance. This trend is again observed for a TTI value of 0.25 ms. In this case, average throughput improves (+21 %) and target is almost fulfilled. However, mean packet round trip time is far from reaching the objective and cannot be improved even reducing the TTI value.

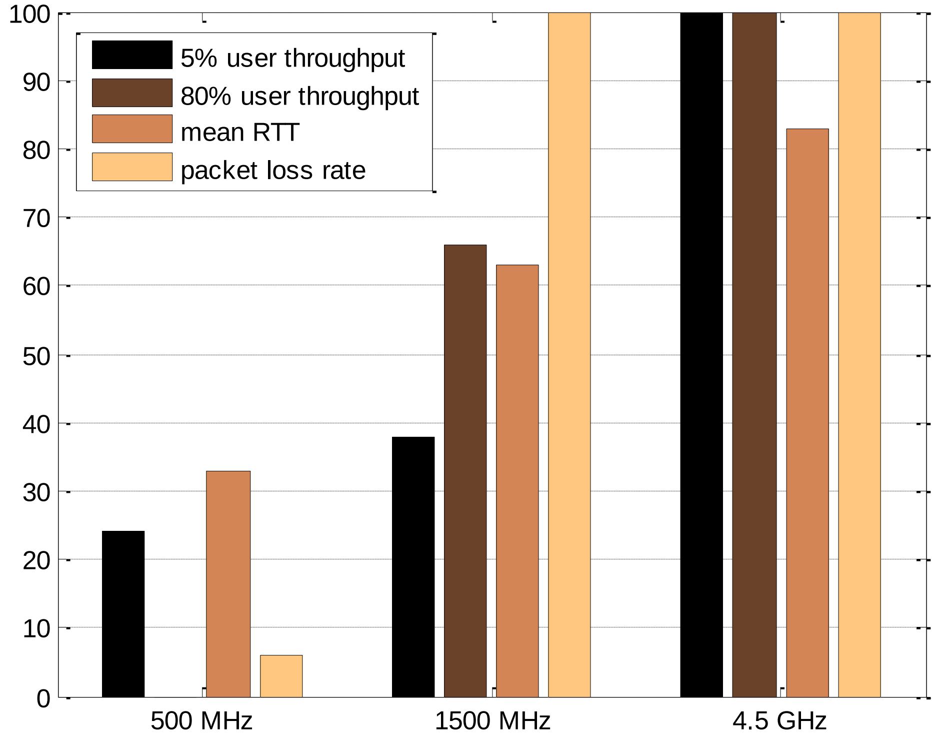

Figure A-6: Level of satisfaction of KPI for TC1.

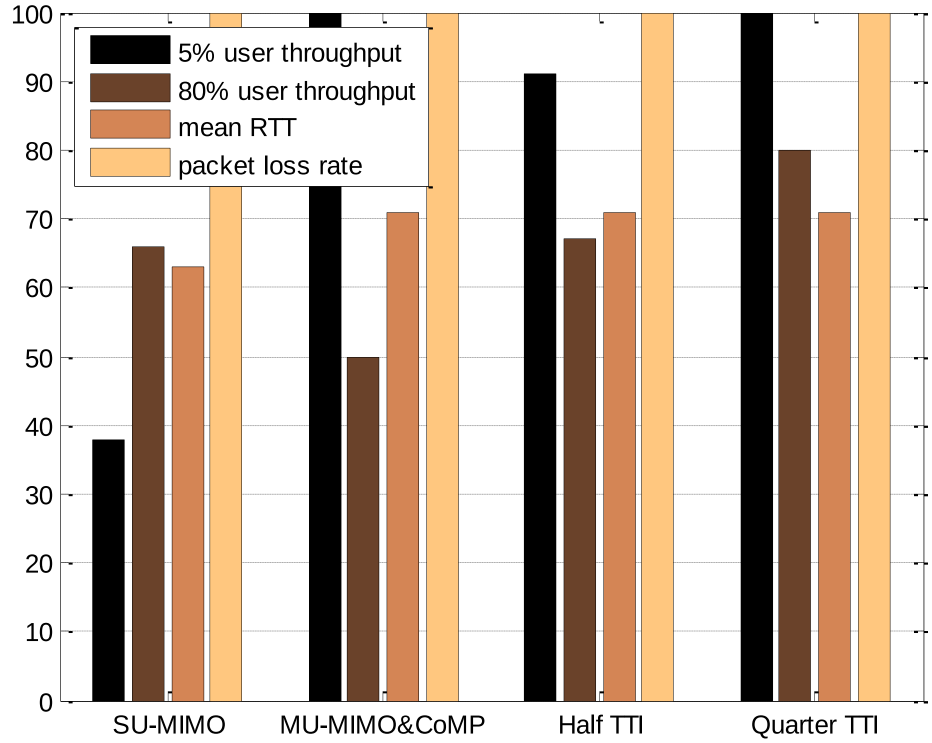

Figure A-7: Level of satisfaction for different transmission schemes and 1500 MHz bandwidth.

After several trials increasing bandwidth, we found out that the fibre optics and processing time is around 6 ms (time per fibre optic link is assumed to be 1 ms, and processing time in routers is also assumed to be 1 ms) and radio time cannot be less than 2.2 ms per direction, that is 4.4 ms in total. Therefore, the only way of reaching the goal is to improve fibre optic or routing time around 10% so as to have less than 10 ms in RTT time. If this is possible, with 1.875 GHz the system will be able to fulfil all system requirements.

A.2 TC2: Dense urban information society

A.2.1 Description of the test case

The “Dense urban information society” test case is concerned with the connectivity required at any place and at any time by humans in dense urban environments. We here consider both the traffic between humans and the cloud, and also direct information exchange between humans or with their environment. The particular challenge lies in the fact that users expect the same quality of experience no matter whether they are at their workplace, enjoying leisure activities such as shopping, or being on the move on foot or in a vehicle. Further, a particular aspect arising in urban environments is that users tend to gather and move in “dynamic crowds”, for instance because people are waiting at a traffic light or bus stop, which leads to sudden high peaks of local mobile broadband demand. Similar cases might arise as well in indoor environments with a spontaneous crowd concentration in a common part of the building.

TC2 is concerned with the connectivity required at any place and at any time by humans in dense urban environments. We consider here both the traffic between humans and between human and the cloud, and also direct information exchange between humans or with their environment.

Public cloud services: Besides classical services such as web browsing, file download, email, social networks, we will see a strong increase in high definition video streaming and video sharing, possibly also with higher requirements for image resolution, e.g. 4K standard. Besides a massive increase in the data volumes connected to the usage of public cloud services, a key challenge in communication systems beyond 2020 will lie in the fact that humans will expect the same reliable connectivity to the cloud anytime and anywhere.

Device-centric services: A full experience of the augmented reality, information could be fetched from various sources, such as sensors, smart phones, wirelessly connected cameras, databases, servers, and used locally in the device or sent to be processed in the cloud. Some of these devices may provide information about the surrounding of the users by measuring a certain phenomenon or by providing information about the presence of certain objects of interest. Based on the information harvested from surrounding devices and other sources, the UE could provide the user with contextual information so as to help the users to better understand and enjoy their environment.

The challenge for mobile communication systems beyond 2020: The mobile technology, completely transparent for users, will allow network access at any location and any time with service quality comparable to current wired broadband access with optical fibre.

A.2.2 Main KPI and requirements

Main KPIs of TC2 are summarized in the table below. More details on the definition of these KPIs can be found in [MET13-D11].

Table A-3: Main KPIs defined for TC2 [MET13-D11].

KPI	Requirement
Traffic volume per subscriber	500[Gbyte/month/subscriber] in DL and UL
Device density	200’000 per km^2
Traffic volume per area	700 [Gbps/km^2] DL and UL,
Experienced user data rate	60/ 300 [Mbps], UL / DL, with 95% availability (max rates up to 1 [Gbps])

A.2.3 Simulation models

Simulations follow simulation details included in [MET13-D61]. In the following, we include a short description of these models and deviations.

Environment model

For this test case, we assume three environment models as a derivative of original TC2 model defined in [METIS13-D61]. According to investigated deployments, we adjust the size of the model accordingly to the complexity of the simulated scenario to achive reasonable run times of rhe simulations. As a main KPI in TC2 is putted on evaluation of xMBB we have selected:

- Office environment with regular rooms sizes 10 meters x 10 meters (12 rooms)
- Office environment with open space - both have been selected for indoor ultra-dense networks evaluation.
- Outdoor environment 3x3 buildings for outdoor pico nodes evaluation. Scheme is based on [METIS13-D61] TC2 model
- Outdoor environment with realistic buildings distribution.

For TC2 evaluation three environments together with models will be described further in subsections.

Deployment considerations

For TC2 evaluation we consider:

- Ultra dense small cells deployments for indoor and outdoor environment
- Pico deployments for outdoor environment
- Macro deployments for wider area dense urban information society

Specific details are provided for each environment in relevant subsection.

Propagation model

For small cells outdoor studies, we use METIS model described in [METIS13-D61] as Propagation Scenario number 1 (PS#1).

For the ultra-dense networks coverage we use PS#7 with and without walls attenuation from the same source. For macro deployments, PS#3 is used.

Traffic model

The FTP-traffic model described in [METIS13-D61] is used, adapting the reading time to achieve the desired data rates.

Mobility model

The users are stationary for the duration of the simulation.

A.2.4 Technology components

Technology components used directly in the evaluation of TC2 are listed in Table A-4.

Table A-4: Main technology components evaluated in TC2 simulations.

WP/Taks	TeC	Name
WP2	TeCC1.1	Air interface in dense deployments – Frame structure
WP2	TeCC1.2	Air interface in dense deployments – Dynamic TDD
WP2	TeCC1.3	Air interface in dense deployments – Harmonized OFDM
T4.1	TeC6-A1	Coordinated fast uplink downlink resource allocation in UDN
T4.2	TeC17	Downlink multi-User SCMA (MU-SCMA) for mobility-robust and high-data rate MN-M

The principle advantages of the TeC's are listed below:

WP2-TeCC1.1 Air interface in dense deployments – Frame structure

- Provides reduced transmission latency (TTI = 0.25 ms and ≈1 ms HARQ cycle for cmW)
- Allows very efficient wideband transmission e.g. 100 MHz to single user

WP2-TeCC1.2 Air interface in dense deployments – Dynamic TDD

- Flexibility in UL/DL resource allocation allows full bandwidth allocation and adaptation to burst traffic.
- Very efficient dynamic switching between UL and DL phase, is implemented due the optimisation for short distance communication (up to 150 meters cell range) by significant reduction of guard periods
- Enables continues control signalling flow due to the fast switching

WP2-TeCC1.3 Air interface in dense deployments – Harmonized OFDM

- Physical layer numerology requires scalability to offer support for multiple carrier frequencies and frequency bands: subcarrier spacing increase due to the phase noise and cyclic prefix length decrease due to the shortened delay spread

T4.1-TeC6-A1 Coordinated fast uplink downlink resource allocation in UDN

- Utilise directly benefits of the WP2-TeC1.1.3
- In fully dynamic TDD resource allocation without any coordination it is very likely that constellation of interfering nodes and terminal will result in transmissions with very poor SINR conditions.

T4.2-TeC17: Downlink multi-User SCMA (MU-SCMA) for mobility-robust and high-data rate MN-M

- offers better spectrum efficiency due to shaping gain of multi-dimensional constellations and allows overloaded non-orthogonal multiple access due to sparsity of codewords
- contributes towards the more efficient resource utilization and user multiplexing in code/power domains
- reduces of the overhead caused by dynamic multi-TP CSI feedback
- significantly increases of the robustness to channel aging
- enables UE-centric open-loop CoMP for UDN in which interference management and frequent handover is challenging

A.2.5 Assumptions

The common assumptions are listed in this section. However, deployment specific assumptions are included in specific subsections A.2.6.

This evaluation is performed for lower bands for dmW and cmW range (2.6 - 15 GHz) In comparison to TC1 the main assumption was to evaluate mmW. To make a fair comparison we assume spectrum available for transmission on the level of 200 MHz for each evaluated approaches, however the offered traffic is scaled down to the band actually included in the simulation. The evaluation is performed in the way that simulations where the evaluation KPI is experienced user data rate in UL & DL.

The performed simulation studies focus on three approaches:

Approach 1: The WP2-TeC1.3 and T4.1-TeC6-A1 defines first evaluation approach and is trying to answer following questions:

- What level of improvement can be expected by applying of the dynamic TDD with distributed/central resource allocation /user scheduling?
- How sensitive are these gains for different deployments / environments (e.g. in case of high and low cell isolation)?
- Can we minimize degradation or can we gain any performance improvements if we apply sophisticated fully centralized resource allocation?

Approach 2: T4.2-TeC17 defines second evaluation approach for TC2 evaluation and is trying to answer following question:

- What performance improvement can be achieved simply by applying open loop SCMA scheme on top of OFDM modulation in case of CoMP and non CoMP transmission modes?

- Is SCMA helping to simplified interference management especially in high load cases?

Approach 3: Is a capacity/user performance study comparing legacy technologies, evolution of legacy systems towards higher frequencies in cmW and revolutionary 5G MBB system utilising 5G features in cmW and answers following questions:

- What are the limitations of legacy systems like LTE-A in fulfilling TC2 requirements?
- Is it possible from capacity point of view to fulfil TC2 requirements only by straightforward extension to LTE-A to cmW or is it necessary to use 5G MBB features?
- Is it possible to cover most of the TC2 traffic data volume by macro networks only?

A.2.6 Evaluation of approach 1 in indoor UDN deployments

Deployment and assumptions

For approach 1 evaluation is done in indoor UDN deployment. For this purpose, we define exemplary TC2 like indoor environment limited to the single floor of the building 30x40 meters. There are 12 rooms in high isolation scenario (HighIS) or it is 1200 m^2 open space in low isolation scenario (LowIS). The scenario assumes those access nodes are deployed in the centre of each room in HighIS or exactly on the same coordinates in case of LowIS. Users' positions are fixed and they do not change between High or LowIS. There are 36 UEs in total equally distributed in each room. This scenario is assumed to be isolated from outside interferences. Scenario is depicted on Figure A-8. Table A-5 shows numerical assumptions.

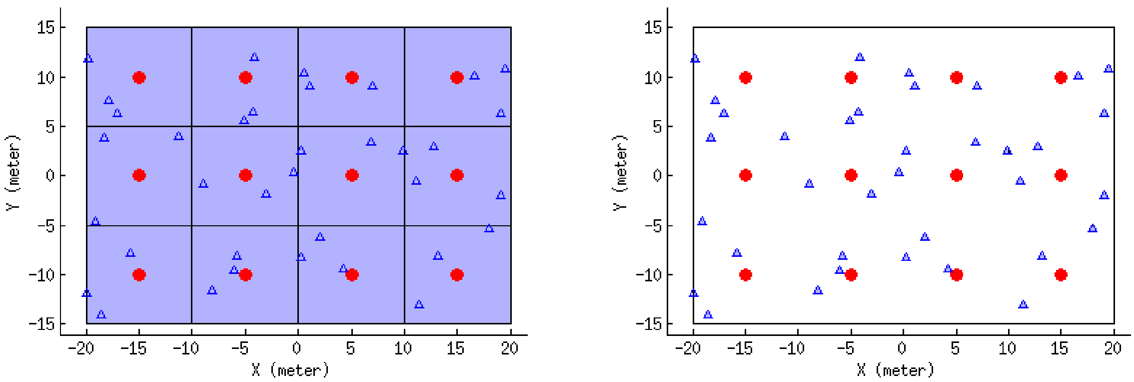

Figure A-8: Indoor deployment with high and low isolation (AP's isolated by walls).

Results

The key performance indicator for TC2 is putted on the experienced user data rate. According to the [METIS13-D61] the definition of this metric is a packet size divided by actual time of the packet delivery.

The KPI should be met in 95% of cases so consequently metric must be set on 5 percentile of user throughput or as an equivalent on the 95 percentile packets delay.

Table A-5: Simulation assumption for indoor TC2 evaluation.

Parameter	Assumption
Carrier frequency	2.6 GHz
System bandwidth	20 MHz
Frame structure	WP2-TeCC1 TTI = 0.25 ms
Tx /Rx scheme	Flexible TDD, SU-MIMO 2x2 IRC, SVD Precoding optimized per individual user.
Scheduling schemes	Flexibility/ Centralization options a) Local with fixed TDD; UL/DL resources 1:4 b) Centralized fixed TDD; UL/DL resources 1:4 c) Local with flexible TDD d) Centralized with flexible TDD Proportional fair scheduler takes in to account max packet delay and CQI/CSI for calculation of individual user scheduling metric. Scheduler performs wide band resource allocation.
Pathloss model	PS#7 with wall attenuation: High cells isolation scenario / Separated rooms: 5 dB Low cell isolation scenario / Open space: 0 dB
Fast fading	Flat channel
Users indoor	3 UEs / 100 m^2
Deployments	Single floor : 12x rooms 10 m x 10 m or 1200 m^2 of open space 1, 0.5, 0.25 AP/room ; room or equivalent 100 m^2
Traffic	Packets size 64, 96, 128, 160, 192, 256 kB Packets mean arrival time: DL 0.1 sec. / UL 0.4 sec. Packets are not dropped from the buffer.

In this evaluation, we show cumulative distributions of packet delays for multiple packet sizes using four scheduling options in high and low isolation scenario. Table A-6 shows dependencies between packet sizes used in evaluations, offered load per AP and per entire area. Table includes also value of the packet delay required to achieve user experienced throughput on the level of 300 Mbps and 60 Mbps in DL and UL respectively.

Table A-6: Offered total traffic load in 200 MHz bandwidth.

Packets size [kB]	Offered traffic per AP [Mbps]	Offered traffic in the evaluation area [Mbps]	Max Packet delay for 300 Mbps of experienced user Tput in DL [ms]	Max Packet delay for 60 Mbps of experienced user Tput in UL [ms]
64	192	2304	17	87
96	288	3456	26	128
128	384	4608	34	171
160	480	5760	43	213
192	576	6912	51	256
256	768	9216	68	341

The exemplary results of cumulative distribution for DL and UL packet delay for a packet size 128 kB are depicted on Figure A-9-10.

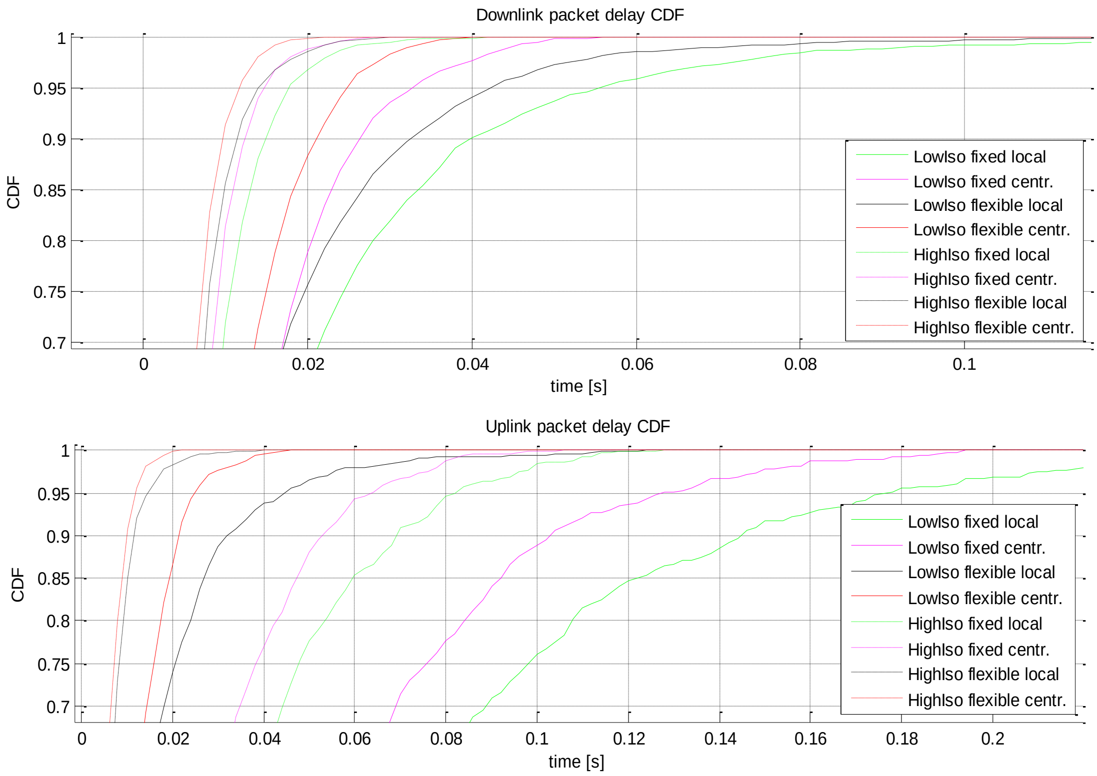

Figure A-9: Exemplary DL and UL packet delay cumulative distribution for packet size 128 kB and high (dashed) and low (solid) cell isolation scenarios and four scheduling options.

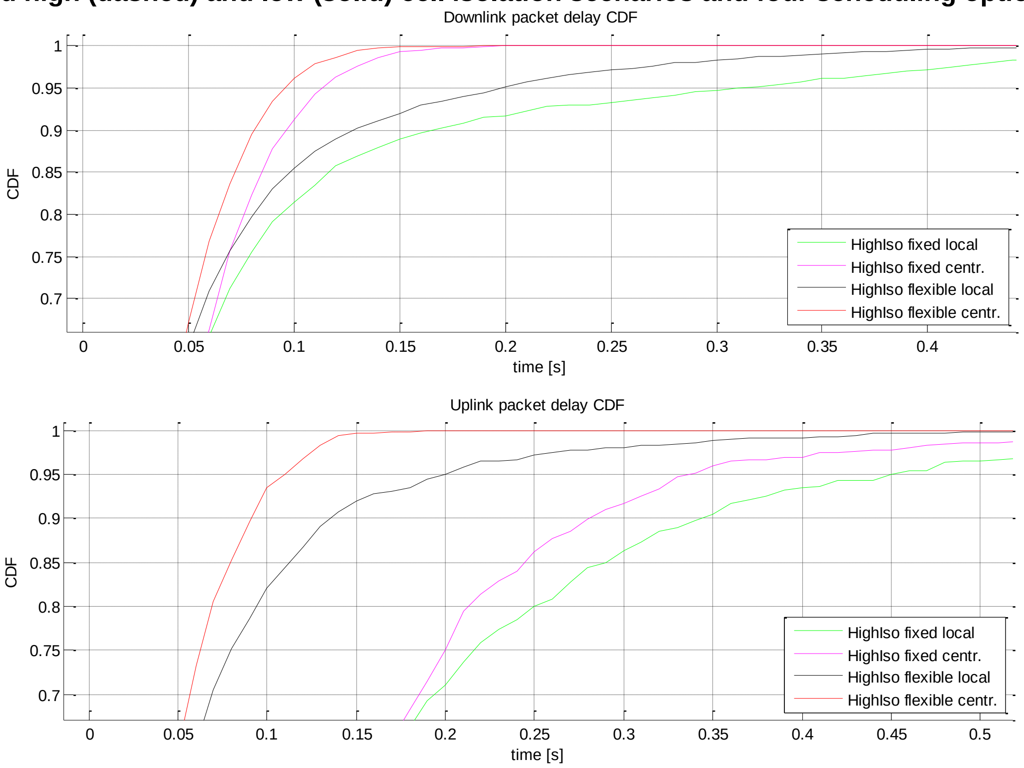

Figure A-10: Exemplary DL and UL packet delay distribution for packet size 256 kB and high cells isolation and four scheduling options (for low isolation delay requirements are not fulfilled for this amount of traffic).

Exemplary results indicate behaviours that are visible in all following results presented in tables below:

- In case of low cell isolation scenario (LowIS) interference is becoming a major difficulty for the system. Because of this reason 95% packet delay increase up to 2.5 times in comparison to HighIS.
- Results for the centralised scheduling and resource allocation are always outperforming local scheduling (resources assigned individually by each AP).
- Due to the disproportion of resource allocation between UL and DL resources (1:4) the gain from the enabling dynamic TDD is always significantly higher. WP2-TeCC1 enables flexible access to the all resources in short period of time while fixed allocation decreases average link capacity 5 times. In case of DL results benefits are visible in smaller extent – only 20% more resources can be used. This effect is clearly visible on the median packet delay.
- The increase of packet size from 128 kB to 256 kB (and offered load from 4.6 Gbps to 9.2 Gbps in entire area) increased packet delay 10x in HighIS and far beyond required delay in LowIS. Mentioned packet sizes are maximum packet sizes(offered load) when delay requirements and main KPI of experienced user data rate is fulfilled it is 128 kB and 256 kB for low and high IS. However thanks to the centralisation and flexible TDD these limits can be moved further in some case even for 20-30%.

Table A-7: High cell isolation – DL/UL Packet delay [s] and delay reduction for 1 AP per 100 m^2.

Packet size [kB]	max delay DL [s]	High Isolation “separated rooms” Downlilnk							
		1	2	3	4	delay reduction			
		fixed local	fixed centr.	flex.local	flex. centr.	1-2	1-3	2-4	3-4
96	0.026	-	-	-	-	-	-	-	-
128	0.034	0.018	0.015	0.014	0.012	18%	22%	21%	17%
160	0.043	0.030	0.025	0.024	0.019	17%	19%	24%	23%
192	0.051	0.050	0.040	0.039	0.031	21%	23%	23%	21%
224	0.060	0.086	0.064	0.066	0.05	26%	23%	22%	24%
256	0.068	0.310	0.115	0.200	0.095	63%	35%	17%	53%

Packet size [kB]	max delay DL [s]	High Isolation “separated rooms” Uplilnk							
		1	2	3	4	delay reduction			
		fixed local	fixed centr.	flex.local	flex. centr.	1-2	1-3	2-4	3-4
96	0.128	-	-	-	-	-	-	-	-
128	0.171	0.082	0.064	0.014	0.012	22%	83%	82%	16%
160	0.213	0.112	0.098	0.026	0.020	13%	77%	80%	23%
192	0.256	0.174	0.146	0.040	0.031	16%	77%	79%	23%
224	0.294	0.254	0.208	0.068	0.052	18%	73%	75%	24%
256	0.341	0.450	0.340	0.200	0.110	24%	56%	68%	45%

colors: green indicate dele below max packed delay related with exp. user rate KPI DL 300 Mbps / UL 60 Mbps; orange – up to 150% of max delay; red more than 150% of max delay

The full set of simulation results for packet delay is shown in Table A-7-8. In tables we also indicated percentage gains 1-2) coming from introduction of centralization to fixed TDD, 1-3) gains introduced by applying flexible/dynamic TDD and 2-4 & 3-4) indication of gains from applying both enhancements in the same time. On Figures A 11-14 we present 95% packet delay vs. packet size as an outcome of the simulation results. In Table A-9 we have provide the resource utilization corresponding to Table A-7-8.

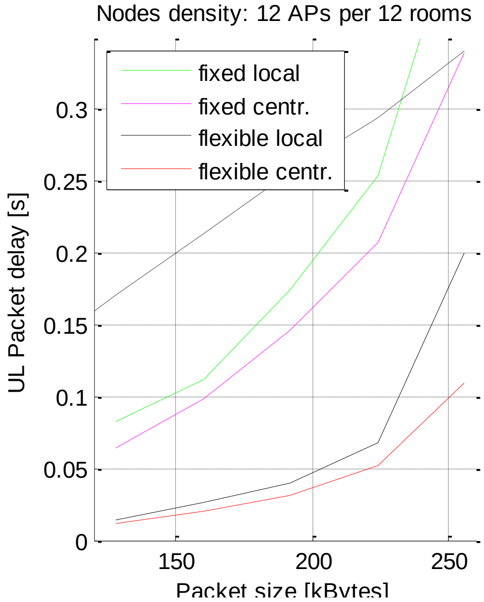

Figure A-11: High isolation UL packet delay vs. packet size.

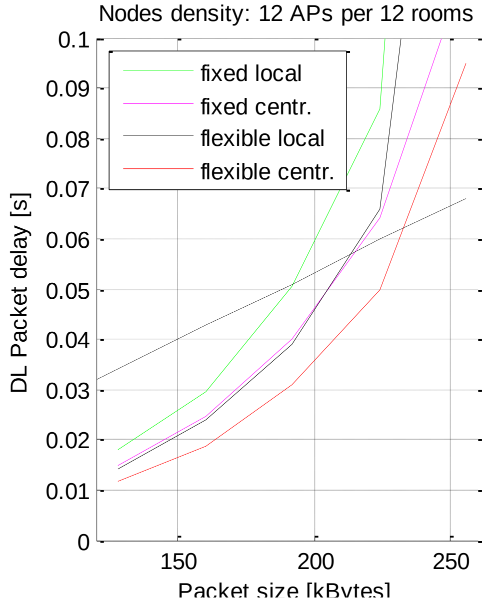

Figure A-12: High isolation DL packet delay vs. packet size.

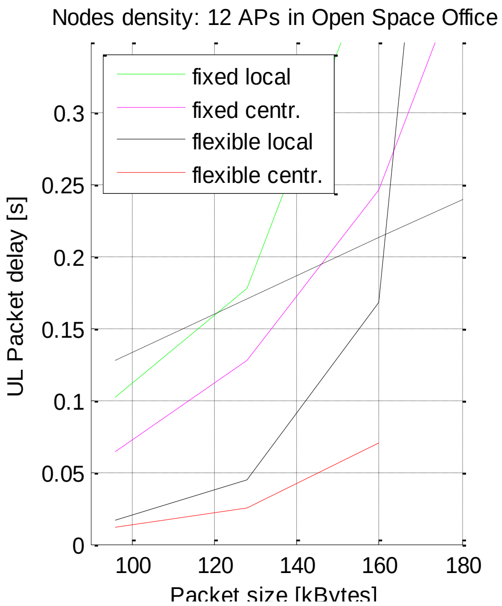

Figure A-13: Low isolation scenario 1AP/100m^2 UL packet delays vs. packet sizes.

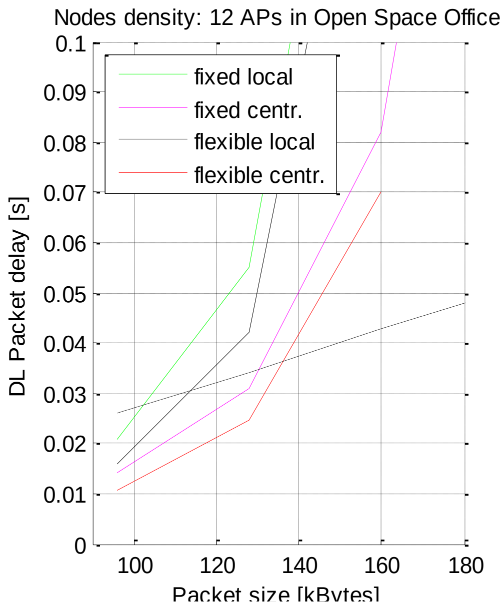

Figure A-14: Low Isolation 1AP/100m^2 scenario DL packet delays vs. packet sizes.

Table A-8: Low cell isolation "open space" – DL/UL Packet delay[s] and delay reduction for 1AP per 100m2.

Packet size [kB]	max delay DL [s]	**Low Isolation "open space" Downlink**							
		1	2	3	4	delay reduction			
		fixed local	fixed centr.	flex.local	flex. centr.	1-2	1-3	2-4	3-4
96	0.026	0.021	0.014	0.016	0.011	33%	24%	23%	32%
128	0.034	0.055	0.031	0.042	0.025	44%	24%	20%	41%
160	0.043	0.198	0.082	0.174	0.070	59%	12%	15%	60%
192	0.051	1.540	0.246	1.420	-	84%	8%	-	-
224	0.060	1.768	0.848	1.8	-	52%	-2%	-	-
256	0.068	3.148	1.960	3.148	-	38%	0%	-	-

Packet size [kB]	max delay DL [s]	Low Isolation "open space" **Uplink**							
		1	2	3	4	delay reduction			
		fixed local	fixed centr.	flex.local	flex. centr.	1-2	1-3	2-4	3-4
96	0.128	0.102	0.064	0.016	0.011	37%	84%	82%	28%
128	0.171	0.178	0.128	0.045	0.025	28%	75%	81%	45%
160	0.213	0.420	0.246	0.168	0.070	41%	60%	72%	58%
192	0.256	1.500	0.494	1.144	-	67%	24%	-	-
224	0.294	2.2	1.116	1.4	-	49%	36%	-	-
256	0.341	2.978	1.968	2.140	-	34%	28%	-	-

colors: green indicate dele below max packed delay related with exp. user rate KPI DL 300 Mbps / UL 60Mbps; orange – up to 150% of max delay ; red more than 150% of max delay

Table A-9: Physical layer resource utilization.

	High Isolation separated rooms				Low Isolation open space			
	1	2	3	4	1	2	3	4
Packet size [kB]	fixed local	fixed centr.	flex.local	flex. centr.	fixed local	fixed centr.	flex.local	flex. centr.
96	-	-	-	-	26%	18%	25%	17%
128	41%	26%	41%	25%	24%	20%	24%	20%
160	33%	26%	32%	26%	65%	42%	65%	39%
192	42%	34%	42%	33%	82%	68%	83%	-
256	76%	66%	79%	67%	97%	94%	98%	-

Below we provide answers to the questions from Section A.2.5.

- What level of improvement can be expected by applying the dynamic TDD with distributed/local resource allocation /user scheduling?

  As expected, the highest gains are indicated by UL results (30-80% delay reduction) The gain comes from the full utilisation of the resources in case of dynamic TDD while in the fixed TDD proportions are set 1:4 accordingly to expected differences in averaged traffic load in UL&DL. In DL gains are moderate (0-30% of delay reduction). Interesting observation is that gains decline proportionally to the packet size or higher AI utilisation. Second interesting observation is that introduction of the dynamic TDD to already centralised network result in very similar performance improvement.

- How sensitive are these gains for different deployments / environments (e.g. in case of high and low cell isolation)?

  The results for high and low cell isolation indicate similar performance improvement.

- Can we gain any performance improvements if we apply sophisticated fully centralized resource allocation? Is it possible to mitigate all types interference in the system (inter cell, cross link)?

  The gain from introduction of the centralised resource allocation and interference management is visible for fixed and flexible TDD in similar level. Gains increase with the increase of the offered load (PHY layer utilization) and vary between (20-60 %). Analysing results for high and low cell isolation we conclude that, for similar PHY layer utilisation, gains are slightly higher for LowIS (40-60 %) than HighIS (20-40 %). Gains in UL& DL are in general on the equal level.

The next step of this evaluation is related with impact of the nodes density on the overall network performance and user experienced data rates.

For this purpose ISD between cells have been increased from 10 m to 20 and 33 meters and in evaluation area we simulate 6 and 3 APs respectively. For clearness, results are presented in the final form as user experienced throughput vs. load in the considered area.

The scenario requirement the traffic volume per area according to TC2 definition is defined as 0.7 Tbps/km^2. However, in this evaluation we are capable to fulfil user experience rates with data volume equal to 4-6 Gbps in an area of 0.0012 km^2 (40 meters x 30 meters) and that correspond to 3.3 to 5 Tbps/km^2 on 200 MHz in open space area (assuming 10 meters ISD). With similar ISD but with 5 dB isolation between APs and locating APs every room we can achieve even higher rates between 7-9 Gbps on 200 MHz. With decrease of the nodes density we observe acceptable load level decrease proportional to ≈1/sqrt(2). However, we still fulfil requirement for TC2 where most of the traffic demand is located in indoor environment.

The result is presented in short form in Table A-10.

Table A-10: Total load per considered area fulfilling TC2 requirements on 200 MHz BW for DL.

ISD	Nodes density	Open space (min max performance) [Gbps]		Isolated rooms (min max performance) [Gbps]	
10m	1	4	6	7	9
20m	0.5	2.7	3.5	4	5.5
37m	0.25	2.2	2.95	2.95	4

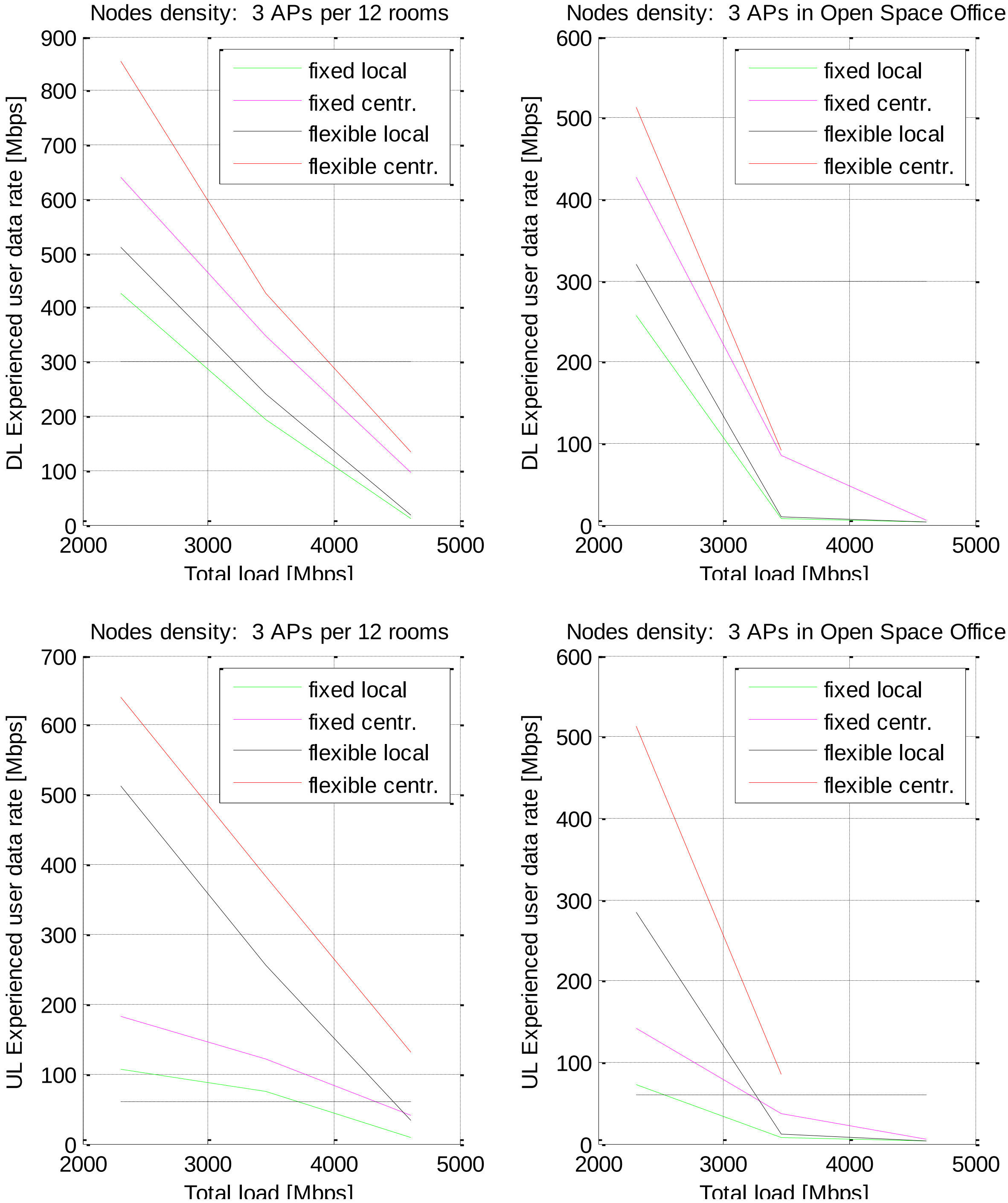

Figure A-15: Experienced user data rate vs. total load in the network for fixed and flexible AI / local and centralized scheduling for 3 AP in the area = density 0.25 AP/room.

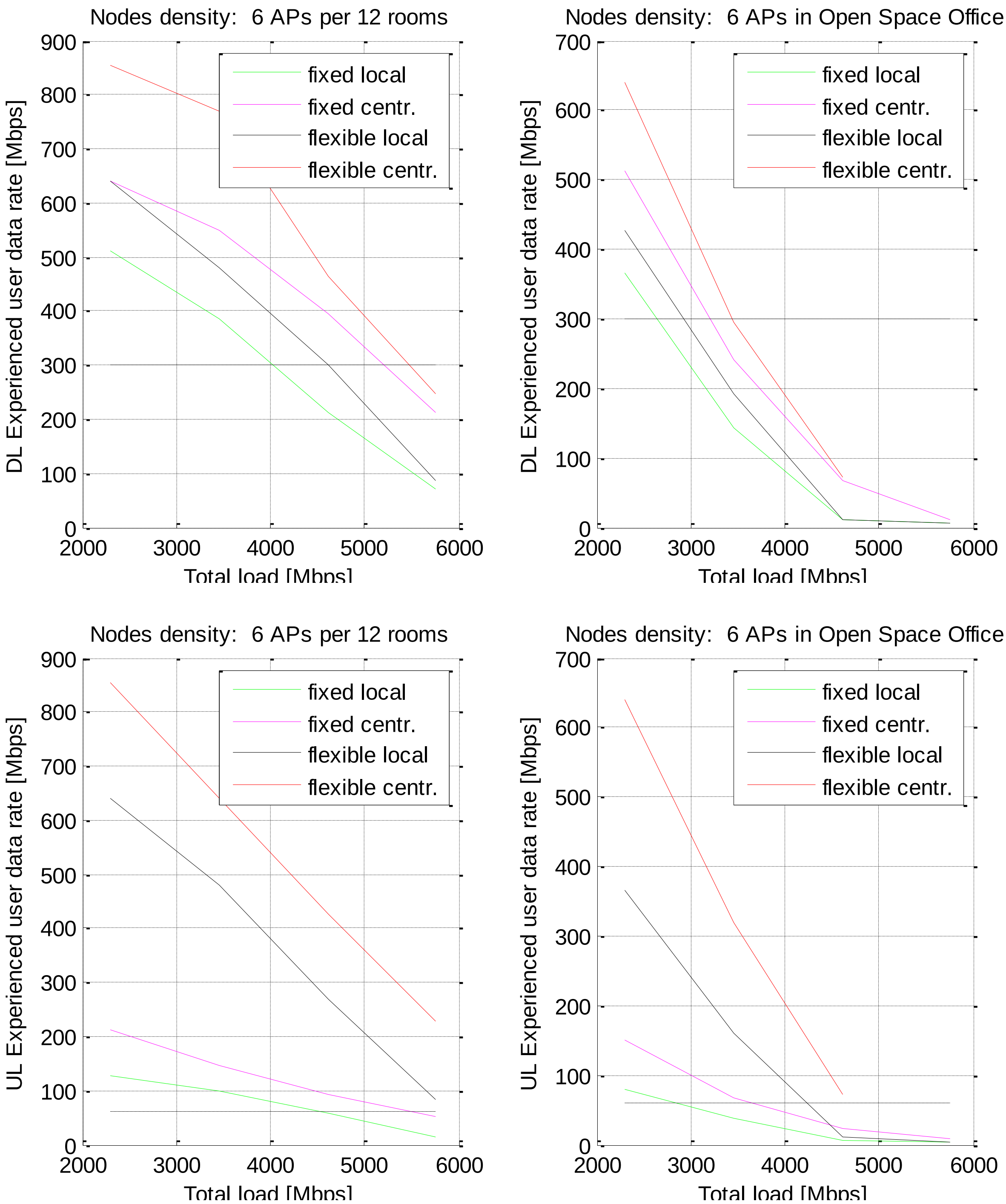

Figure A-16: Experienced user data rate vs. total load in the network for fixed and flexible AI / local and centralized scheduling for 6 AP in the area = density 0.5 AP/room.

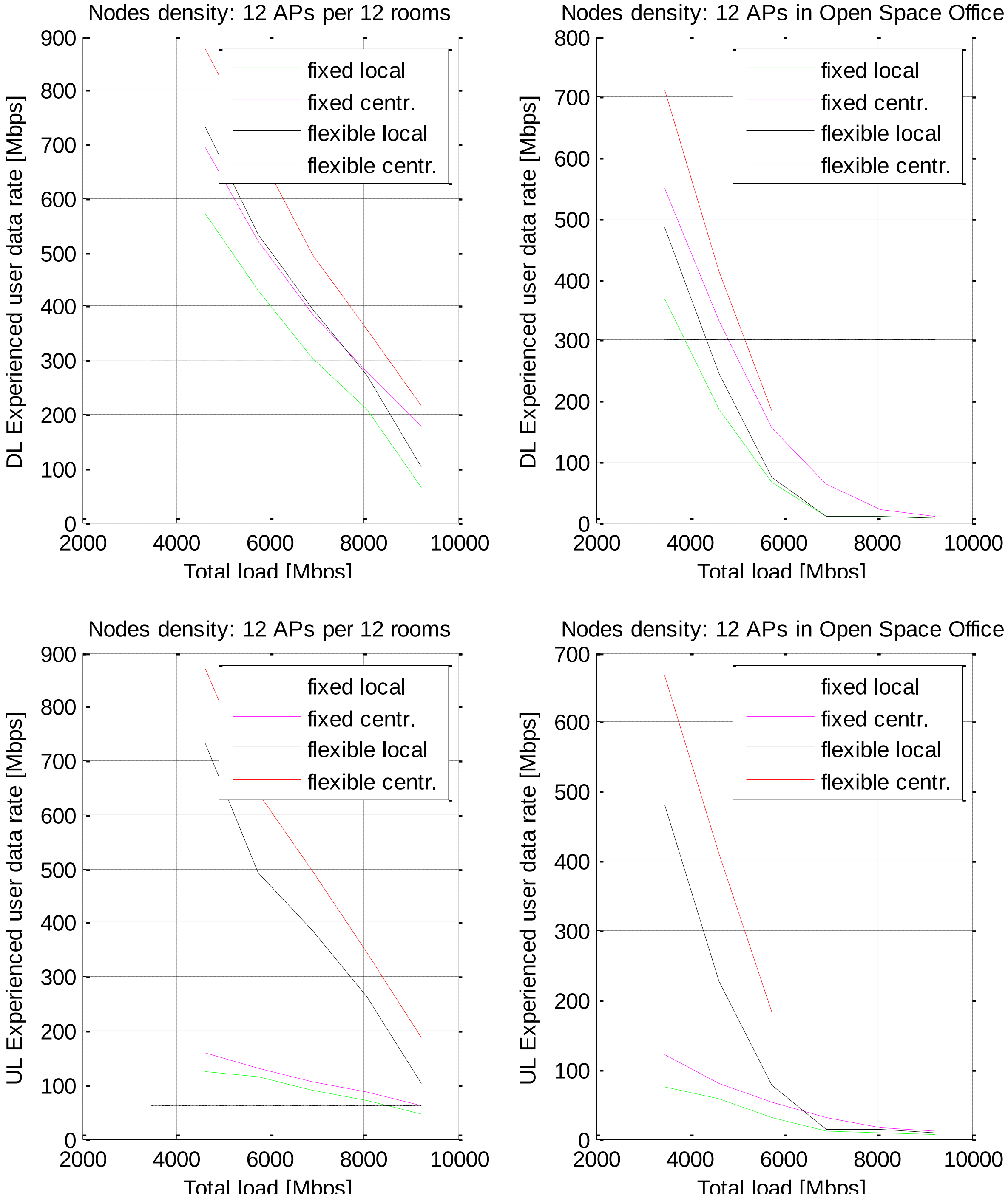

Figure A-17: Experienced user data rate vs. total load in the network for fixed and flexible AI / local and centralized scheduling for 12 AP in the area = density 1 AP/room.

A.2.7 Results for outdoor TC2 pico deployments

Deployment and assumptions

In this case we focus on a simplification of the outdoor part of TC2, including only 9 blocks distributed in a 3x3 grid, as represented in Figure A-18. The other assumptions in this simulations are summarized in Table A-11.

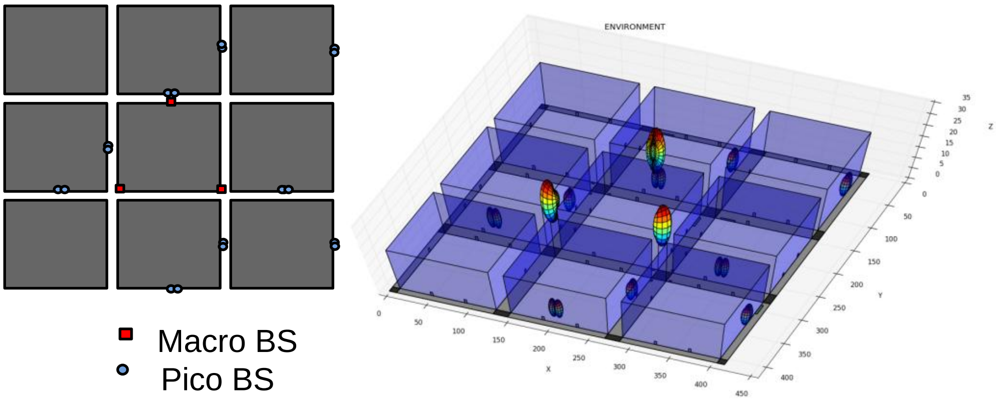

Figure A-18: Deployment assumption for the second approach.

Table A-11: Main assumptions in the scenario.

Parameter	Value
Deployment	Simplified Madrid grid with wrap around, 18 pico cells with outdoor users only
Number of users	Average 10 users per cell
TP transmission power	28 dBm for micro cell
CoMP size	2
Traffic model	FTP2 non-full buffer or full buffer traffic
Packet inter-arrival time	Average 1 s with exponential distribution
Number of transmit antennas	2 uncorrelated antennas
Number of receive antennas	2 uncorrelated antennas
System bandwidth	10 MHz at 2.6 GHz carrier frequency
Channel type	Rayleigh fading channel with 10-tap freq. selectivity
Transmission Mode	2×2 SM or 2x2 SFBC, open-loop
User speed	3 km/h and 50 km/h
HARQ	Incremental redundancy (IR) HARQ with up to 4 retransmissions
Scheduler	Proportional fair scheduler or weighted sum-rate scheduler
RBG size for scheduling	50 RBs for wideband scheduling
Waveform	MU-SCMA, OFDMA
SCMA codeword dimension	4 OFDMA tones
Detection	MPA for SCMA and MLD for OFDMA
CQI feedback	Perfect CQI. Feedback report every 10 TTIs.
OLLA	Enabled with 10% BLER for first transmission

Results

Results analyse the performance of Multi-user SCMA as compared with OFDMA. Both approach utilizes 2x2 open loop spatial multiplexing MIMO. SCMA allows for code multiplexing of the users using SCMA codewords of length 4 OFDM tones each. Multiple codewords are spanned over 10 MHz system bandwidth with 50 RBs. For OFDMA also a wideband scheduling (50 RBs) is assumed. The results are provided for system with and without CoMP transmission in open loop mode.

The system-level simulation results are shown in Table A-12 for cell aggregate throughput and cell edge throughput with full buffer traffic, for both SM and Alamouti transmission modes. The transmission modes are evaluated for low speed (3 km/h) and high speed (50 km/h) scenarios. Due to fast variation of the channel and interference, the performance of the system drops for high speed case. However, the relative gain of MU-SCMA over OFDMA maintains even for high speed scenario where the closed-loop multiple access schemes such as MU-MIMO fails due to the channel aging effect.

Table A-12: System-level simulation results comparing DL OFDMA and DL MU-SCMA for low and high speed users and SM and Alamouti transmission modes with full buffer traffic.

			Throughput (Mbps)	Coverage (Kbps)	TP Gain	Cov. Gain
3 km/h	2×2 SM	OFDMA	44.41	417.6		
		MU-SCMA	55.19	548.2	24.3%	31.3%
	2×2 SFBC	OFDMA	30.13	377.6		
		MU-SCMA	45.86	605.7	52.2%	60.4%
50km/h	2×2 SM	OFDMA	41.28	318.7		
		MU-SCMA	50.8	442.3	23.1%	38.8%
	2×2 SFBC	OFDMA	29.19	292.4		
		MU-SCMA	43.17	502.8	47.9%	72.0%

The relative throughput and coverage gains of MU-SCMA over OFDMA are shown in Figure A-19 for low and high speed cases. As illustrated in this figure, the relative gain is stable regardless of the user speed. The relative gain is between 23-39% for SM mode and 48-72% for Alamouti mode. These results confirm the capability of MU-SCMA to provide high throughput and high quality of user experience independent of the users' mobility status and their speeds.

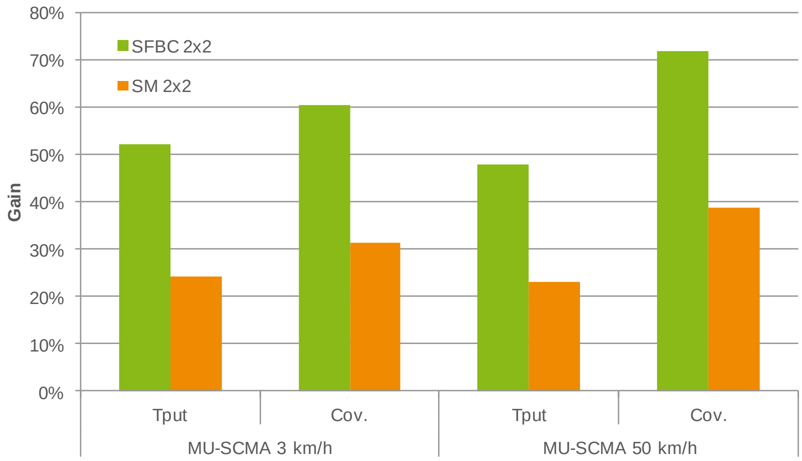

Figure A-19: Performance gain of DL MU-SCMA over DL OFDMA for low and high speed scenarios with full buffer traffic.

Fo the non-full buffer traffic, first we show the percentage of packets delivered in due time (<0.5s) for different traffic loads in Figure A-19 and Table A-13.

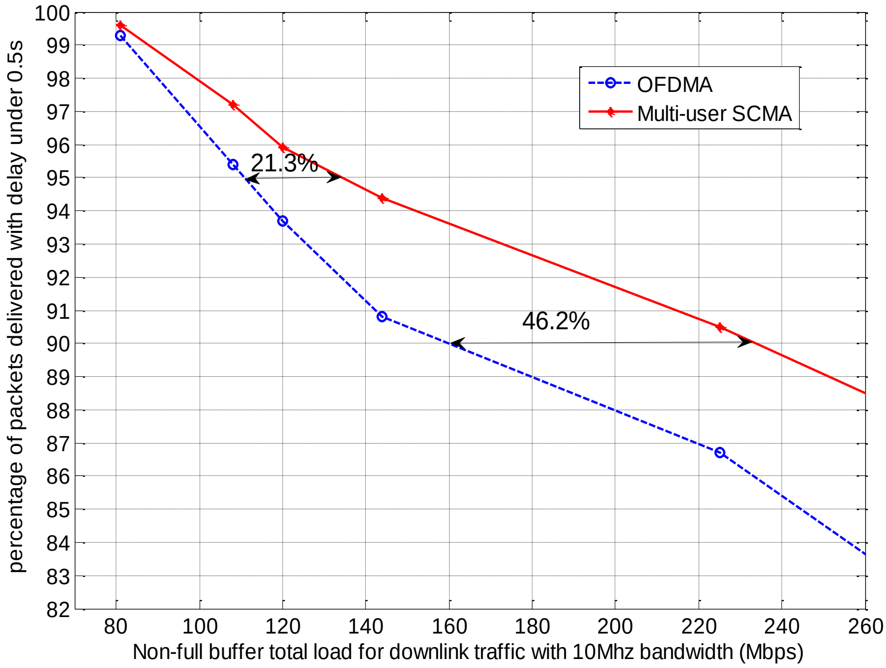

Figure A-20: Packets delivered in due time for different technologies and traffic.

Table A-13: Summary of results. Supported total load at 10 MHz (Mbps) for the following percentage of successful packet delivery with 0.5 s delay.

	95% packet delivery w/ <0.5 s delay	90% packet delivery w/ <0.5 s delay
OFDMA	110.9	159.6
Multi-user SCMA	134.4	233.7
Gain	21.3%	46.2%

In considered setup MU-SCMA provided a significant gain over OFDMA which manifests in the cell edge performance. These results are captured in Figure A-16, which shows packet delivery with delay below 0.5 s, comparing SU-OFDMA w/o CoMP with open loop MU-SCMA/CoMP. Assuming 0.5 s delay requirement for 95% of packets, MU-SCMA can support more than 21% further load compared to OFDMA. This gain sufficiently increase if we relax delay requirement to 90%. Note that here the load is evaluated for 10 MHz system bandwidth. The load can proportionally increase with bandwidth while the delay profile still maintains unchanged.

Looking in more details to the delay distribution (see Figure A-21 and Table A-14), we can conclude that more than 107% perceived throughput gain at 95th%tile throughput CDF and, among the packets that satisfy 0.5 delay, MU-SCMA delivers packets much faster than OFDMA. It is characteristic that SCMA and OFDMA meet the requirement for more than 70% of transmitted packets. Results indicate cut off value of the delay beyond the performance results saturates at the fixed level between this two analysed access technologies. If PF scheduler is replaced with a better criterion, which takes into account the latency in packet prioritization, it can improve the overall latency and the perceived throughput of the system.

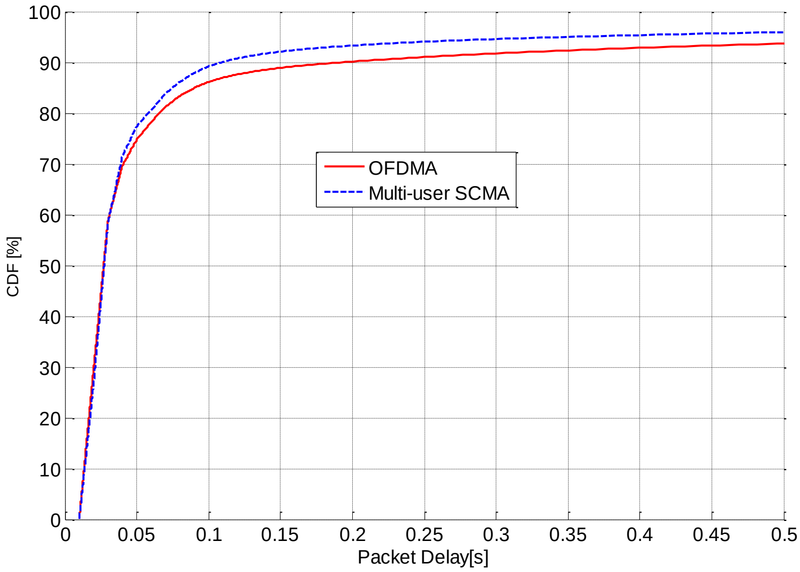

Figure A-21: CDF distribution of packet delay for OFDMA and MU-SCMA.

Table A-14: Summary of CDF delay for total traffic load = 120 Mbps at 10 MHz bandwidth.

Perceived throughput (Mbps)	At 5th %tile of throughput CDF	At 10th %tile of throughput CDF
OFDMA	0.91	3.45
MU SCMA	1.89	6.09
Gain	107.6%	76.2%

Next, Figure A-22 shows the comparison between MU-SCMA/CoMP and OFDMA-CoMP, looking at the impact of load in the system performance. Table A-15 summarizes the supported load for the different assumptions. Figure A-22 depicts the percentage of packets that can be delivered within 0.5 s for different traffic loads. Considering the criteria of 95% of delivered packets, MU-SCMA can support ≈83% and 14% higher load comparing to OFDMA and OFDMA-CoMP, respectively. When we relax this criterion to 90% of delivered packets, MU-SCMA supports 68% higher load than OFDMA and 13% for OFDMA–CoMP.

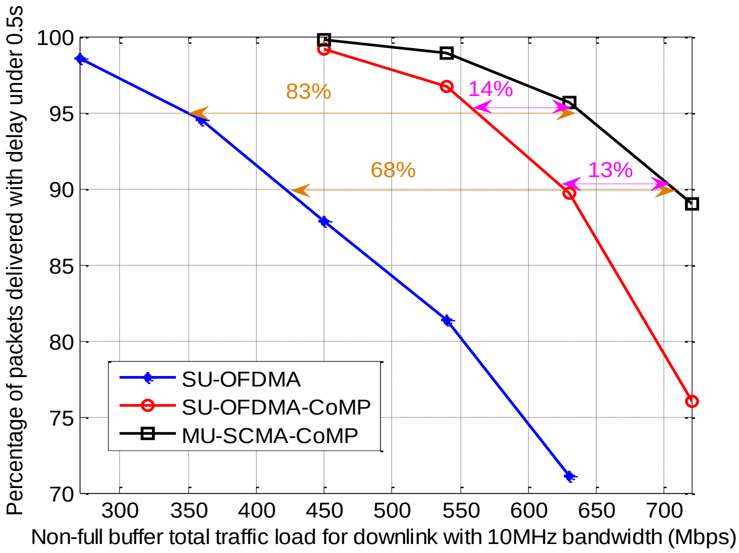

Figure A-22: Percentage of packets delivered in due time for OFDMA and MU-SCMA with CoMP.

Table A-15: Summary of supported load at 10 MHz for different points in the delay CDF. Supported total load at 10 MHz (Mbps) for the following percentage of successful packet delivery with 0.5 s delay.

	95% packet delivery w/ <0.5 s delay	90% packet delivery w/ <0.5 s delay
OFDMA	349	420
OFDMA-CoMP	561.5	625.5
MU-SCMA/CoMP	639.1	706.3
Gain over OFDMA	83.1%	68.2%
Gain over OFDMA-CoMP	13.8%	12.9%

Notably, in this deployment scenario with outdoor users only with lower impact of interference, the gain of CoMP is limited. To show the benefit of MU-SCMA/CoMP in a more diverse scenario with mixed indoor and outdoor users, the full buffer traffic of mixed scenario is evaluated. Simulation results in terms of throughput and coverage gains are illustrated in Figure A-23 for full buffer traffic with MIMO transmission mode for low speed (3km/h) and high-speed (120 km/h) scenarios. It can be observed that the gain of DL MU-SCMA/CoMP over OFDMA and OFDMA-CoMP is high (30-35% throughput gain and 65-75% coverage gain), for both low and high-speed users. Furthermore, the gain of DL MU-SCMA/CoMP over OFDMA baselines is even higher for high speed scenario which implies MU-SCMA/CoMP is more robust against the user mobility compared to OFDMA.

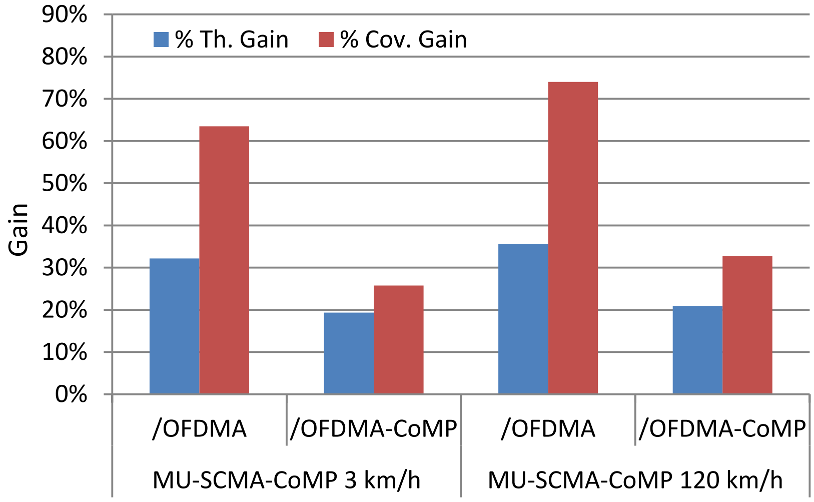

Figure A-23: Gain of MU-SCMA/CoMP over OFDMA baselines for low speed and high speed scenarios.

A.2.8 Results for outdoor TC2 macro deployments

This last analysis of TC2 focuses on the macro-deployment and the performance in the outdoor part of the TC2 scenario. The aim is to study the impact of cmW in the system behaviour and the potential of this new band of spectrum with usage of antenna array for high beam forming gains.

Deployment and assumptions

The area is 2 km x 2 km with 1442 multi-floor buildings with different heights. No wrap around, but edge effects are handled by using a centrally located subset of all cells (with 1 km x 1 km) for performance evaluations. The centrally located subset environmental setting is given in Figure A-24. In this study, 80% of the traffic is assumed to be generated inside the buildings.

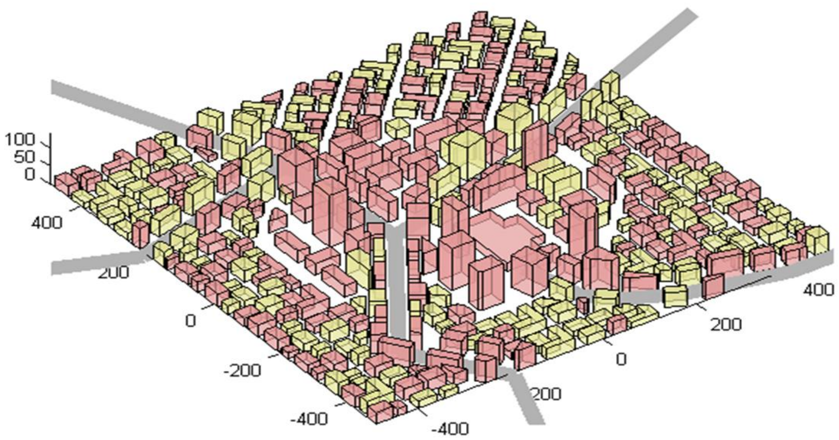

Figure A-24: The centrally located subset of all cells for performance evaluations (the yellow buildings are old while the red buildings are new).

In the evaluations the following two different network deployments have been considered:

- **Default deployment**: i) capacity layer (7 three-sector macro sites located at rooftop, i.e. 45 m), ii) coverage layer (28 three-sector macro sites located at rooftop, i.e., 30 m). The Default deployment is shown in Figure A-25.

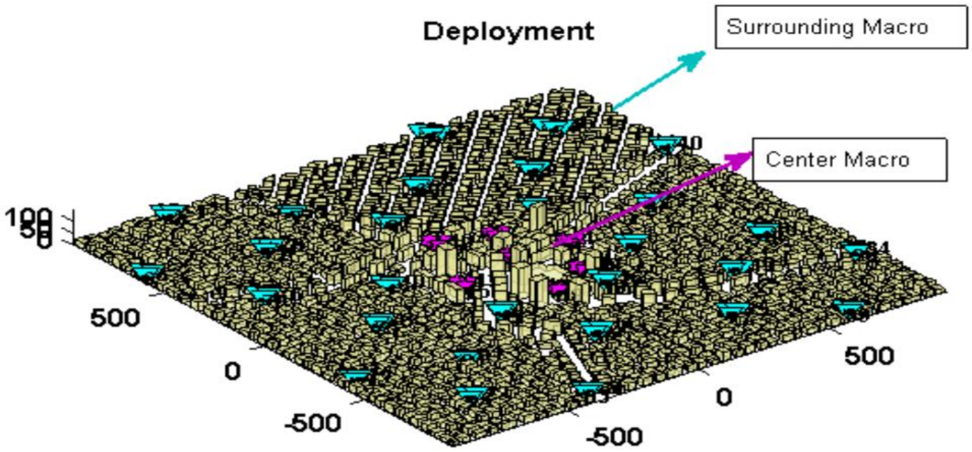

Figure A-25: The Network layout for Default deployment.

- **Densified deployment**: network deployment is densified by deploying new three-sector macro sites as shown in Figure A-26. More specifically, the capacity layer consists of 11 sites with an antenna height of 45 m, while the coverage layer consists of 89 sites with an antenna height of 30 m.

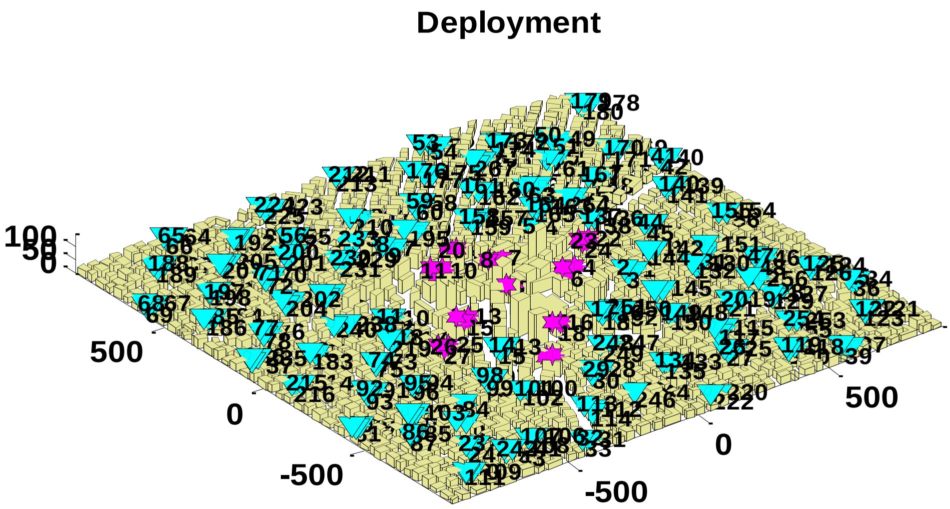

Figure A-26: Network layout of Densified deployment.

The simulation assumptions are summarized in Table A-16. Based on the simulation assumption above, the system is evaluated both in a baseline setting of LTE, 2.6 GHz, and in a setting with higher carrier frequency – which in this evaluation is 15 GHz.

Table A-16: Simulation assumptions.

	LTE@2.6	LTE@15	5GMBB@15
Bandwidth	20 MHz	100 MHz	100 MHz
Carrier frequency	2.6 GHz	15 GHz	15 GHz
Deployment	Terminals located at height 1.5m, 6000 user bins. 80% of the traffic is generated indoors.		
Propagation model	Frequency-dependent path loss model based on the Simulation guidelines [MET13-D61].		
Duplex Mode	TDD [Configuration 1]		
BS Antenna model	742215_fitted[2] (max Gain = 18dBi)	742215_fitted (max Gain = 18 dBi)	Antenna array[3]
Transmit powers	DL: 46 dBm		
	UL: 23dBm (maximum)		
Terminal Antenna model	Isotropic, antenna gain: -8 dbi	Isotropic, antenna gain: -8 dbi	isotropic antenna gain: 3 dbi
Number of UE Receive Antennas	2		
Number of UE Transmit Antennas	1	1	2
Beamforming at BS	No	No	UE-specific BF (GoB)
Noise figure	UL: 2.3 dB in macro BS DL: 9 dB in terminal		
Traffic	equal buffer, 1 000 000 users/km^2 and 40% market share, 16.67 busy hours per day		

The performance is evaluated for the following five different cases:

- Case 1: LTE@2.6 – Default deployment
- Case 2: LTE@15 – Default deployment
- Case 3: LTE@15 – Densified deployment
- Case 4: 5GMBB @15 – Default deployment
  - With 5x20 antenna array
- Case 5: 5GMBB@15 - Densified deployment
  - With 5x20 antenna array

Case 1 is LTE at 2.6 GHz carrier frequency (in default deployment). Case 2 is LTE at 15 GHz (in default deployment). Case 3 is LTE at 15 GHz carrier frequency (in

[2] Horizontal Half Power Beamwidth = 65, Front-To-Back Ratio = 25, Vertical Half Power Beamwidth = 6.5, Side Lobe Level = -17, Max Total Attenuation = 30

[3] Antenna array with different configuration: (5x20)

densified deployment). Case 4 is 5GMBB (beamforming capabilities) at 15 GHz (in default deployment). Case 5 is 5GMBB at 15 GHz (in densified deployment).
It is assumed that a single layer is transmitted/received per UE and polarization. Only single-user MIMO is considered. The beam grid is created by applying DFT vectors over the antenna elements. The beam-forming is separable in azimuth and elevation so that separate DFT vectors are applied over the antenna array columns and rows. In each antenna dimension (horizontal and vertical) the DFT is oversampled by a factor two, i.e., there are twice as many beams as antenna elements in each dimension. For a 5x20 array, this amounts to 400 beams in the grid. For each UE, the beam in the grid that gives the highest beam-forming gain is selected.

Results

In the following study TC2 like scenario for macro deployment was performed. In two parts, first we analyse user throughput for different radio access technology starting from LTE on 2.6, LTE on 15 GHz and going up to the 5G MMB like RAT on 15 GHz. Due to the poor pathloss condition on higher frequencies we also increase network density. In second part we provide results for carrier aggregation between LTE on 2.6 GHz and LTE or 5GMBB on 15 GHz.

Single RAT

Figure A-27 to Figure A-29 shows DL user throughput versus traffic (load) for the different simulation cases.

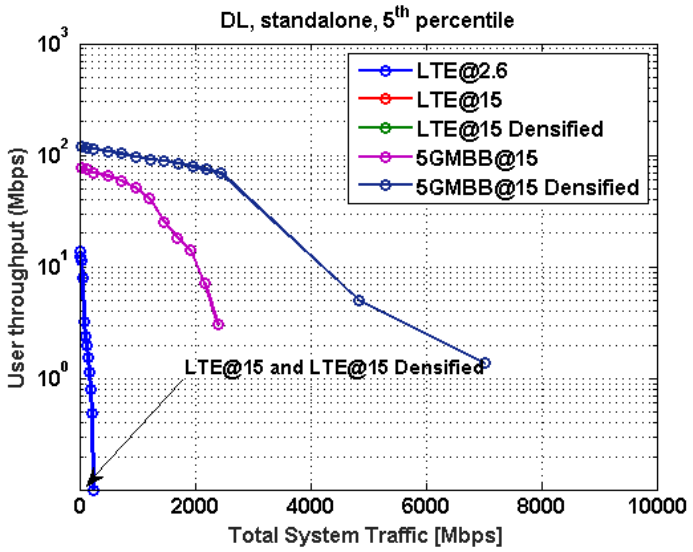

Figure A-27: DL user throughput vs. traffic for the simulation case 5%-ile.

The 5%-ile user throughput for LTE@15 is zero for both the default and densified deployments. This is due to that more than 5% of UEs are below the dropping threshold which is 56 kbps. LTE achieves 14 Mbps at low load but drops rapidly as the load increases. With 5GMBB and the default deployment the target throughput of 100 Mbps is not reached. At low traffic, 78 Mbps is achieved. With 5GMBB and the densified deployment that target throughput can be achieved up to total system traffic of 900 Mbps. The densification does not give a large improvement of the user throughput at low load, but gives a large increase in system capacity.

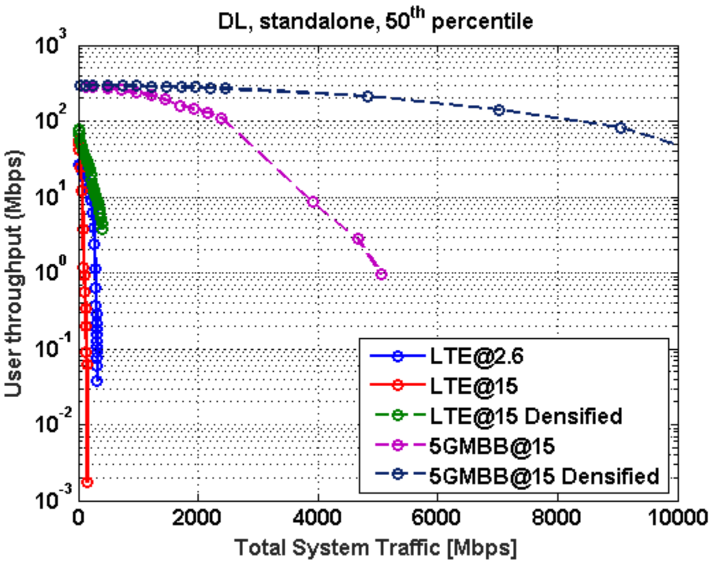

Figure A-28: DL user throughput vs. load for the simulation case 50%-ile.

At the 50%-ile, LTE@15 outperforms LTE@2.6 at low traffic for both the default and densified deployments. At high traffic, the throughput for LTE@15 with the default deployment drops below that of LTE@2.6. With the densified deployment, LTE@15 has higher throughput than LTE@2.6 also at high traffic.

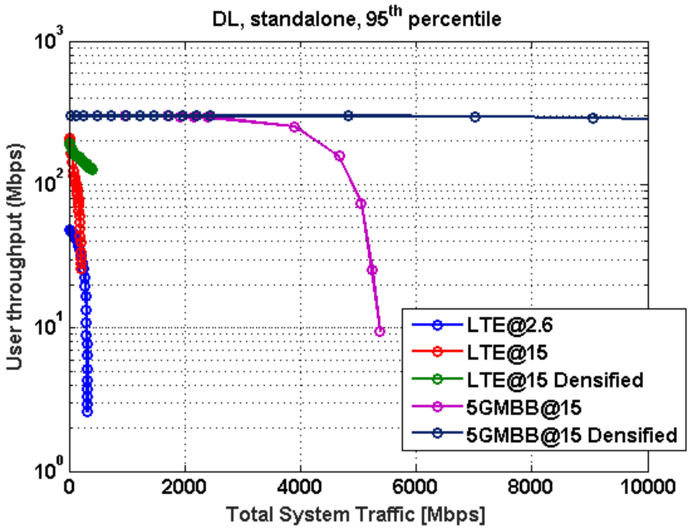

Figure A-29: DL user throughput vs. traffic for the simulation case 95%-ile.

In Figure A-29 we can see that the 95%-ile throughput for 5GMBB reaches the maximum bit rate, 300 Mbps, except for high traffic and can carry much higher system traffic than LTE.

On the other hand, UL throughput vs. traffic is shown in Figure A-30 to Figure A-32.

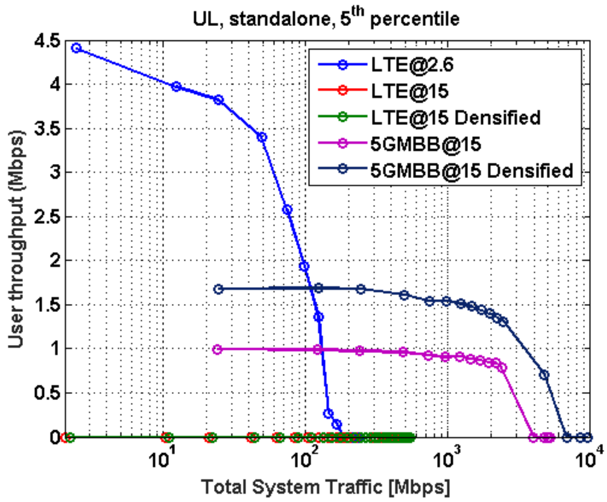

Figure A-30: UL user throughput vs. traffic for the simulation case 5%-ile.

The 5%-ile throughput is zero for LTE@15 also for the UL. At low traffic, LTE@2.6 has higher 5%-ile throughput than 5GMBB. This is probably due to the high propagation loss for the 5%-ile UE at 15 GHz. On the other hand, 5GMBB can carry higher system traffic thanks to the beamforming capability.

The 50%- and 95%-ile throughput are much higher for 5GMBB than LTE. See Figure A-31 and Figure A-32.

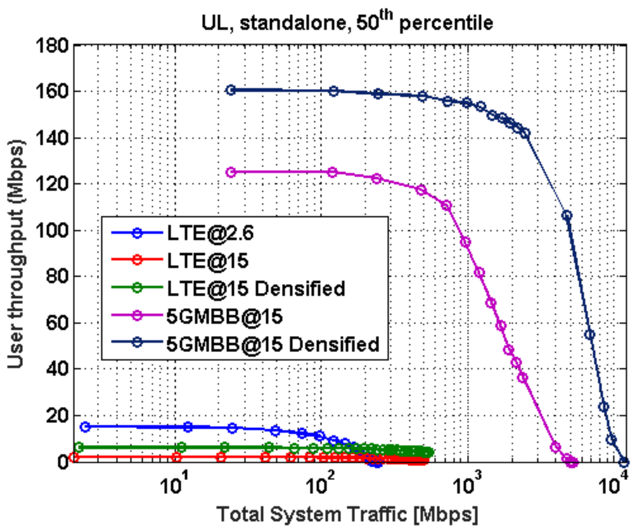

Figure A-31: UL user throughput vs. traffic for the simulation case 50%-ile.

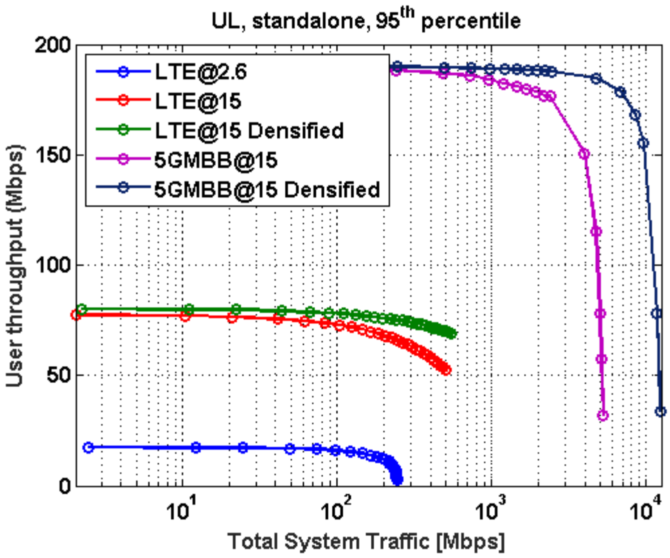

Figure A-32: UL user throughput vs. traffic for the simulation case 95%-ile.

Carrier aggregation

Figure A-33 to Figure A-35 shows DL user throughput vs. traffic for the different simulation cases.

Carrier aggregation of LTE at 2.6 GHz together with 5GMBB at 15 GHz outperforms the carrier aggregation setting of LTE at 2.6 GHz together with LTE at 15 GHz. Both of these two carrier aggregation approaches significantly outperforms the LTE baseline at 2.6 GHz carrier frequency.

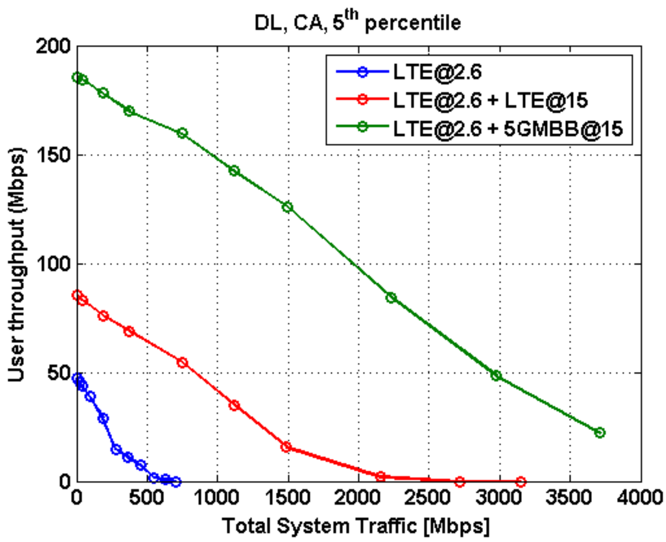

Figure A-33: CA DL user throughput vs. traffic for the simulation case 5%-ile.

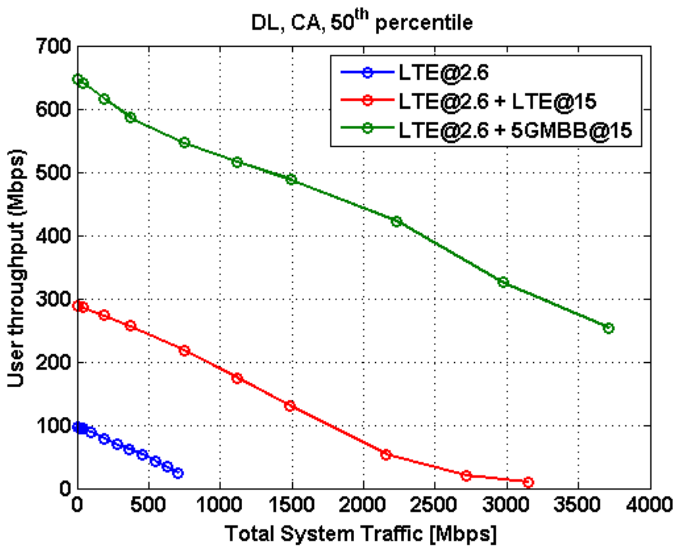

Figure A-34: CA DL user throughput vs. traffic for the simulation case 50%-ile.

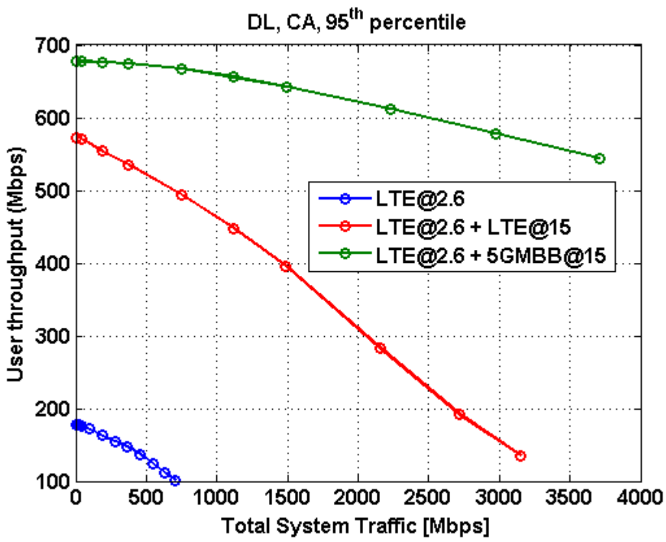

Figure A-35: CA DL user throughput vs. traffic for the simulation case 95%-ile.

A.3 TC3: Shopping mall

A.3.1 Description of the test case

TC3, the Shopping mall, is a test case that addresses a future communication environment in a large shopping mall with high density of users with various needs.

The wireless network of the shopping mall enables both customer-related services and operational services.

A.3.2 Main KPI and requirements

The Shopping mall, TC3, is a setting with challenging traffic demands that was defined in D1.1 [MET13-D11]. The main requirements and KPIs are:

- Traffic volume per area: 170 (67) Gbps/km^2 DL (UL),
- Traffic volume per subscriber: 1.07 Gbyte DL+UL,
- Experienced user data rate: 300 (60) Mbps DL (UL),

together with high availability and reliability.

A.3.3 Simulation models

Environmental model

An environmental model of the shopping mall is described in the Simulation guidelines [MET13-D61]. This setting is illustrated in Figure A-36 and contains shops (yellow), walls (blue), corridors (white) and a food court (red).

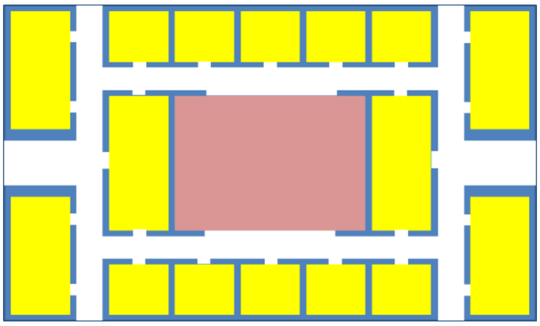

Figure A-36: Environmental setting of the Shopping mall.

Deployment considerations

In terms of deployment mmW is considered. The simulation setting and simulation topologies are specified in Section A.3.4.

Propagation model

The propagation aspects are modelled by ray-tracing based on the existing material in [MET13-D61] and [MET14-D63]. The propagation results of the entire shopping mall are available on [MET14-Web]. In this study the propagation results were refined.

Traffic model

The FTP-traffic model described in [MET13-D61] is used.

Mobility model

The users are assumed to be static.

A.3.4 Assumptions

Simulation setting

The major aspects of the simulation setting are the following:

- Bandwidth of 2 GHz (at around 60 GHz) which is enabled by the wide bandwidth and MAC mmW TeCs. Part of the band, 100 MHz, is dedicated for the control channel.
- Wireless self-backhauling (APs with in band wireless self-backhauling to aggregation nodes) which is enabled by T3.3-TeC2.
- Contention based MAC (common for aggregation nodes, wireless APs and UEs) which is enabled by the TeCs: MAC mmW and Wireless self-backhauling.
- High-gain beamforming which is enabled by the WP2-TeC1.1 high-gain BF. There are 64 elements per AP, and 16 elements per UE. All using single polarization.
- Flexible OFDM (subcarrier spacing at 360 kHz, 100 MHz bandwidth per allocation unit, i.e. resource block) which is enabled by the flexible OFDM TeCs.

The geographical location of the APs and the UEs are given in Figure A-37.

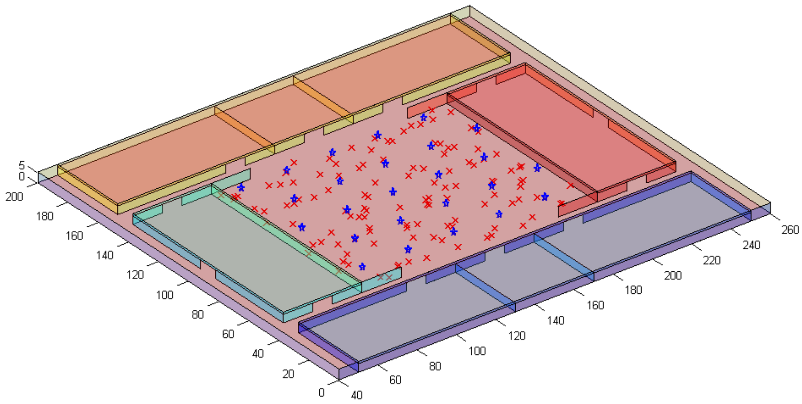

Figure A-37: The blue-stars indicate the possible AP locations (placed in a hexagonal grid), whereas the red-crosses indicate the possible UE locations (placed in a pseudo-uniform grid).

Simulation parameters

The total throughput target is 5.6 TB per hour. This is modelled as 82 files (each with the size 20 MB) per second (Poisson arrival) with one file per user. The traffic split is 70% in downlink and 30% in uplink. The file transfer is User Datagram Protocol (UDP). MAC ensures the transmissions.

The users are deployed as they have a file. Only static users are considered (i.e. the UE is assumed to remain static during the download/upload which typically is less than a second). The UE positions are randomly selected from 128 available locations

Simulation topology

Two different simulation topologies are considered within this study. Note that the considered simulation topologies not necessarily are the optimal deployments.

In the first topology only six Aggregation Nodes (AgN) are considered. Their geographical locations are given in Figure A-38, where each AgN is highlighted as an orange circle.

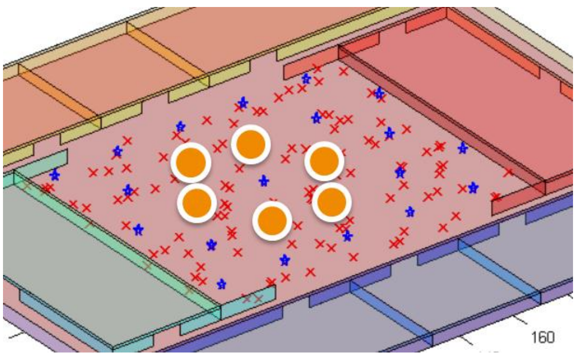

Figure A-38: Simulation topology with six aggregation nodes, 6 AgN.

In the second topology six aggregation nodes plus four wireless Aggregation Nodes (wAN) are considered, where the wAN are using wireless self-backhauling. Their geographical locations are given in Figure A-39, where each AgN is highlighted as an orange circle and each wAN is highlighted as a green circle.

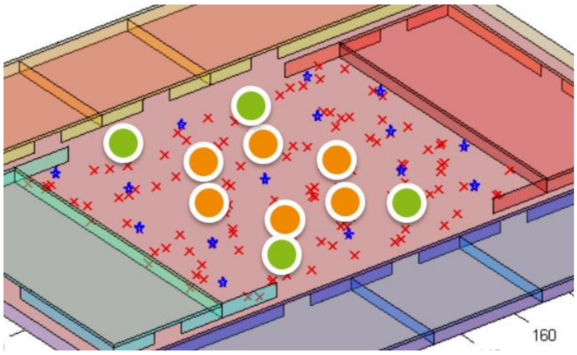

Figure A-39: Simulation topology with six aggregation nodes plus four wireless aggregation nodes, 6 AgN + 4 wAN.

A.3.5 Technology components

In the evaluation of the Shopping mall the main technology components used are the following ones:

- WP2-TeCC1.1: Air interface for dense deployment - Frame structure,
- WP2-TeCC1.2: Air interface for dense deployment - Dynamic TDD,
- WP2-TeCC1.3: Air interface for dense deployment - Harmonized OFDM,
- WP2-TeC12.3: MAC for UDN & mmW,
- T3.3-TeC2: Interference Aware Routing and Resource Allocation in an mmW UDN.

More details on these TeCs can be found in [MET15-D2.4] and [MET15-D3.3].

The WP2-TeCC1 components enable flexible OFDM, in addition the WP2-TeCC1.3 also enables wide bandwidth and high carrier frequency. The WP2-TeC12.3 enables MAC mmW. The T3.3-TeC2 enables wireless self-backhauling.

A.3.6 Results

In the performance evaluation the experienced throughput and object delay is presented. In addition, a SNR comparison is made to evaluate the effect of adding wireless nodes.

The experienced throughput is given in Figure A-40.

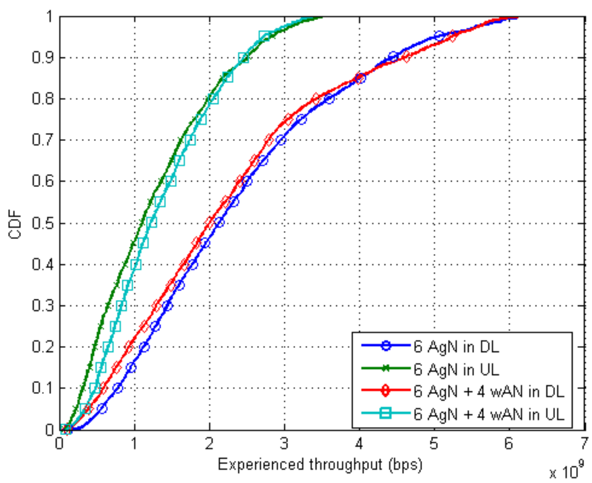

Figure A-40: User experience CDF of average file transfer datarate, where the average is over the time between file demand and full reception.

The 5th percentile and Median results are presented in Table A-17.

Table A-17: Experienced throughput in TC3.

Performance		Target value (i.e. required value) Median	Simulation results			
			6 AgN		6 AgN + 4 wAN	
			5th perc.	Median	5th perc.	Median
Experienced throughput*	Downlink	300 Mbps	690 Mbps	2.1 Gbps	565 Mbps	2.0 Gbps
	Uplink	60 Mbps	225 Mbps	1.1 Gbps	339 Mbps	1.2 Gbps

The object delay is given in Figure A-41.

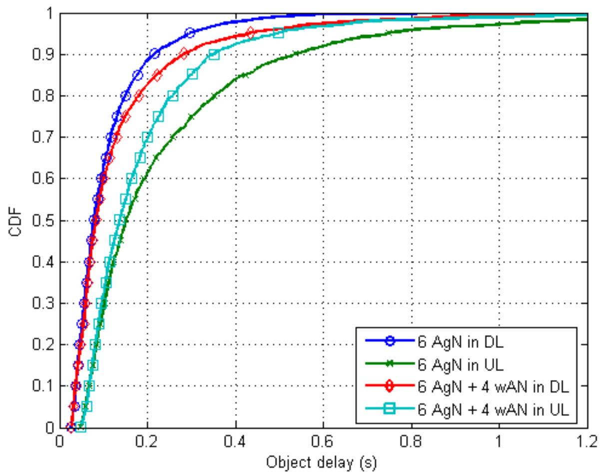

Figure A-41: CDF of total file delay, where the time is between file demand and full reception.

The 95th percentile and Median results are presented in Table A-18.

Table A-18: Total file delay in TC3.

Performance		Target value (i.e. required value) 95th perc.	Simulation results			
			6 AgN		6 AgN + 4 wAN	
			95th perc.	Median	95th perc.	Median
Total file delay*	Downlink	95%: < 1 s	296 ms	78 ms	430 ms	82 ms
	Uplink	95%: < 1 s	745 ms	151 ms	495 ms	137 ms

The requirement is that at least 95% of the users are to have less than one second in total file delay. Part from 6 AgN in UL, approximately no user needed more than one second.

A RX SNR comparison in downlink between 6 AgN and 6 AgN + 4 wAN is presented in Figure A-42, to study the effect of adding wireless nodes.

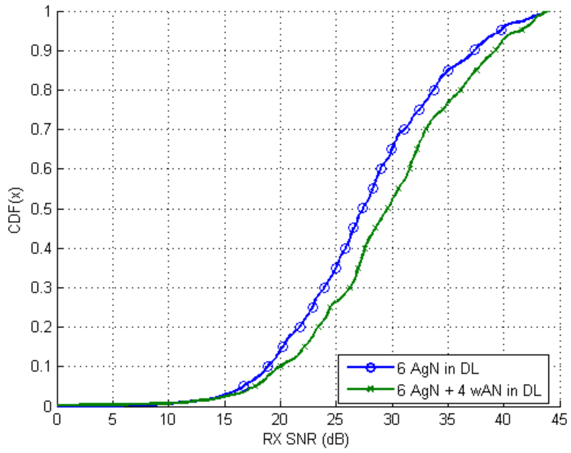

Figure A-42: RX SNR comparison in downlink between six aggregation nodes, 6 AgN, and six aggregation nodes plus four wireless aggregation nodes, 6 AgN + 4 wAN.

Adding wireless nodes improves the SNR with approximately 2-3 dB for 80% of the users' reception (despite that the deployment in an open space is not optimal for wireless backhaul).

A.4 TC4: Stadium

A.4.1 Description of the test case

The stadium use case relies on an existing market, where anyway operators experience today a "difficulty" in providing a service with good quality of experience; providing then service with high level of quality of experience could be considered as a thorough new market. The mentioned "difficulty" is mainly related to the extreme crowdedness of the stadium that requires very peculiar deployments.

In this sense, this can be considered as mostly an operator-centric use case, also in the case of local data exchange performed as an example by network controlled direct D2D, where the operator provides the infrastructure and the service for the users, here intended as traditional users equipped by evolved phones. From a technical point of view, the general challenge is to offer a reliable and extremely huge bandwidth service to a multitude of users temporarily located in a single cell already deployed area.

The situation is a football match that gathers many people interested in watching and exchanging high quality video contents. People can exchange multimedia content inside the stadium or transmit them outside, particularly during the intervals of the main event in the stadium. Although two kind of categories are described in [MET13-D11], simulations only focus on the "pull" category, where spectators consume traffic.

A.4.2 Main KPI and requirements

Main KPIs of TC4 are summarized in the table below. More details on the definition of these KPIs can be found in [MET13-D11].

Table A-19: Main KPIs defined for TC4 [MET13-D11].

KPI	Requirement
Traffic volume per subscriber	9 [Gbyte/h] per subscriber DL+UL in busy period
Average user data rate during busy period	0.3-3 [Mbps] (for UL+DL)
Traffic volume per area	0.1-10 Mbps/[m2] / (stadium area 50,000 [m^2])
Experienced user data rate	0.3-20 [Mbps] DL+UL
Latency in the radio access network	< 5 [ms]

A.4.3 Simulation models

Simulations follow simulation details included in [MET13-D61]. In the following, we include a short description of these models and deviations.

Environmental model

The environment of TC4 is limited to the stadium area. Platforms for spectators are roofed and tilted in order to provide a good visibility to the audience, hence appropriate modelling of Stadium requires 3D dimensioning. All area of stadium except the playground is covered with a deck at the height of 33 m. The angle of the tribunes is 30º with respect to the ground. For the sake of simplicity, the focus is only on one side of the bleacher, more specifically, on an area of 100 m x 50 m.

Deployment considerations

There is a dense network of small cells antennas deployed at the rooftop of the stadium and directed toward the audience. Thirty small cells access points are connected with optical fibre to a common baseband unit. To limit intercell interferences small cells antennas are highly directive. Both sub 6 GHz and mmW deployments are allowed for Stadium, although the focus will be on below 6 GHz assumption.

This scenario is assumed to be isolated from outside interferences. By default, small cells are deployed on out band frequency with respect to macro layer.

In the bleacher under study there are 9751 users distributed uniformly in the considered area. The distance between the users is 1 m along the minor stadium axis and 0.5 m along major stadium axis. There are 49 rows with 199 UEs each. Additionally, users separated along minor axis have different height, linear to slant of the stadium (30º).

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

Propagation model

The propagation model for TC4 needs to characterize Line of Sight (LOS) transmission from the small cell antennas deployed at the deck of the stadium and targeted at the audience. For this purpose, an outdoor UMi LOS model will be used as defined in [ITU08]. Additionally, for D2D traffic PS#9 is proposed [MET13-D61]

Still these models must be used with the necessary modification for 3D calculations:

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

Traffic model

The FTP-traffic model described in [METIS13-D61] is used, where users are downloading 50 Mbytes files (in case of D2D transmission the file size is equal to 25 Mbytes) every 20 s. This results in a downlink traffic of 9 Gbytes/h.

Mobility model

The users are stationary for the duration of the simulation.

A.4.4 Assumptions

In simulations, the access points are connected to a central baseband unit via fiber optics. This central entity is also connected through fibre optics to a Security Gateway that provides access to the MNO core network. Given the availability of the central entity, the system could operate as a cloud RAN, in the sense that access points are seen by the network as a set of transmission points configuring a virtual MIMO system. Another possibility is that all access points act as conventional cells. Simulations will show the potential benefit of the cloud RAN solution.

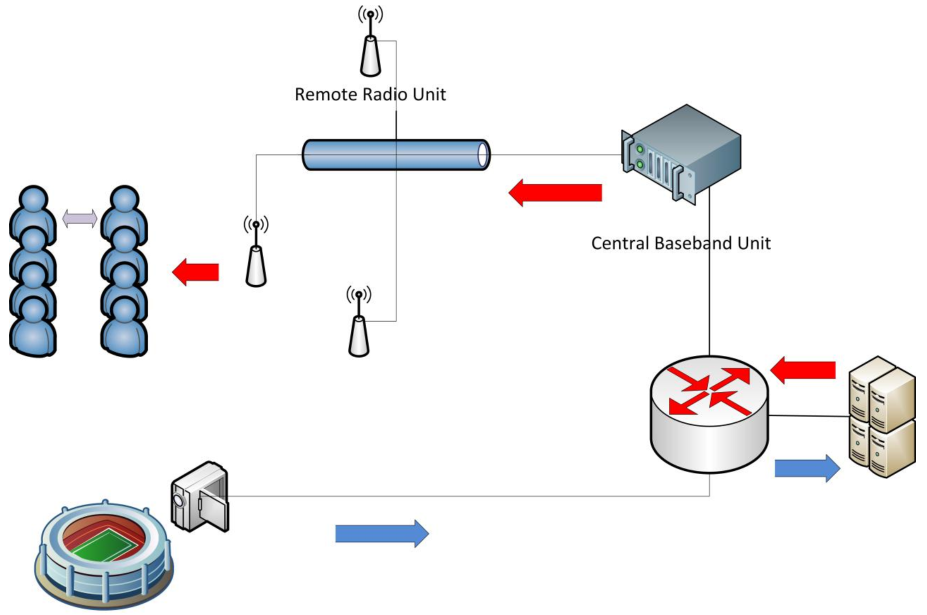

Figure A-43: Architecture of the radio access network in TC4 evaluations.

Concerning traffic flows, 85 % of users are receiving video traffic in DL, 50 MB each 20s, whereas the remaining 15 % of users are exchanging data with D2D operation mode, 25 MB each 20 s in both directions. The focus is only on the latency from the central baseband unit to the user (RAN), which must be lower than 5 ms.

Concerning the propagation, for the AP-to-UE links, we used TC4 path loss maps available at [MET14-Web], being PS#9 used for the UE-to-UE D2D links [MET13-D61].

180 MHz is initially allocated to cellular communications at 2.6 GHz, and 20 MHz (UL+DL) for D2D communication at 60 GHz. Stations and users have 8 antennas (4 cross polarized pairs) and antennas at base stations have 17 dBi gain.

Given the relevance of confining transmitted signal to the area of interest, we are working on the following customized configuration of antennas:

- Antennas at x=10 → tilt=95º, θ_{3dB}=10º, ϕ_{3dB}=15º
- Antennas at x=25 → tilt=85º, θ_{3dB}=15º, ϕ_{3dB}=20º
- Antennas at x=40 → tilt=65º, θ_{3dB}=20º, ϕ_{3dB}=35º

being θ_{3dB} the beamwidth in the horizontal plane and ϕ_{3dB} the beamwidth in the vertical plane. The resulting wideband signal to interference plus noise ratio can be seen in Figure A-44.

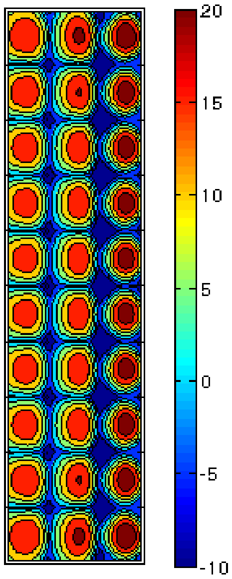

Figure A-44: Wideband SINR [dB] with customized tilt and antenna pattern in the bleacher.

A.4.5 Technology components

The main characteristic of this TC is the huge amount of data, and the ultra-density of access node. As in TC1, there exists a central unit able of assuming the control of the whole system. This enables the cloud-RAN concept that is thoroughly investigated in a progressive manner, including SU-MIMO, MU-MIMO, coordinated MU-MIMO and cloud RAN.

On the other hand, working with beyond 6 GHz bands, the frame structure must be redefined following the results in WP2-TeCC1. In the case of cloud RAN with a massive availability of antennas, massive MIMO techniques will be used, including T3.1-TeC1b, T3.1-TeC7, T3.1-TeC11 and T3.2-TeC13. Moreover, other subsidiary techniques will be used, to reduce interferences (T3.2-TeC11 and T4.1-TeC10) and to facilitate D2D communications (T4.1-TeC3-A1). The table below summarizes all TeC included in the simulations.

Table A-20: Main technology components evaluated in TC4 simulations.

WP/Taks	TeC	Name
WP2	TeCC1.1	Air interface in dense deployments – Frame structure
WP2	TeCC1.2	Air interface in dense deployments – Dynamic TDD
WP2	TeCC1.3	Air interface in dense deployments – Harmonized OFDM
T3.1	TeC1b	DFT based Spatial Multiplexing and Maximum Ratio Transmission (DFT-SM-MRT) for mmW large MIMO
T3.1	TeC7	Massive MIMO Transmission Using Higher Frequency Bands
T3.1	TeC11	Heterogeneous Multi-cell, MU Massive-MIMO, massive SDMA
T3.2	TeC11	Decentralized Interference Aware Scheduling
T3.2	TeC13	Interference mitigation based on JT CoMP and massive MIMO
T4.1	TeC3-A1	Distributed CSI-based Mode Selection for D2D Communications
T4.1	TeC10	Overlapping Supercells for Dynamic Effective User Scheduling Across Bands

A.4.6 Results

In our simulations a 20 Mbps traffic source has been used, with the time between packets fixed to 1 ms. It is important to consider that traffic sources of all the users are synchronized, i.e., sources generate packets at the same time to emulate the broadcast of a service over the stadium.

We obtain the mean radio access latency of these packets and the mean experienced user data rate of each user. In order to calculate the latter, we average the data rate of each packet received by a user. The data rate is defined as the packet size divided by the time required to transmit the packet over the air, plus the time between retransmissions if needed. Additionally, we provide the packet loss percentage to have a complete picture of the system performance.

Table A-21: TC4 results summary.

Configuration		Experienced user data rate	Latency in the radio access network	Packet loss
Requirement		0.3-20	< 5 ms	N.A.
BW x 20 (3.6 GHz)	MU-MIMO	5% CDF: 1.4 Mbps 80% CDF: 20.0 Mbps	4.69 ms	4.8 %
	MU-MIMO + COMP	5% CDF: 16.1 Mbps 80% CDF: 20.0 Mbps	3.60 ms	0.03 %
	MU-MIMO + MASSIVE MIMO	5% CDF: 15.1 Mbps 80% CDF: 20.0 Mbps	3.61 ms	0.03 %
	MU-MIMO + COMP + MASSIVE MIMO	5% CDF: 20.0 Mbps 80% CDF: 20.0 Mbps	3.42 ms	0.00 %
BW x 10 (1.8 GHz)	MU-MIMO	5% CDF: 0.8 Mbps 80% CDF: 20.0 Mbps	6.20 ms	14.4 %
	MU-MIMO + COMP	5% CDF: 1.2 Mbps 80% CDF: 20.0 Mbps	5.15 ms	5.5 %
	MU-MIMO + MASSIVE MIMO	5% CDF: 4.4 Mbps 80% CDF: 20.0 Mbps	4.32 ms	2.2 %
	MU-MIMO + COMP + MASSIVE MIMO	5% CDF: 14.4 Mbps 80% CDF: 20.0 Mbps	3.84 ms	0.2 %

In the configuration labelled as “MU-MIMO + COMP” 8 antennas are placed at transmitter and receiver and coordination is implemented among preconfigured clusters of 9 cells. In configuration “MU-MIMO + COMP + MASSIVE MIMO”, base station has a 64-antenna elements array. It is assumed that this 64 elements array is equivalent to an 8 elements array with 9 dB antenna gain in each element.

Results show that increasing the available bandwidth 20 times from the original assumptions in METIS [MET13-D61] up to 3.6 GHz is enough to reach the requirements of this TC for any of the MIMO schemes studied. They also show that in this scenario there is a significant gain in using massive MIMO scheme. This means that using multiple antennas to have the same multiplexing gain as a smaller array is useful in this scenario. In fact, with 1.8 GHz and a combination of MU-MIMO and massive MIMO all the requirements are fulfilled, even without the use of COMP.

Figure A-45 presents the CDF of user experienced data rate with 3.6 GHz of bandwidth. As expected, the maximum value is the data rate of the traffic source, 20 Mbps. More than 20% of the users present this data rate for all the configurations. Figure A-46 shows the packet latency CDF for the same bandwidth. More than 80% of packets are received in less than 5 ms. Therefore, latency goal is clearly fulfilled as shown in Table A-21.

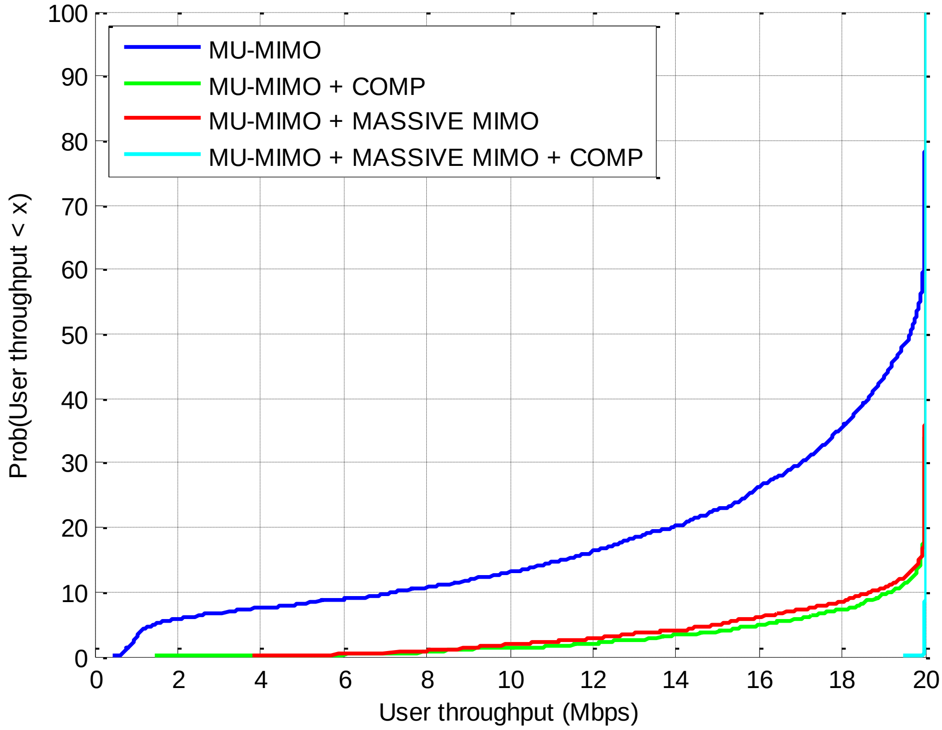

Figure A-45: Experienced user data rate CDF with 3.6 GHz bandwidth.

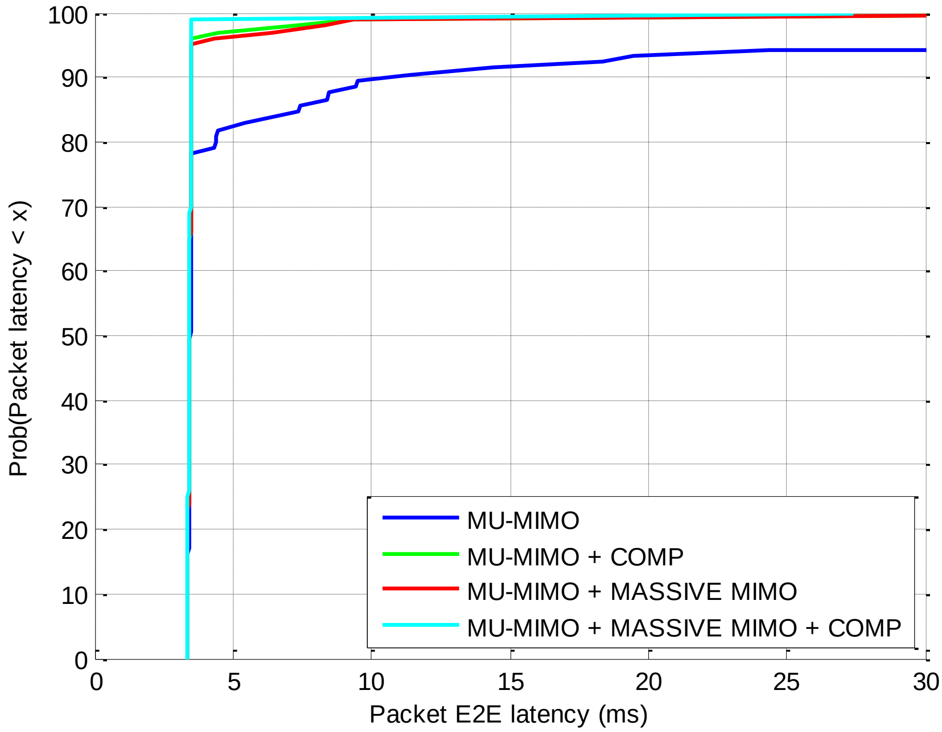

Figure A-46: Packet latency CDF with 3.6 GHz bandwidth.

Figure A-47 presents the CDF of user experienced data rate with 1.8 GHz of bandwidth. As expected, the maximum value is the data rate of the traffic source, 20 Mbps. More than 20% of the users present this data rate for any configuration. Compared with the data rates achieved with 3.6 GHz, an increasing number of users get data rates that are lower than 20 Mbps. Figure A-48 shows the packet latency CDF for the same bandwidth. More than 60% of packets are received in less than 5 ms. However, latency goal is fulfilled only for the combination of MU-MIMO, massive MIMO and COMP, as shown in Table A-21.

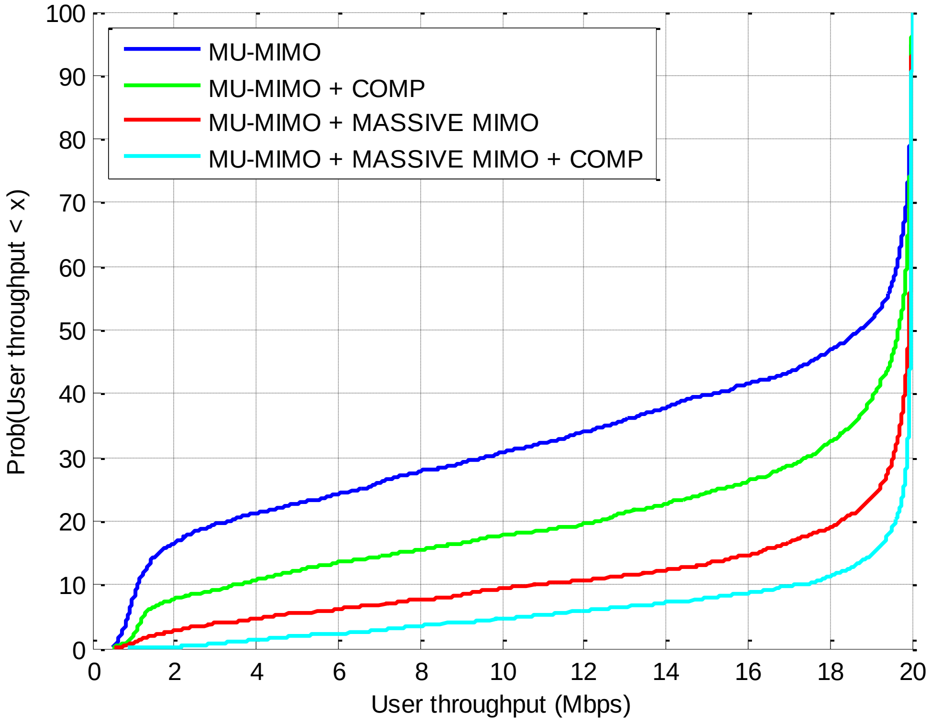

Figure A-47: Experienced user data rate CDF with 1.8 GHz bandwidth.

The results of this study would be different if the packet size, or equivalently the time between packets, was larger. We have performed additional simulations with a 20 Mbps data source configured with a time between packets of 2 ms instead of 1 ms. Main results are presented in Figure A-49 and Figure A-50. It is important to see that with the new time between packets, each packet is larger, and hence “artificially” a higher data rate can be achieved if the time to transmit the packet is similar. Therefore, the 20 Mbps limit seen in previous figures is not a hard limit, but depends on the specific configuration of the source. Obviously, the increase in packet sizes implies an increase of the mean packet latency. However, this increase is limited to 1 ms in our simulations, and hence, latency requirement can still be fulfilled.

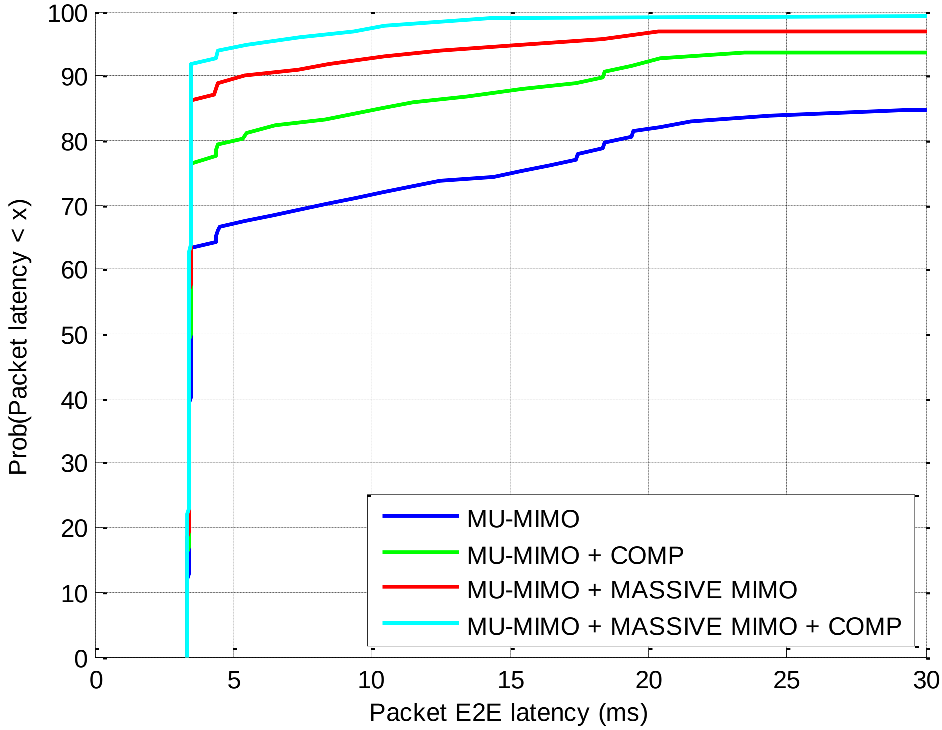

Figure A-48: Packet latency CDF with 1.8 GHz bandwidth.

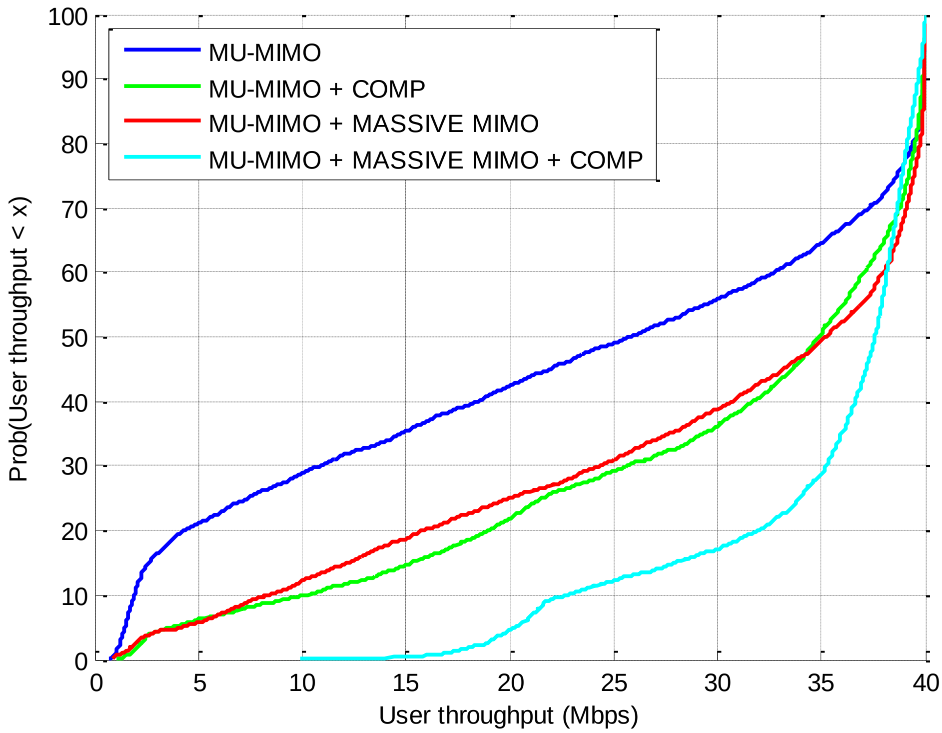

Figure A-49: Experienced user data rate CDF with 1.8 GHz of bandwidth and time between packets of 2 ms.

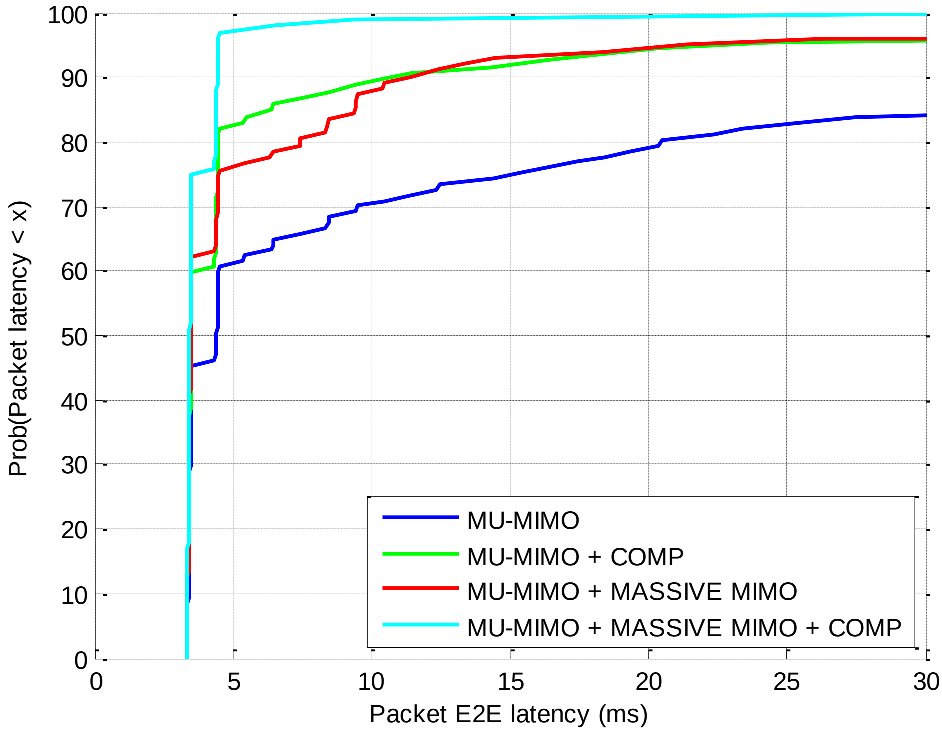

Figure A-50: Packet latency CDF with 1.8 GHz of bandwidth and time between packets of 2 ms.

A.5 TC5: Teleprotection in smart grid network

A.5.1 Description of the test case

Real-time communications may require real-time monitoring and alerting functionalities and an immediate response to altered system conditions that may occur at a remote distance from the site controlling the process. Providing such real-time communication, with guaranteed latency and jitter at a low cost is the main challenge raised by this test case. Naturally, a wireless communication system enabling reliable information delivery with low E2E latency may have further applications, e.g. in wireless factories (applications in factory automation, especially process automation) or mobile health.

This test case focuses on a smart energy distribution system. This grid system aims at improving the efficiency of energy distribution and requires prompt reaction in terms of a reconfiguration of the network and routing lines in response to unforeseen events that may damage the system. In the case of teleprotection where messages must be sent between substations to prevent the power system from cascading failures and damage, timely information is critical. If the network is not able to react to the altered system conditions fast enough the energy distribution network is in danger to collapse. The time constraints to be fulfilled here lie in the range of a few milliseconds.

For example, if a fault happens at one particular substation, this message must be relayed to other affected substations within milliseconds in order for protection mechanisms to react in time. If failing to do so, it is likely to cause damage to the grid and to be costly for the energy distribution company. Given the critical nature of these events, low latency, high reliability and quality of service prioritization are essential for the communication link.

A.5.2 Main KPI and requirements

In this test case the only requirement is to be able to forward a control message of 1521 bytes from one substation to a set of neighbor substations in less than 8 ms with 99.999 % reliability.

Main KPIs of TC5 are summarized in the table below. More details on the definition of these KPIs can be found in [MET13-D11].

Table A-22: Main KPIs defined for TC5 [MET13-D11].

KPI	Requirement
Experienced user throughput	Approximately about 200 [byte] up to 1521 [byte] of information reliably delivered within 8 [ms]
End-to-end latency	8 [ms] One Trip Time for an event-triggered message that may happen anytime
Reliability	99.999%
User/device density	Dense urban: around hundreds per [km^2]

A.5.3 Simulation models

Simulations follow simulation details included in [MET13-D61]. In the following, we include a short description of these models and deviations.

Environmental model

The environment of TC5 is the same as TC2, that is, the Madrid grid. In this urban area 42 substation are randomly deployed in outdoor locations, close to the building edges.

In order to avoid border effects wrap around is considered. Therefore 9 copies of the Madrid grid are considered. In each copy the number of substations is 42, where we have considered 200 substations per km^2 (the Madrid grid area is around 0.21 km^2).

Deployment considerations

Deployment considerations are those of TC2, including macro and pico-cells, since only outdoor scenario is of interest.

Propagation model

The propagation models used in TC5 are PS#1 (pico-cells outdoor coverage), PS#3 (macro-cells outdoor coverage) and PS#9 (direct substation-to-substation communication) as proposed in [MET13-D61].

Traffic model

Traffic modeling is not relevant in this test case, since packets are event-driven. Suddenly a packet is generated with some target substations (no more than the closest 10 substations).

Mobility model

Substations are stationary, and therefore no mobility model is needed. They are randomly placed in each simulation in pedestrian areas surrounding buildings, excluding the part occupied by pedestrian crossings and bus stops.

A.5.4 Assumptions

Architecture

Substations are wirelessly connected to the base stations. In case of sharing the base station Local IP Access (LIPA) is used, that is, routing happens directly in the base station, without the need to go to core network entities. Substations may also use D2D links for redundancy transmission. Discovery is assumed to already exist, since substations are static and can be made offline.

In case of transmission between two substations without direct coverage and not connected to the same base station, conventional routing is used.

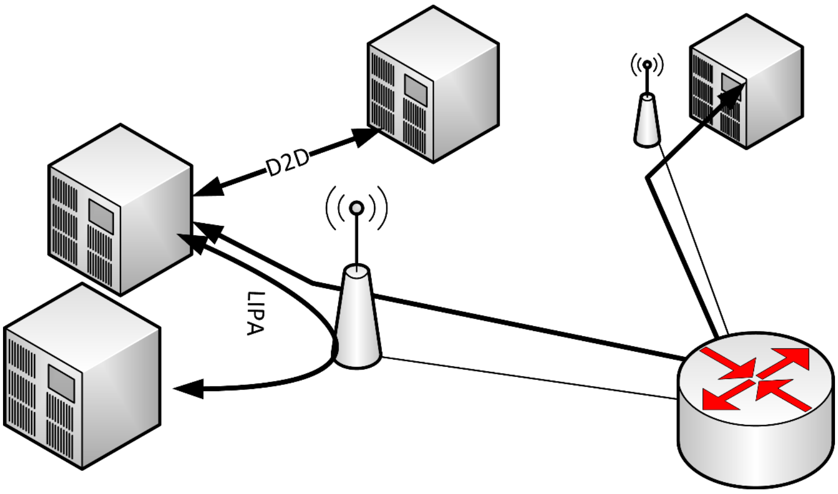

Figure A-51: Architecture of the radio access network in TC5 evaluations.

If in D2D coverage, direct communication between substations will happen in parallel with infrastructure-based traffic. Moreover, system allocates the highest priority to this teleprotection traffic and consequently there is no need to add other traffic on the simulations, since its effect will be null.

Available bandwidth

200 MHz for cellular links and 20 MHz for D2D links.

Spatial multiplexing

Substations are assumed to have 8 antennas.

We assume that in OFDM and FBMC spatial multiplexing allows us to multiplex up to 4 layers in parallel without mutual interference. In SCMA, up to 6 layers are code-multiplexed, while spatial multiplexing increases multiplexing capability 4 times, up to 24 layers.

Reduced subframe lengths

The baseline configuration is the LTE subframe length of 1 ms. However, we have considered reduced values of 0.5 ms and 0.25 ms.

Link level results

Link level results provided by FBMC proponent, for FBMC and OFDM includes detailed specification of the SNR required by each MCS to achieve 90% reliability. It is assumed that 1 additional dB is required to achieve 99.999% reliability.

SCMA link level curves have been assumed to be equal to OFDM curves plus an offset (3.3 dB better).

Delay budget

Concerning the delay budget, uplink transmission time for the legacy technology (LTE-A) is assumed to be a random number uniformly distributed between 0 and 5 plus 6 ms. For the improved METIS system with MMC capabilities and new air interfaces (FBMC or SCMA), this latency is calculated as a random number uniformly distributed between 0 and 1 plus 1 ms.

Downlink transmission time depends on the number of users connected to the cell, their SINR and the bandwidth, which is 200 MHz in the simulations. Resource scheduling prioritizes the user with best SINR in our solution. In D2D links, it depends on the SINR and bandwidth of the D2D link.

System load

In order to calculate the SINR experienced by a device, it is assumed that all stations transmit with the maximum available power. That is, the system is highly loaded.

A.5.5 Technology components

In this scenario, the frame structure (WP2-TeCC1) is also very important to define the maximum latency. Moreover, modification of signalling and new radio interfaces shall be evaluated (WP2-TeCC8.1 and T4.2-TeC16) due to the communication nature of this test case. Moreover, other subsidiary techniques will be used to enable D2D communications (T4.1-TeC3-A1 and T4.1-TeC4-A1). The table below summarizes all TeCs included in the simulations.

Table A-23: Main technology components evaluated in TC5 simulations.

WP/Taks	TeC	Name
WP2	TeCC1.1	Air interface in dense deployments – Frame structure
WP2	TeCC8.1	FBMC
T4.1	TeC3-A1	Distributed CSI-based Mode Selection for D2D Communications
T4.1	TeC4-A1	Multi-cell coordinated resource allocation for D2D
T4.2	TeC16	Scalable solution for MMC with SCMA

The rationale for each component selection is explained in the next lines:

Air interface in dense deployment - Frame structure (WP2-TeCC1.1)

This TeC allows us to consider that each subframe can be used in downlink or uplink dynamically.

FBMC (WP2-TeCC8.1)

The use of this technique instead of OFDM has several implications in our study:

- The SINR required to obtain a given throughput is lower in FBMC. In average, this gain is about 0.3 dB.
- Substation access to uplink channel is faster than in LTE-Advanced since no contention process is needed to obtain the timing advance information.

Distributed CSI-based Mode Selection for D2D Communications (T4.1-TeC3-A1)

The use of this TeC enables the correct establishment of D2D links.

Multi-cell coordinated resource allocation for D2D (T4.1-TeC4-A1)

This TeC ensures that resources are allocated to D2D thorough the whole deployment.

Scalable solution for MMC with SCMA (T4.2-TeC16)

The use of this technique instead of OFDM has several implications in our study:

- The SINR required to obtain a given throughput is lower in SCMA than in OFDM. In average, this gain is about 3.3 dB. This SINR offset is a simple abstraction methodology to overally model the aggregate impact of SCMA codebooks, SCMA overloading, and the MPA joint detector.
- Substation access to uplink channel is faster than in LTE-Advanced since no contention process is needed.
- Multiple layers can be code-multiplexed even with only 1 transmitting antenna. Up to 6 layers can be multiplexed without mutual interference.

A.5.6 Results

In our simulations, each user transmits packets to its closest neighbours. The number of neighbours is increased from 1 to 10. For each number of target neighbours the maximum time needed for the packet to reach all the neighbours is recorded. With these values we show three kinds of results:

- We plot a CDF of the maximum times considering all the users, and all the possible numbers of target neighbours.
- For the entire set of users we get the maximum value needed to reach 1 neighbour, 2 neighbours and up to 10 neighbours. These new values represent the performance of the worst case user.
- For the entire set of users we get the mean value needed to reach 1 neighbour, 2 neighbours and up to 10 neighbours. These new values represent the performance of the mean case user.

We have first studied the performance of a LTE-like system (OFDM-based), a FBMC-based system, and a SCMA-based system, all of them without spatial multiplexing and with a subframe length of 1 ms.

In OFDM we see that LIPA provides a marginal improvement in low percentiles of the CDF. The reason is that the probability of having multiple substations connected to the same cell (being capable of using LIPA) is low. In fact, the most likely scenario is to have 2 substations connected to a same cell. Therefore, it is difficult to have a clear benefit from LIPA. D2D can be used with more probability, although still the number of cases in which it can be used is low. See in Figure A-52 that it is beneficial in about 20% of cases. However, for those users using D2D the benefit is huge compared to that provided by LIPA. Finally, the combined effect of LIPA and D2D provides only a marginal gain compared to the scenario with only D2D. Note that the upper part of the CDF is far beyond the 8 ms required for this test case. Specifically, the highest latency value is 21.96 ms (for all configurations).

The benefits of LIPA and D2D follow the trend shown for OFDM. The main difference with OFDM is a shift of the curve to lower values. The main reason is the avoidance of the channel access procedure used in OFDM. Additionally, both technical solutions are more efficient than OFDM, and need a lower SINR to provide the same throughput. SCMA is more efficient than FBMC. This explains that SCMA provides lower latencies. However, the top of the curves are beyond the 8 ms requirement (12.00 ms in FBMC with D2D, and 10.60 ms in SCMA with D2D).

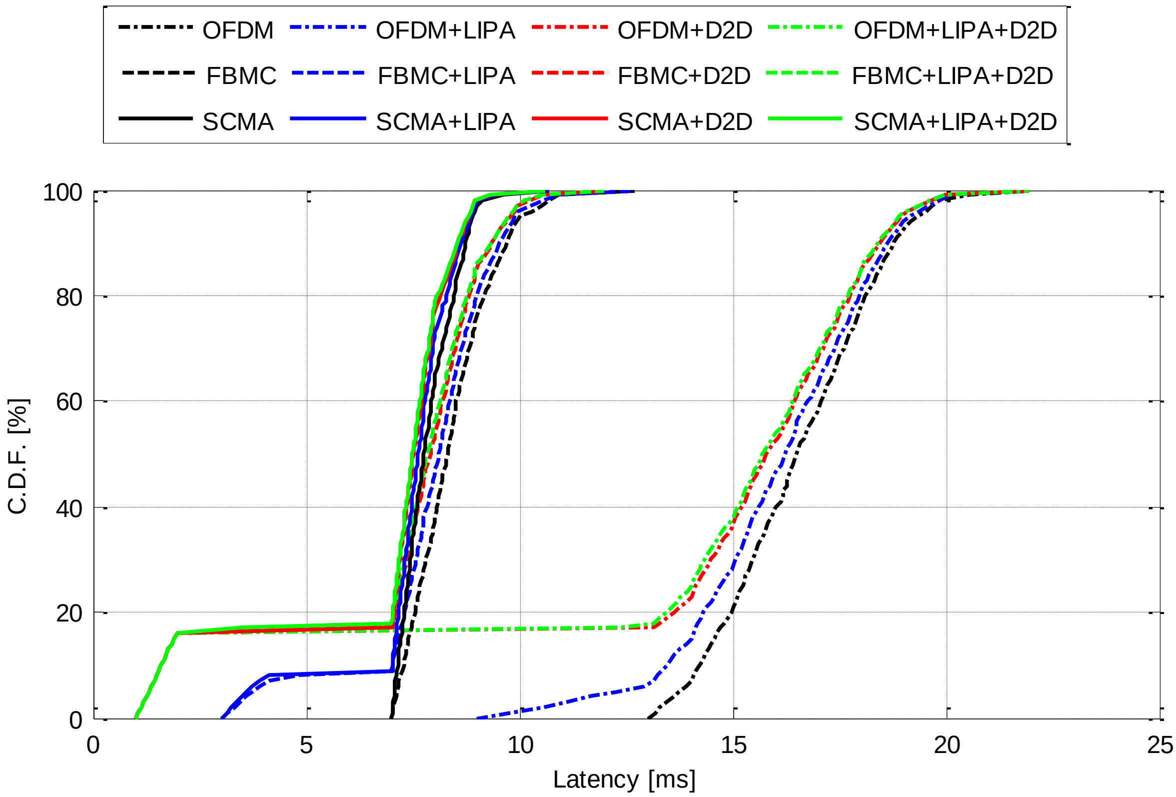

Figure A-52: Latency CDF without spatial multiplexing and 1 ms subframe.

We have then considered reduced subframe lengths. With 0.5 ms, the maximum delays are 15.48 ms for OFDM, 10.50 ms for FBMC and 9.30 ms for SCMA. That is, requirement is not fulfilled. Results are summarized in Figure A-53.

With 0.25 ms, the maximum delays are 12.74 ms for OFDM, 10.15 ms for FBMC and 8.65 ms for SCMA. That is, requirement is not fulfilled. Results are summarized in Figure A-54.

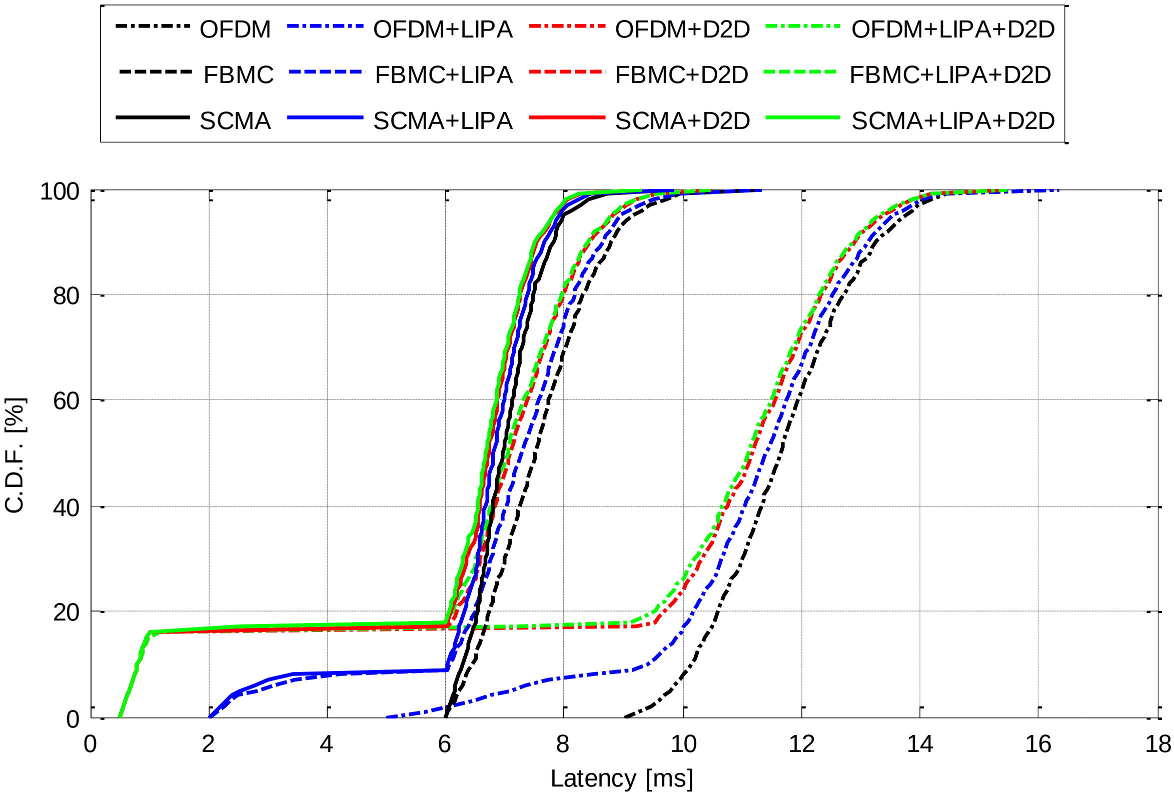

Figure A-53: Latency CDF without spatial multiplexing and 0.5 ms subframe.

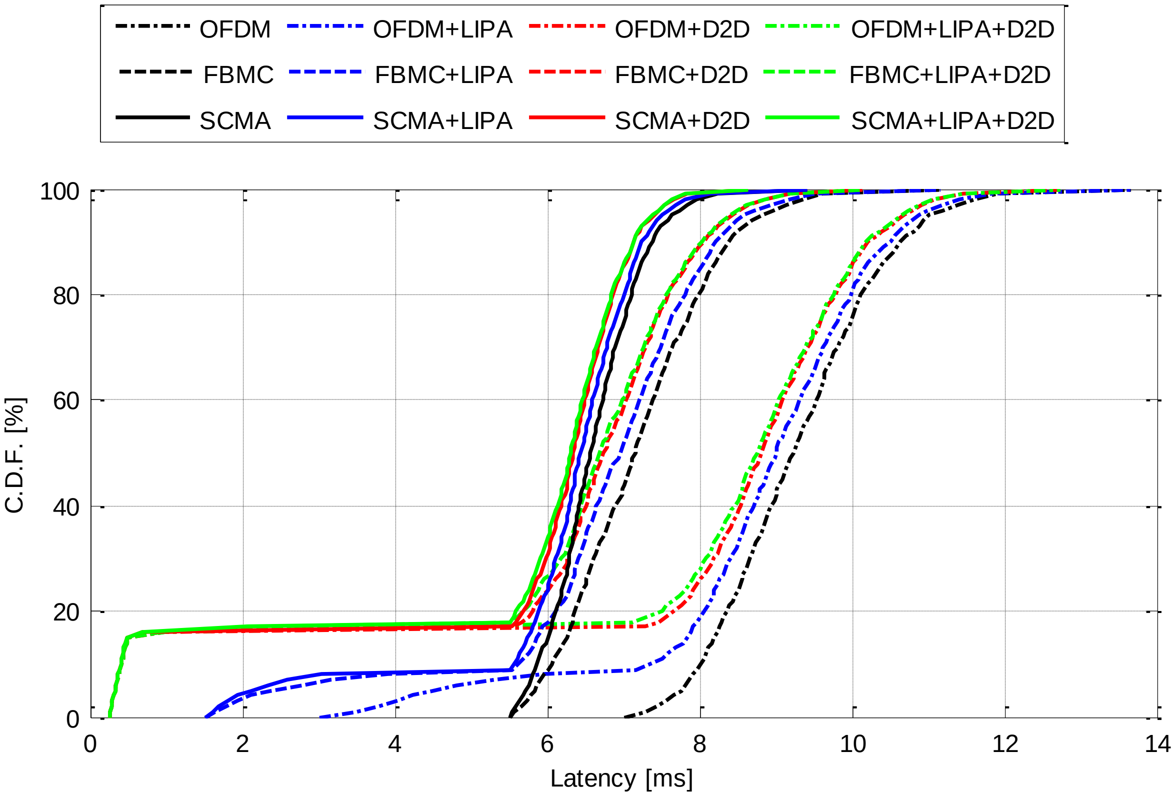

Figure A-54: Latency CDF without spatial multiplexing and 0.25 ms subframe.

In the next step, we have considered spatial multiplexing capabilities. Specifically, as above mentioned, in OFDM and FBMC up to 4 layers are multiplexed in our solution, while in SCMA up to 24 layers are multiplexed.

Results with 1 ms subframe length, 0.5 ms and 0.25 ms have been collected. With 1 ms, the maximum delays are 18.96 ms for OFDM, 8.96 ms for FBMC and 8.00 ms for SCMA (see Figure A-55). That is, requirement is not fulfilled, but in SCMA it is almost fulfilled.

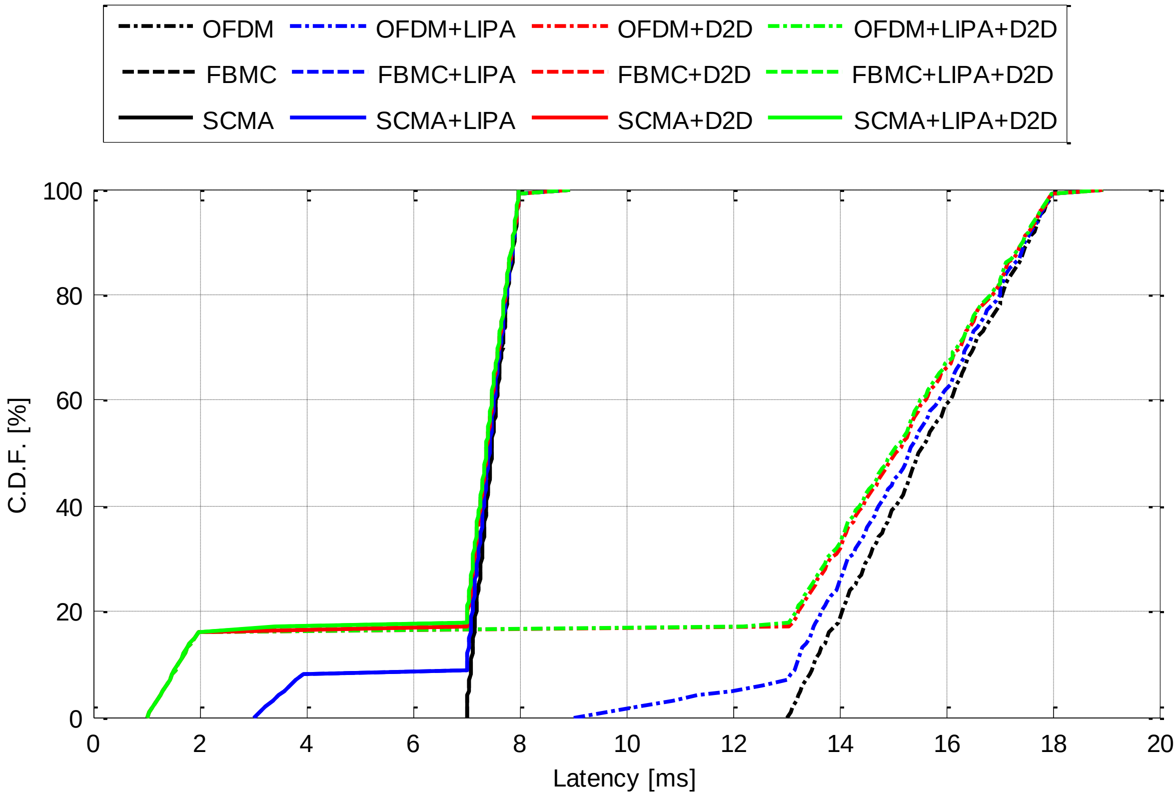

Figure A-55: Latency CDF with spatial multiplexing and 1 ms subframe.

With 0.5 ms, the maximum delays are 12.48 ms for OFDM, 7.48 ms for FBMC and 6.50 ms for SCMA (see Figure A-56). That is, requirement is fulfilled by FBMC and SCMA.

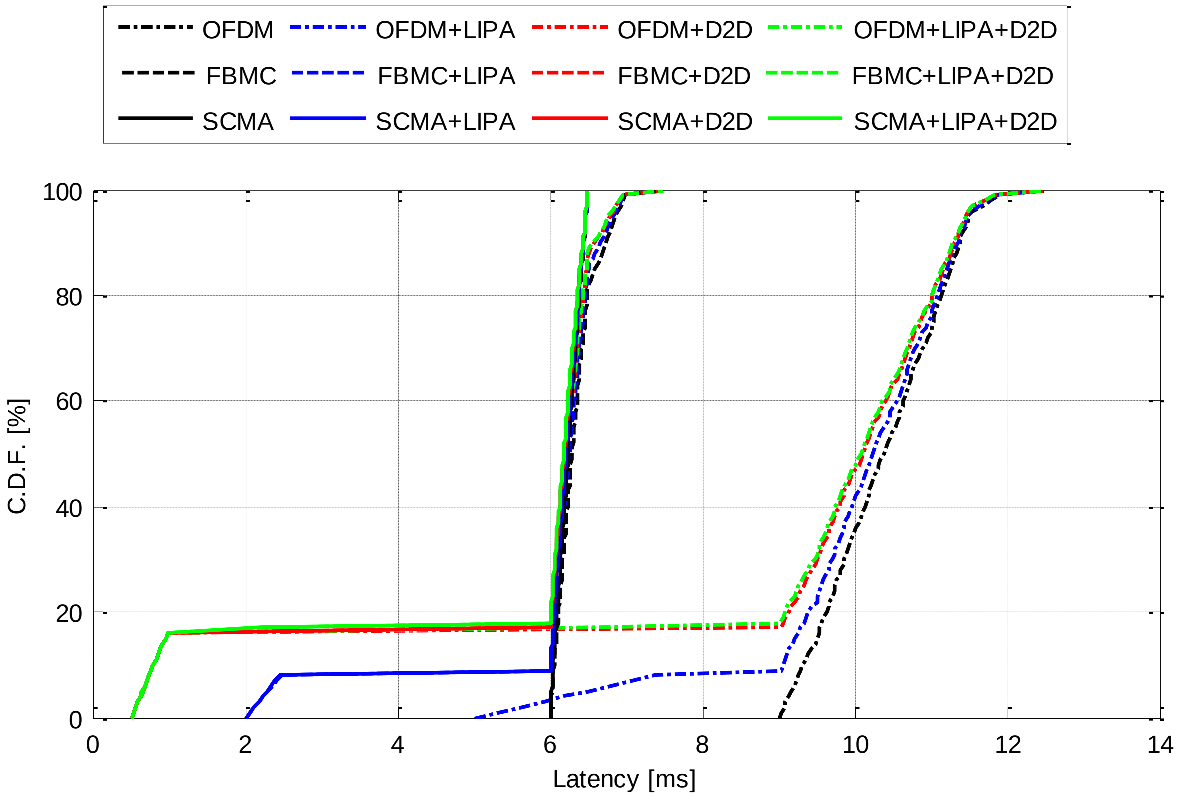

Figure A-56: Latency CDF with spatial multiplexing and 0.5 ms subframe.

With 0.25 ms, the maximum delays are 9.24 ms for OFDM, 6.75 ms for FBMC and 5.75 ms for SCMA (see Figure A-57), i.e. only FBMC and SCMA meet requirements.

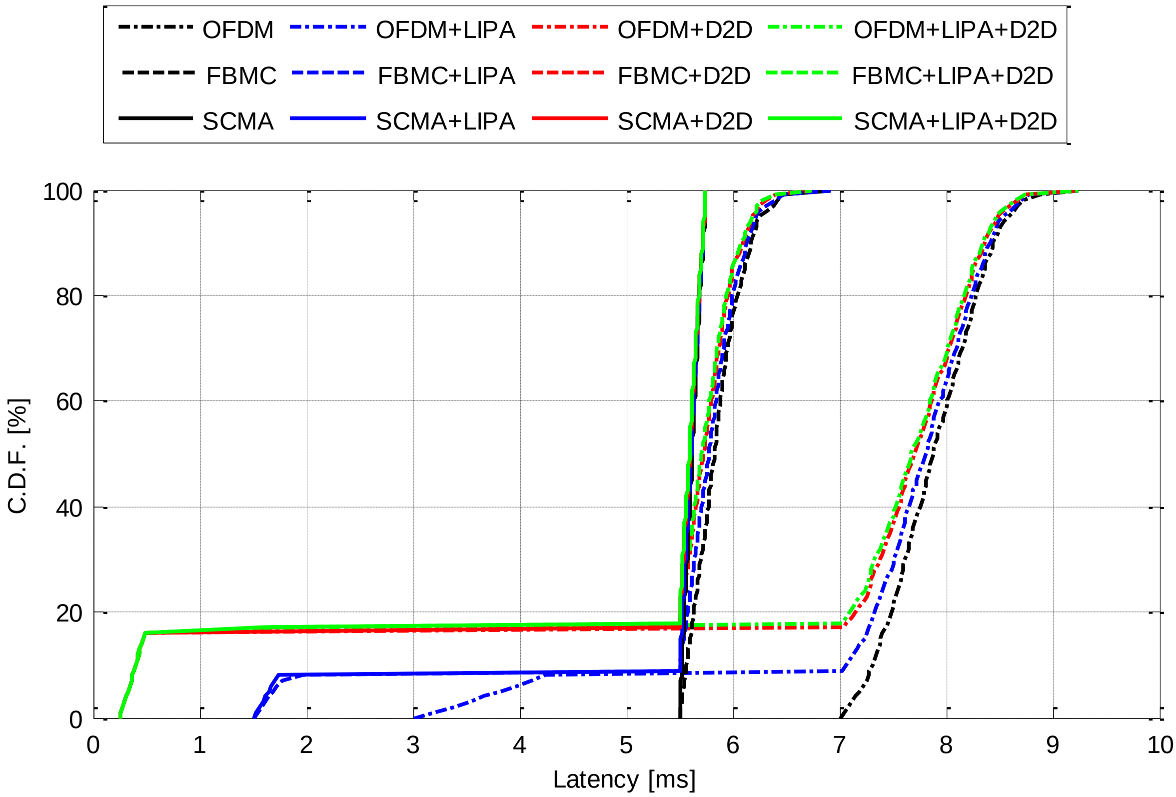

Figure A-57: Latency CDF with spatial multiplexing and 0.25 ms subframe.

Next tables explain the gain achieved with each technological solution. We consider only two configurations. The simplest configuration without spatial multiplexing and 1 ms subframe and the configuration with spatial multiplexing and 0.5 ms subframe. For the first configuration, next tables show the maximum value and the mean value needed to reach a number of neighbour stations for several system configurations.

Table A-24: Maximum latency (ms) needed to reach a number of neighbour substations without spatial multiplexing and 1 ms subframes.

Modulation	Config	1 neig.	2 neig.	5 neig.	10 neig.
OFDM	Cellular	19.64	19.96	21.96	21.96
	LIPA	19.64	19.96	21.96	21.96
	D2D	18.98	19.96	21.96	21.96
	LIPA+D2D	18.98	19.96	21.96	21.96
FBMC	Cellular	9.97	10.92	12.69	12.69
	LIPA	9.92	10.92	12.69	12.69
	D2D	8.98	10.34	11.96	12.00
	LIPA+D2D	8.98	10.34	11.96	12.00
SCMA	Cellular	8.00	8.98	10.60	10.69
	LIPA	8.00	8.96	10.60	10.69
	D2D	8.00	8.96	10.60	10.60
	LIPA+D2D	8.00	8.96	10.60	10.60

Table A-25: Mean latency (ms) needed to reach a number of neighbour substations without spatial multiplexing and 1 ms subframes.

Modulation	Config	1 neig.	2 neig.	5 neig.	10 neig.
OFDM	Cellular	15.75	15.96	16.52	17.17
	LIPA	13.66	15.10	16.30	17.00
	D2D	5.46	9.68	15.35	16.82
	LIPA+D2D	5.36	9.59	15.23	16.77
FBMC	Cellular	7.67	7.86	8.39	9.00
	LIPA	5.58	7.00	8.18	8.83
	D2D	3.19	5.05	7.71	8.68
	LIPA+D2D	3.09	4.96	7.61	8.63
SCMA	Cellular	7.48	7.55	7.82	8.25
	LIPA	5.39	6.70	7.70	8.11
	D2D	3.15	4.92	7.33	8.00
	LIPA+D2D	3.06	4.84	7.23	7.97

For the second configuration, next tables show the maximum value and the mean value needed to reach a number of neighbour stations for several system configurations.

Table A-26: Maximum latency (ms) needed to reach a number of neighbour substations with spatial multiplexing and 0.5 ms subframes.

Modulation	Config	1 neig.	2 neig.	5 neig.	10 neig.
OFDM	Cellular	11.50	11.98	12.48	12.48
	LIPA	11.50	11.98	12.48	12.48
	D2D	11.50	11.98	12.48	12.48
	LIPA+D2D	11.50	11.98	12.48	12.48
FBMC	Cellular	6.94	6.98	7.48	7.48
	LIPA	6.50	6.98	7.48	7.48
	D2D	6.50	6.98	7.48	7.48
	LIPA+D2D	6.50	6.98	7.48	7.48
SCMA	Cellular	6.50	6.50	6.50	6.50
	LIPA	6.50	6.50	6.50	6.50
	D2D	6.50	6.50	6.50	6.50
	LIPA+D2D	6.50	6.50	6.50	6.50

Table A-27: Mean latency (ms) needed to reach a number of neighbour substations with spatial multiplexing and 0.5 ms subframes.

Modulation	Config	1 neig.	2 neig.	5 neig.	10 neig.
OFDM	Cellular	10.27	10.28	10.36	10.51
	LIPA	8.18	9.44	10.30	10.47
	D2D	3.40	6.18	9.76	10.41
	LIPA+D2D	3.31	6.10	9.68	10.40
FBMC	Cellular	6.24	6.25	6.32	6.45
	LIPA	4.15	5.41	6.26	6.42
	D2D	2.27	3.88	5.97	6.37
	LIPA+D2D	2.18	3.79	5.89	6.36
SCMA	Cellular	6.24	6.24	6.24	6.24
	LIPA	4.15	5.40	6.20	6.24
	D2D	2.27	3.88	5.91	6.21
	LIPA+D2D	2.18	3.79	5.83	6.21

The main conclusions of the analysis are:

- A small amount of users takes a benefit from LIPA and D2D. This has an effect on mean latencies but it does not improve the upper limit of the latency.
- More users can take a benefit from D2D while LIPA in combination with D2D only provides marginal benefit.
- FBMC and SCMA provide benefits for all the users. However, with 1 ms subframes they are not capable to fulfil the latency requirement.
- Subframe reduction (0.5 ms subframes) in combinations with FBMC or SCMA is valid to fulfil latency requirement of this test case.

A.6 TC6: Traffic jam

A.6.1 Description of the test case

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

The Madrid grid model defined in TC2 can be used, being an urban scenario. Therefore, a vehicle density of 1000 vehicles per km^2 can be derived with a maximum of four active users per vehicle. These vehicles are randomly distributed in the TC2 scenario. The mobility model of the vehicles is used according to [MET13-D61].

A.6.2 Main KPI and requirements

Table A-28 shows the required KPIs for TC6 traffic jam whereas Table A-29 shows the related constraints:

Table A-28: KPIs for TC6 traffic jam.

KPI	Value
End user data rate [DL]	100 Mbps
End user data rate [DL]	20 Mbps
Traffic volume per area	408 Gbps/km
End-to-end delay	100 ms
Availability	>95%
Reliability	>95%
User Density	4000 users per km square (1000 cars)
Traffic volume	53 GB/hour/user
User mobility	< 3 to 10 km/h

Table A-29: Constraints for TC6 traffic jam.

KPI	Value
Energy consumption (infrastructure)	In principle no particular constraints; nevertheless low-energy operation of all radio nodes expected due to energy cost and EMF reasons
Energy consumption (UE)	In principle no divergent constraints for UEs, but initial network access and data transport should be handled in a energy-optimized way; this is especially true for devices with battery power supply only.
Cost (infrastructure)	Additional deployment of infrastructure should be avoided
Cost (UE)	No additional costs for UEs

More details of these KPIs can be found in [MET13-D11].

A.6.3 Simulation models

The Simulation follows the simulation guidelines presented in [MET13-D61]. The following passage gives a short overview regarding these models.

Environmental model

The Madrid grid model (TC2) defined in [MET13-D61] is used here to achieve a realistic traffic jam scenario.

Deployment Considerations

In urban scenarios, besides a typical deployment defined in TC2, an extra set of base stations can be assumed to be placed regularly along the road where traffic jam occurs. In our simulation we deployed 13 additional Home eNode base stations and this deployment is depicted in Figure A-58.

Propagation model

To simulate the radio propagation we use the METIS 3D propagation models described in [MET13-D61]. Since outdoor users experience is inspected in this TC, propagation model PS#1 for urban micro cell and propagation model PS#3 for urban macro cell are applied for channel propagation.

In case where D2D communication is evaluated, we use propagation model PS#9, defined in [MET13-D61].

Traffic model

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

Mobility model

The mobility model defined in TC2 is reused here to model the mobility of vehicular users. Here we use a random speed from 3 km/h up to 10 km/h for each individual car.

A.6.4 Simulation assumptions

In order to meet the required objectives of 1000 vehicles per squared kilometre 213 vehicles are deployed in our simulated area. This number results from the scenario dimension of 552 meters x 387 meter. Further, it is also assumed that each vehicle has four users inside. That results in totally 852 users in our scenario. For the cellular network, an operating frequency of 2.6 GHz has been applied according to [MET13-D61]. The bandwidth has been assumed to be 200 MHz for the cellular network.

To achieve the required KPIs we introduce 13 additional small cells in the related scenario. The small cells can be considered as public hotspots which are installed at some crossings or to the walls of buildings. For small cells, isotropic antennas are deployed with antenna height at 2 meters. The operating frequency for small cells is assumed here with 2.6 GHz at 200 MHz bandwidth and 20 dBm is assumed for maximal transmission power. The transmission power can be reduced if it is necessary as described in T4.1-TeC7. To calculate the path loss from a small cell to a user, PS#1 proposed in [MET13-D61] has been applied.

Figure A-58 shows the additional small cells as blue dots.

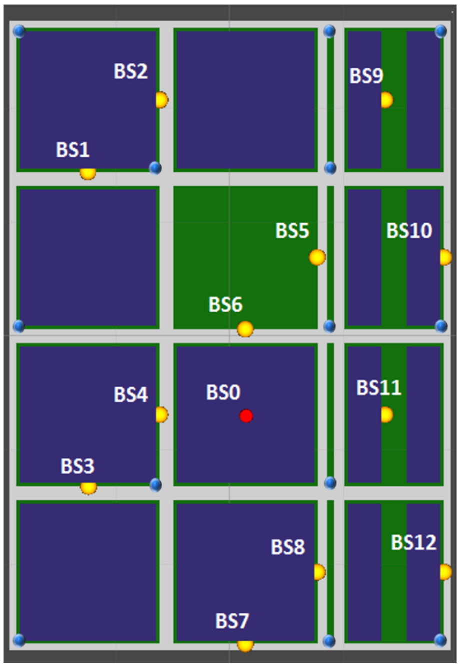

Figure A-58: TC6 Deployment including Home eNodeBs.

Considering the deployment shown in Figure A-58, the resulting SINR distribution (CDF) is shown in Figure A-59. In this case each user is connected to the best base station regarding its SINR level.

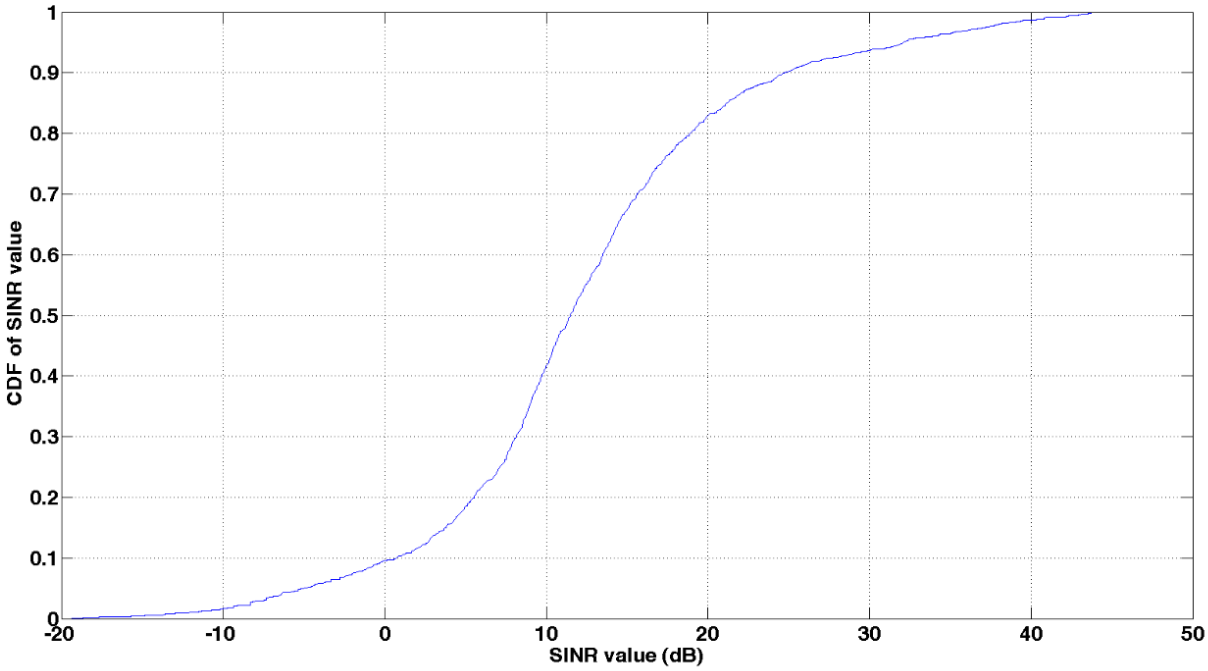

Figure A-59: SINR distribution.

A.6.5 Technology components

The selected TeCs for TC6 are shown in Table A-30, and we give a short overview w.r.t. their principle or advantages in the following.

Table A-30: Main technology components evaluated in TC6 simulation.

WP/Taks	TeC	Name
WP2	TeCC8.1	Filter Bank MultiCarrier (FBMC)
WP2	TeCC11	Sparse Code Multiple Access (SCMA)
T4.1	TeC7	Time-sharing approach to interference mitigation using resource auctioning and regret-matching learning
T4.1	TeC15	further enhanced ICIC in D2D enabled HetNets
WP5	TeC14	Spectrum sharing and mode selection for overlay D2D communication

WP2-TeCC8.1: Filter Bank MultiCarrier (FBMC)

- Filter bank multicarrier (FBMC) provides a higher bit rate and higher spectrum efficiency by avoiding the usage of the cyclic prefix (CP)
- Flexible spectrum access by unsynchronized users
    - Spectrum sharing
- Higher resource efficiency

WP2-TeCC11: Sparse Code Multiple Access (SCMA)

- SCMA increases cell aggregate throughput by 30% to 50%
- SCMA provides open-loop user multiplexing with low feedback overhead and less sensitivity to CQI measurement due to MPA detection and robustness of code domain multiplexing to channel aging
- SCMA provides further resources through system overloading
- Users have chance to be scheduled more frequently with lower end to end delay

T4.1-TeC7: Time-sharing approach to interference mitigation using resource auctioning and regret-matching learning [MET14 D4.3]

- BSs learn the regrets of possible actions
- Decentralized algorithm
- Low user mobility needed
- 15% to 20% gain in throughput comparing to the LTE-A eICIC scheme

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

- D2D reuses the uplink resource of micro cell
- One D2D link can be established if received signal reference power (RSRP) level from the D2D Tx to BS is below certain level
- Interference for cellular links coming from D2D transmitters can be effectively controlled in a centralized manner

System parameters used in this work for T4.1-TeC15 further enhanced ICIC in D2D enabled HetNets:

- RSRP threshold - The minimal RSRP value from user to BS is used here.
- 21 dBm as transmission power for cellular users in uplink.
- 11 dBm as transmission power for D2D users.
- Uplink resource of micro cell is reused (BW=36 MHz at 2.6 GHz).

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

- D2D operates on a dedicated bandwidth exclusively.
- The receiver for each potential D2D link needs to measure the instantaneous SINR value.
- One D2D link can be established if the sensed SINR value by D2D receiver is above a threshold value.
- This TeC provides a decentralized manner to set up D2D links.

System parameters used her for WP5-TeC14 Spectrum sharing and mode selection for overlay D2D communication:

- A SINR value of 10 dB is used as threshold value.
- 21 dBm as transmission power for D2D users.
- A dedicated band at 2.6 GHz with 50 MHz bandwidth is exclusively used.

Delay analysis
With the goal to achieve a maximum end-to-end delay of 100 ms in 95% of all transmissions, the following scheduling method is used:

- Sort Users due to related SINR values
- User with highest SINR value is served first
- Calculate block error probability due to BLER-curve
- In case of error precompute and retransmit using CQI-table
- Packet will be counted as “lost” after three unsuccessful transmissions

Figure A-60 gives an example about how the scheduling for retransmission works.

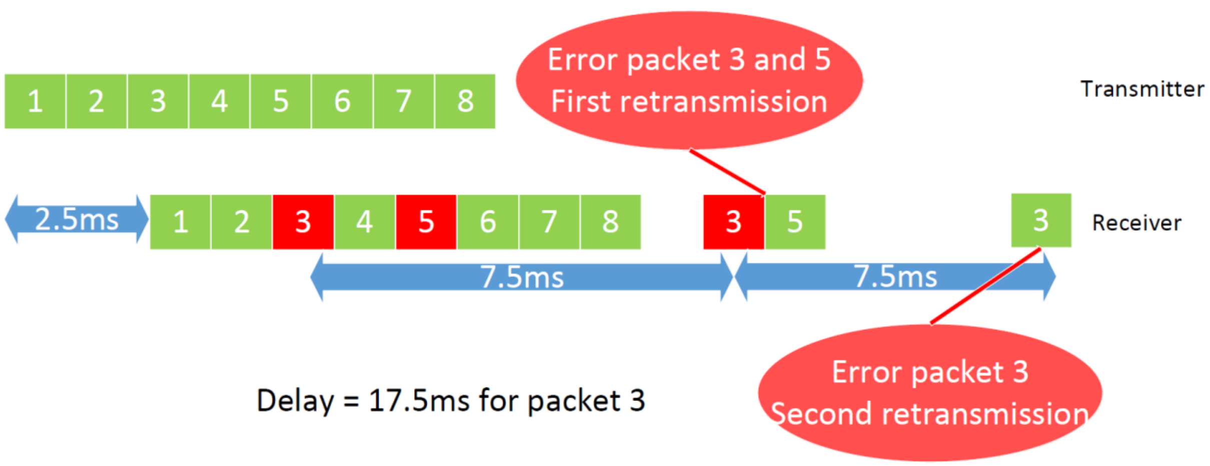

Figure A-60: Scheduling delay.

A.6.6 Results

In the following sections the simulation results will be introduced and compared to the required KPIs.

Figure A-61 shows the CDF of E2E delay of transmitted packages. The green line shows the 95% margin. As can be seen that, by using the described deployment including small cells, the latency requirements can be met in 98% of the cases for downlink and in 97% of the cases for uplink.

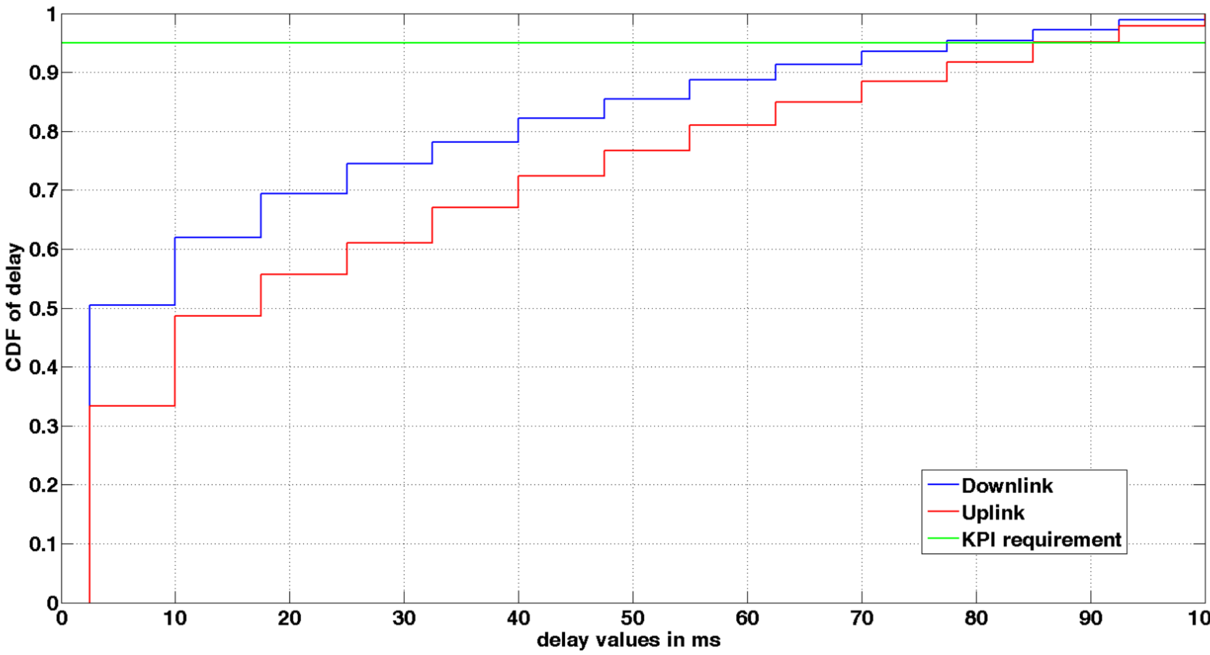

Figure A-61: CDF of Delay (Uplink + Downlink).

Availability

The PDF of the overall availability is shown in Figure A-62. As mentioned before, 95% overall availability is required in this TC. Using the described deployment including Home eNodeBs, we can see from the figure that 92.4% of all users can be served with the cellular network. Thus, in order to fulfil the KPI of 95% availability, unconnected users can be served by D2D communication.

Throughput

From Figure A-63 to Figure A-68, system performance of different TeCs which are used to increase system throughput are given. In Figure A-63, link level performance comparison in between FBMC and legacy OFDM is given. As can be seen from this figure, FBMC provides a performance gain of 13% compared with legacy OFDM technology.

In Figure A-64, the performance gain coming from SCMA compared with LTE is plotted. We can see from this figure that SCMA improves the cell average and cell edge throughputs by 23%-65% which leads to lower bandwidth requirement for the given traffic volume. This performance gain can be held for both downlink and uplink transmission modes and more significant performance gain can be achieved for cell edge users throughput compared with cell average throughput.

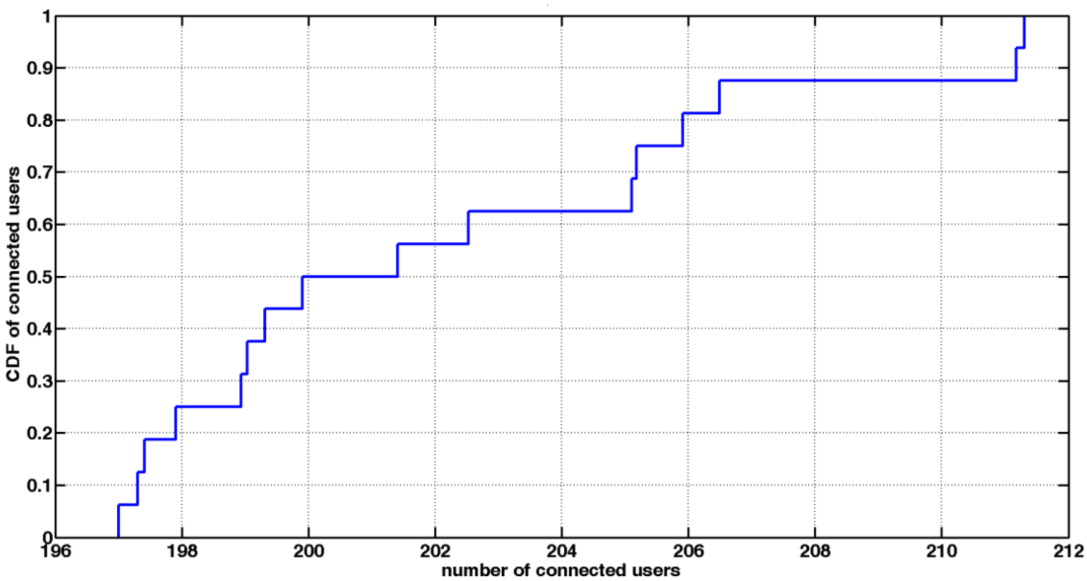

Figure A-62: CDF of connected user.

In this work, the concept to exploit D2D communications for cellular traffic offload is also evaluated. In Figure A-65 and Figure A-66, we evaluate TeCs of Further enhanced ICIC in D2D enabled HetNets and FBMC. The principle here is to reuse uplink spectrum of cellular network and exploit RSRP level from D2D Tx to BS to decide whether one D2D link can be established. In this TeC, a centralized manner is used in order to protect cellular link by mitigating interference from D2D link to cellular link. As we can see from this figure, 8.83 links can be established on average with a median link capacity of 450 Mbps. Therefore, a traffic volume of 3.97 Gbps can be provided additionally with this two TeCs by setting up D2D communications.

In Figure A-67 and Figure A-68, TeCs Spectrum sharing and mode selection for overlay D2D communication and FBMC are evaluated. In this system, D2D links are established in dedicated bandwidth. Besides, for each potential D2D link, the receiver measures the instantaneous SINR value and one D2D link can be established if the sensed SINR value is above a threshold value. Thus, a decentralized manner is used here to mitigate the interference in between D2D links. As shown by this figure, 46.36 links can be established on average with a median link capacity of 600 Mbps. Therefore, a traffic volume of 27.81 Gbps can be provided additionally by these two TeCs.

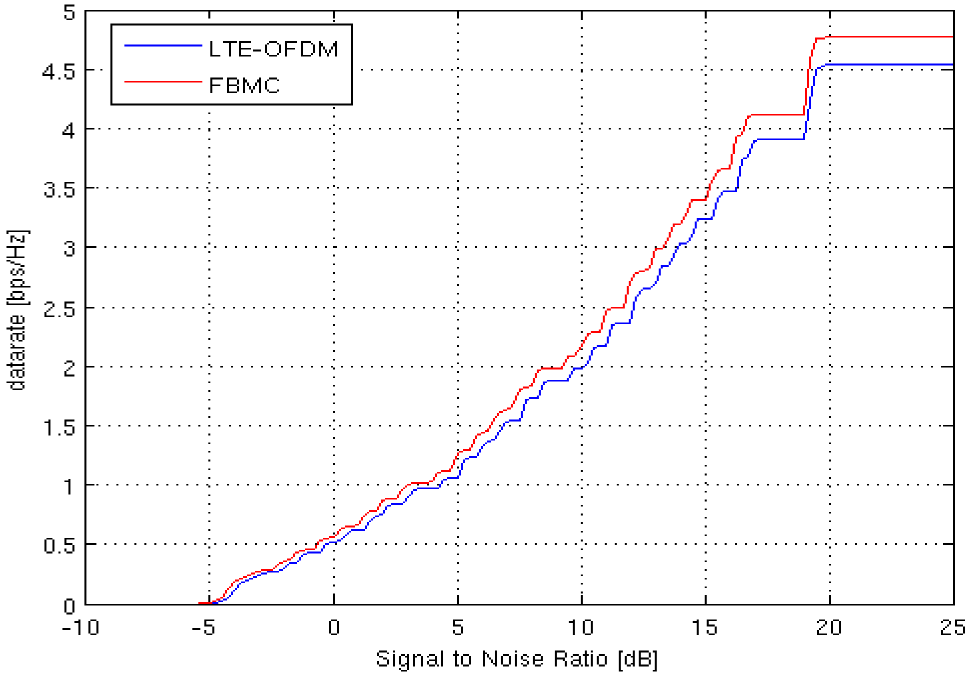

Figure A-63: FBMC vs. OFDM.

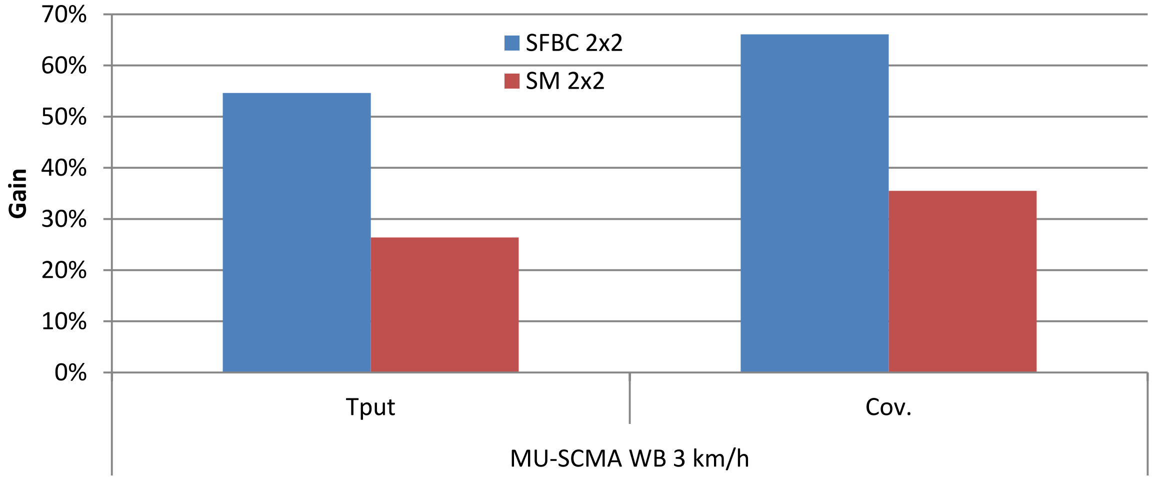

Figure A-64: SCMA.

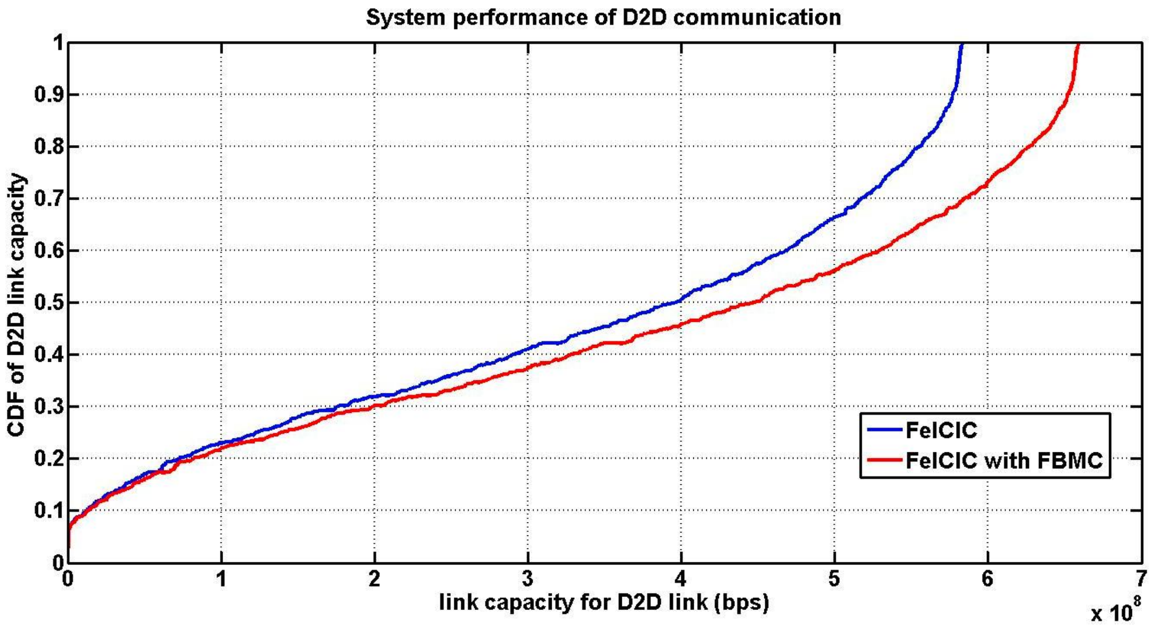

Figure A-65: D2D link capacity.

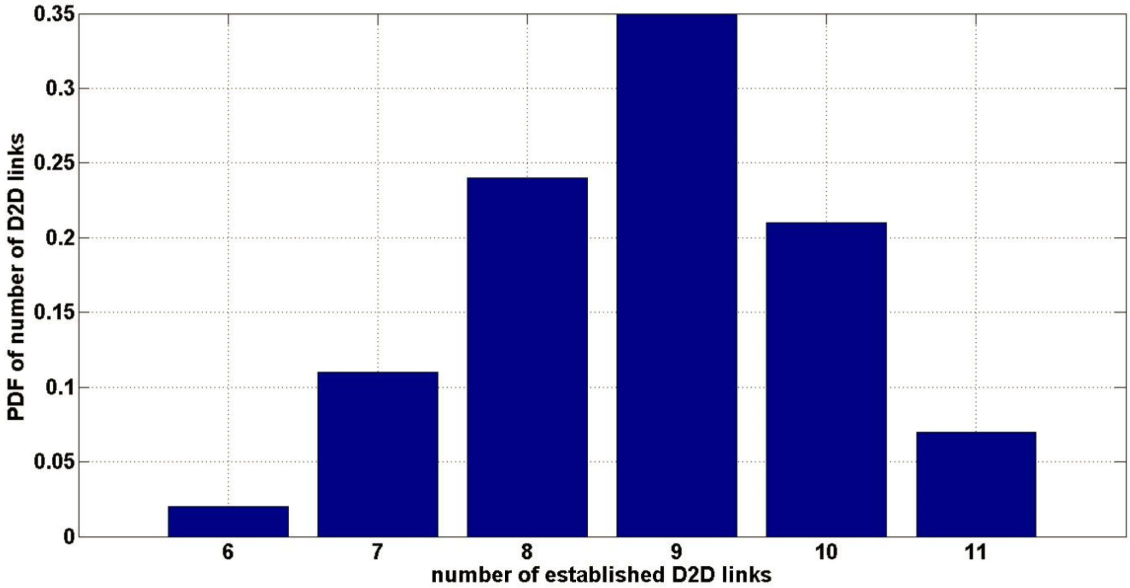

Figure A-66: number of D2D links.

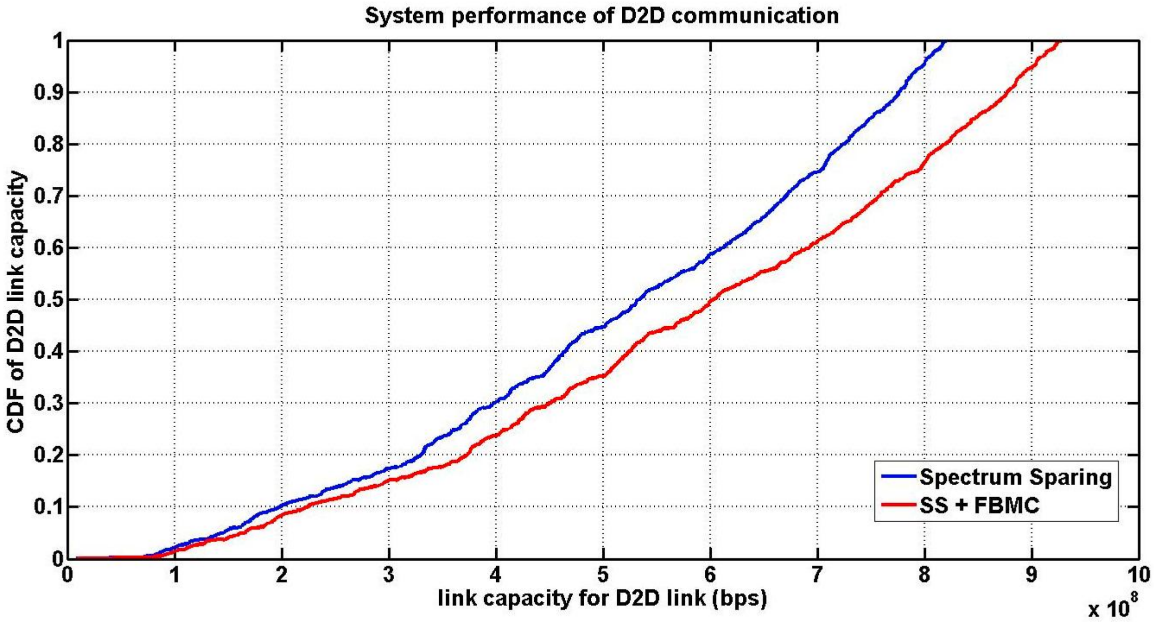

Figure A-67: D2D link capacity.

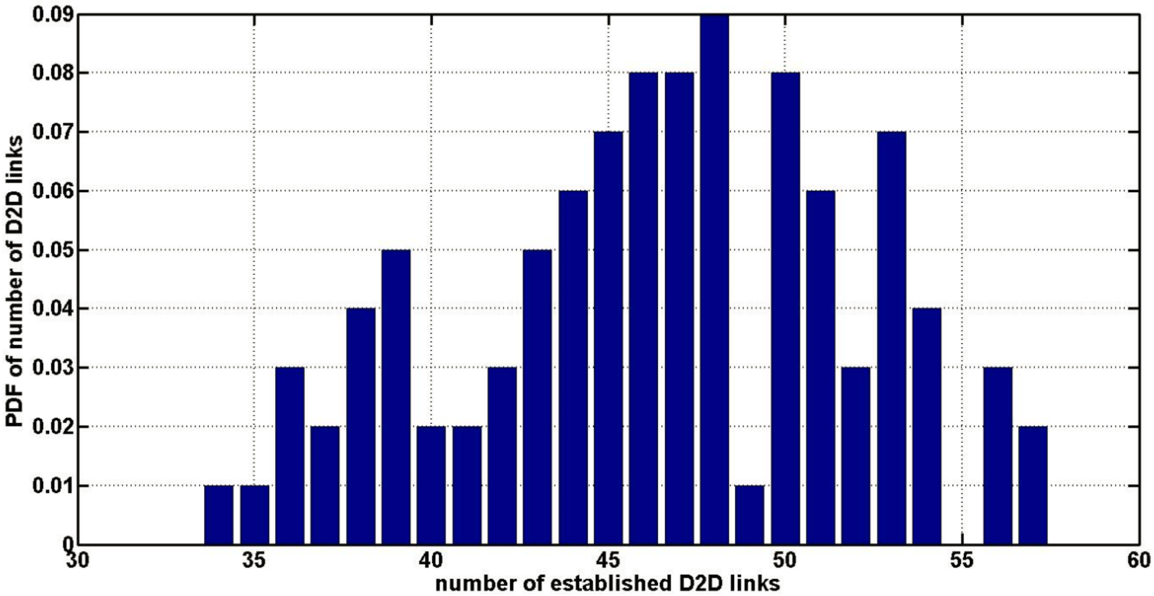

Figure A-68: number of D2D links.

<u>Downlink</u>

Figure A-69 shows system performance for cellular network regarding downlink throughput. System performance of a baseline scheme is also shown here, where neither FBMC nor SCMA is applied. As we mentioned before, a throughput of minimum 100 Mbps per user is required in this TC, which statistically leads to an overall experienced throughput of 85.2 Gbps per simulation scenario. By our simulation, it is seen that the required throughput can be reached in 94.2% of all considered connections. Thus, to fulfil the required KPIs, some traffic has been offloaded to D2D communication.

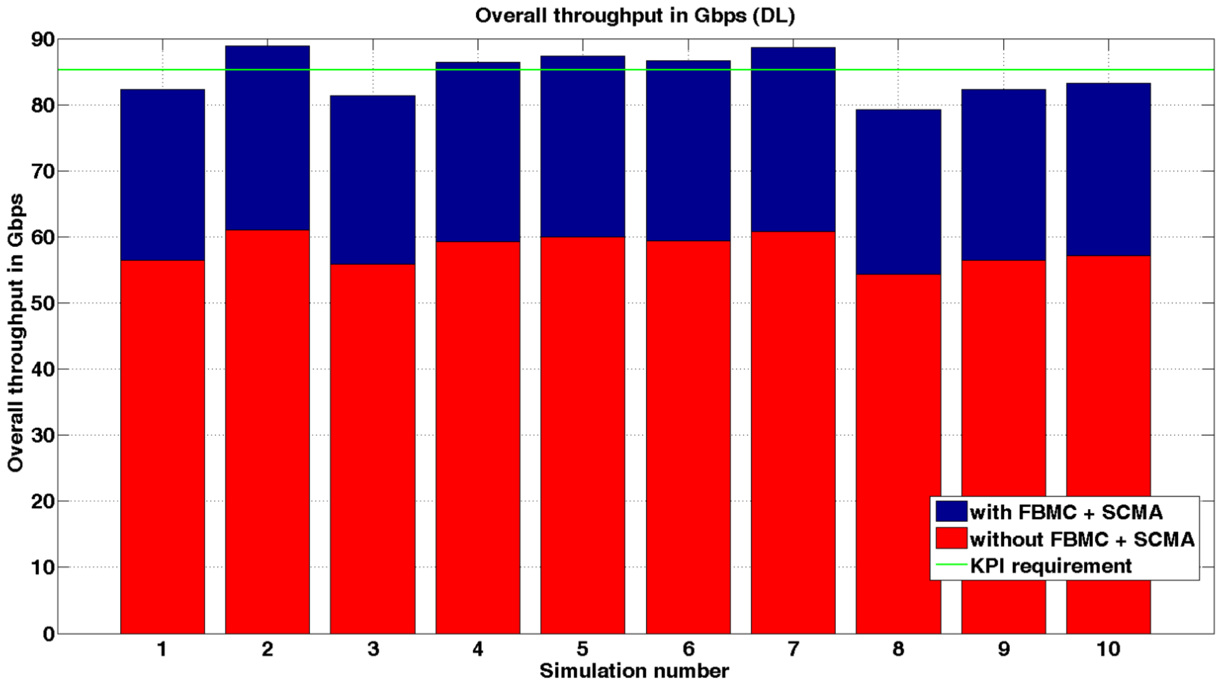

Figure A-69: Downlink throughput with FBMC + SCMA.

<u>Uplink</u>

In uplink, a throughput of minimum 20 Mbps per user is required, which leads to an overall experienced throughput of 17.04 Gbps for the whole simulation scenario. Figure A-70 shows system performance for cellular network regarding uplink throughput. As can be seen here, the required throughput per scenario can be reached with a reliability of 96.3%.

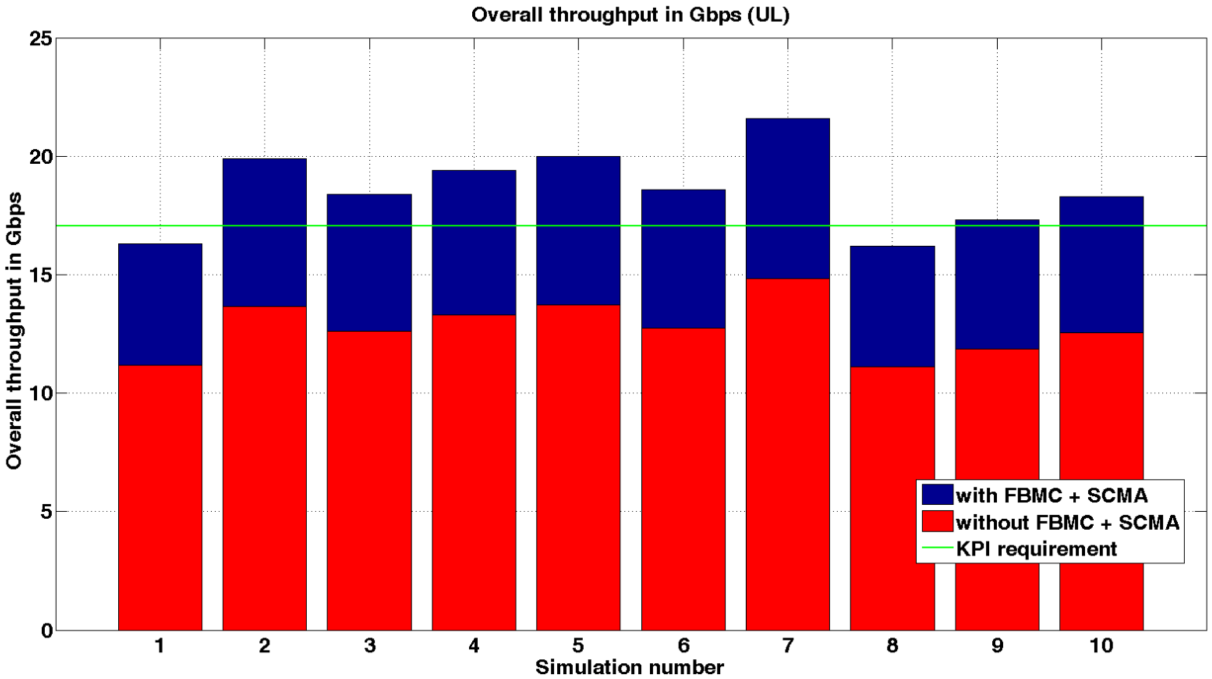

Figure A-70: Uplink throughput with FBMC + SCMA.

Overall results

Figure A-71 shows the CDF of the overall system throughput for the downlink including both cellular and D2D links. A set of 100 independent simulations has been executed. As we can see here, in 96.1% of all simulation set the required minimum throughput of 85.2 Gbps per simulation scenario could have been reached.

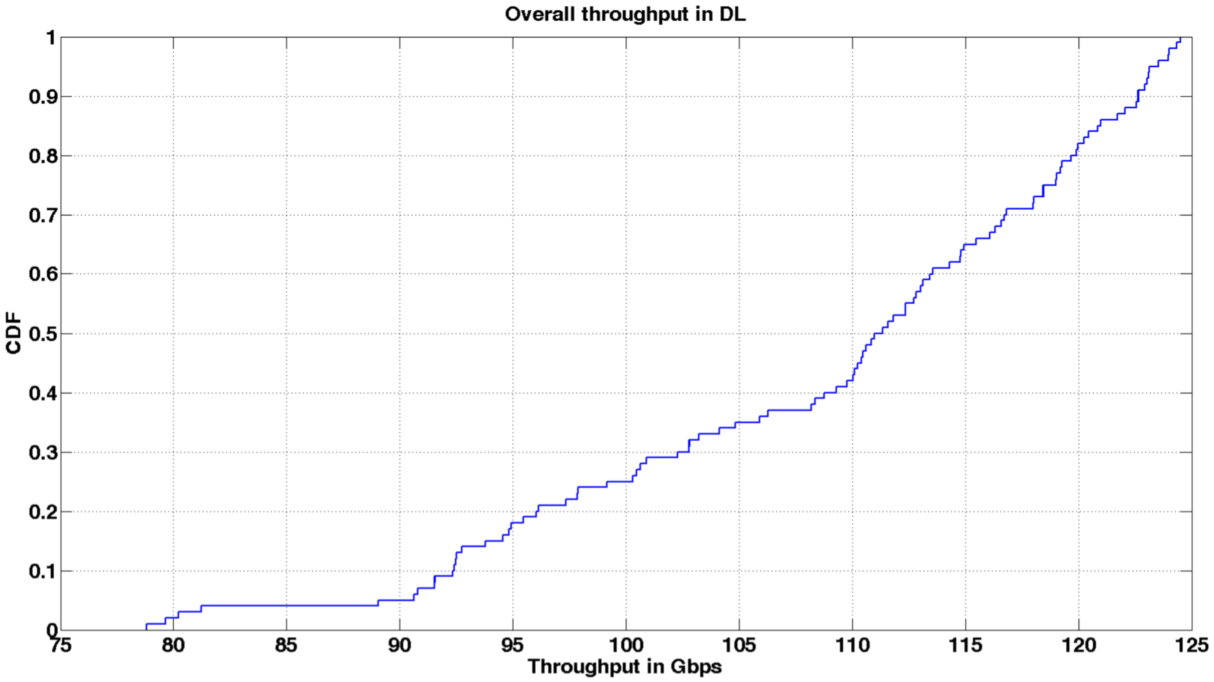

Figure A-71: Overall throughput.

A.7 TC7: Blind Spot

A.7.1 Description of the test case

The Quality of Experience (QoE) of mobile services is significantly degraded in blind spots such as rural areas due to the lack of radio resources and/or low coverage caused by insufficient network deployment. Furthermore, in areas with low coverage, the transmission power generally increases to compensate for the higher propagation losses. This lowers the battery life of smartphones and tables, which is considered as a critical factor for user satisfaction. A very important aspect to consider in this test case is the high correlation between the distribution of vehicles and users. In other words, the higher the data traffic demands, the higher the number of vehicles in the proximities. This property can be exploited to cope with the presence of blind spots in the service area in a flexible and cost efficient manner. This test case is used to look for solutions that could alleviate the degradation of QoS in areas with low coverage.

A.7.2 Main KPI and requirements

Main KPIs of TC7 are summarized in the table below. More details on the definition of these KPIs can be found in [MET13-D11].

Table A-31: Main KPIs defined for TC7 [MET13-D11]

KPI	Requirement
Experienced user data rate	100 (20) [Mbps] DL (UL) with 95% availability in blind spots
Energy efficiency	50% (30%) reduction for UE (infrastructure) should be achieved compared with legacy network

A.7.3 Simulation models

Simulations follow simulation details included in [MET13-D61]. In the following, we include a short description of these models and deviations.

Environmental model

According to the description of the test case, we may have a blind spot due to the lack of transmitters, like in rural areas, or due to an insufficient cell deployment. In this sense, TC2 layout is proposed also for the evaluation of the blind spot effect, assuming that only the macro-transmitter is active in the area. Moreover, 50 % of users are randomly distributed near the vehicles, within a radius of 50 m from each vehicle. Vehicles are randomly distributed along the streets or parking areas.

In order to obtain general conclusions, a more homogeneous user distribution has been forced over the scenario. This was achieved preventing the users to be distributed in the park located at the central part of TC2 scenario.

Deployment considerations

Deployment considerations are those of TC2, but only including the macro-cell site.

Propagation model

The propagation models used in TC7 are PS#3 for the macro-cell outdoor coverage and PS#9 for vehicle-to-pedestrian communication, as proposed in [MET13-D61].

Traffic model

Only outdoor traffic is considered. In order to obtain general conclusions, traffic model is assumed to be a constant bit rate model characterized by fixed packet size and time between packets.

Mobility model

In this assessment, users are static, i.e., static snapshots of the system are studied. In these snapshots short term channel parameters change according to an assumed mobility for each user, but long term channel parameters (shadowing, path losses, etc.) do not change.

A.7.4 Assumptions

Concerning the specific mechanism that this concept of moving network 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 assumed to be as efficient 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 TC7 scenario, where we have assumed the caching probabilities for each traffic type shown in Table A-32.

Table A-32: 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

In this assessment only VT NRT has been studied, in the specific form of a constant bit rate traffic with fixed time between packets of 40 ms. Therefore with probability 0.6 a content will be cached in a car. We have additionally decreased this value to take into account that not all cacheable content will be available in all cars. Assuming that 80% of cacheable content is in any car, we have used an effective caching probability of 0.5 in this study.

Cars can also operate in relaying mode for pedestrians in their vicinity, similarly to the Closed Subscriber Group (CSG) concept. Within the car, a small cell forwards the data to the final destination. Thanks to relaying, users with poor direct link to base stations may benefit from a better communication path comprised of the access link to the relay and the backhaul link from the relay to the cell. Better characteristics of the antenna and the receptor in the vehicle make the dual hop path become better than the single hop. There are two options for the support of wireless relaying via the vehicles in the scenario. First option consists in using an outband approach in which backhaul and relay links operate in different bands. The second option is based on the inband approach and a multi-flow combination with network coding. In this case, backhaul and relay links might share the same spectrum in an efficient manner. This simulation study aims at evaluating the feasibility of this second option.

The evaluation of the TC7 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 Moving Network-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 next procedure is followed user-by-user in a random order to determine if the traffic of a user is cached or relayed:

- Get the best serving cell of the user and the wideband SINR when connecting to this cell.
- Find the closest cars (within a range of 85 m)
- If caching is active,
    - get for each neighbour vehicle not serving cached content to other users, in ascending order of distance, the wideband SINR of the vehicle-to-pedestrian link. If the SINR is higher than 20 dB the vehicle is candidate to serve the user. Randomly determine if the vehicle has cached the content requested by the pedestrian, according to probability mentioned above. If content is cached in the vehicle, this vehicle is selected to serve the user.
- If relaying is active and no vehicles were selected in the previous step,
    - get for each vehicle the best serving cell and the wideband SINR when connecting to this cell
    - if the vehicle-to-cell SINR is such that throughput achievable in this link would be higher than two times the throughput achievable through direct link from cell to pedestrian, the vehicle is selected to serve the user.

Range of 85 m is calculated assuming PS#1, a target SNR of 20 dB and 20 dBm EIRP in the car. While a vehicle can only serve cached content to one user, it can be serving multiple users as a relay.

Wideband SINR calculations consider the different relaying configurations, and how frequencies and time are distributed among the different nodes of the system.

Wrap around has been considered in the assessment, therefore the same amount of pedestrians and cars are distributed through multiple replicas of the TC2 atomic scenario, while statistics are only collected from pedestrians served by cells placed in the central area of the scenario, or by vehicles whose best server is one of the cells placed in the central area. In fact, cells placed in replicas of the scenario do not schedule users dynamically but transmit a constant power, fixed to the maximum amount of available power in this assessment.

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-33.

Table A-33: 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

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

- Antenna gain of the vehicles is 1.5 dBi (accounting feeder losses).
- The noise figure of the vehicle receivers is 5 dB.
- Transmitted power over each 20 MHz is 46 dBm for macrocells, and 20 dBm for vehicles.

A.7.5 Technology components

In this test case, all vehicles may act as relay stations for the end users. Obviously, the first thing to take into account is the selection of the most appropriate nomadic node (T4.3-TeC3-A2) and the possibility of switching on or off this functionality in the vehicles depending on the specific context (T4.3-TeC3-A2). Moreover, T3.3-TeC1 solution is used to coordinate the multi-flow transmissions in the TDD mode. The table below summarizes all TeC included in the simulations.

Table A-34: Main technology components evaluated in TC7 simulations.

WP/Taks	TeC	Name
T3.3	TeC1	Coordinated multi-flow transmission for wireless backhaul
T4.3	TeC3-A2	Dynamic Nomadic Node Selection for Backhaul Optimization
T4.3	TeC4-A2	Activation and de-activation of small cells in UDN

A.7.6 Results

KPIs for TC2 included an experienced data rate of 300 Mbps in downlink and 60 Mbps in uplink, and an average data rate per user of 5 Mbps in downlink and 1 Mbps in uplink. In TC7, only experienced data rate has been specified: 100 Mbps in downlink, and 20 Mbps in uplink. We have translated these figures to average data rates of 1.7 Mbps in downlink and 0.3 Mbps in uplink, according to the relation provided for TC2.

In order to conduct our assessment, a 10 MHz bandwidth for macro-cells was assumed. A nominal data rate of 50 kbps was selected to study the performance of the system and calculate the bandwidth increase needed to fulfil the requirements.

Multiple configurations have been studied. For the sake of comparison a configuration without caching and relaying is the reference (blue line in figures). There is a configuration with layer 3 (L3) relays operating in FDD, where frequency used in relay-user link is different to the frequency used in the other links (green line in figures). Another configuration with layer 2 (L2) relays in FDD with outband backhaul link (red lines in figures) has also been considered. Concerning caching, a configuration with caching but without relaying is simulated (cyan lines), and a configuration with caching and L3 relays is also considered (magenta lines). Finally, two more L2 relay configurations have been assessed: with FDD inband half-duplex (yellow lines), and TDD inband half-duplex (black lines). The text “hd” in legends stands for “half-duplex”.

According to the results shown in Table A-35, in order to have 100 Mbps of experienced throughput in downlink for 90% of users, bandwidth should be increased about 140 times for the configuration without relaying and without caching. That is, up to 1.4 GHz. Nevertheless, to achieve a 95% availability, we need about 2.9 GHz. In fact, we need two times more bandwidth in FDD, However, in this study no multiplexing gain has been considered. Assuming a typical multiplexing gain of 6 (being conservative, we assume that with 8 antennas up to 6 users can be spatially multiplexed), it turns out that for the simpler configuration, in FDD, we would need about 0.97 GHz to fulfil the METIS objective for this test case.

In the configuration with caching, the cellular spectrum could be reduced 0.7 times, down to 0.68 GHz. However, additional bandwidth is required for links to perform caching. Users with cache present about 1.9 Mbps with 10 MHz. Therefore, about 526 MHz is needed in downlink. Considering a multiplexing gain of 4, more realistic for D2D, the required spectrum for uplink and downlink would be 258 MHz. The aggregate needed bandwidth would be 0.938 GHz .This value is quite similar to the bandwidth needed without caching. However, the configuration with caching achieves reduced latencies, above all for those users communicating with a cache server.

The analysed L2 relay configurations are not able to reduce even further the required bandwidth. Due to their high bandwidth consumption (L2 FDD outband) or low experienced throughput (L2 inband half-duplex configurations).

T3.3-TeC1 solution proposes a coordinate multi-flow transmissions in TDD mode that if generalized to this scenario could reduce even further the needed bandwidth. Results would be similar to those of L2 FDD outband, but with half the bandwidth needs. The needed bandwidth would be 0.88 times that of the simpler configuration, that is, 0.85 GHz. The lower bandwidth requirement comes at the cost of increasing transmission powers at base stations and user equipment, not being this increase valid for many scenarios.

Table A-35: Median of mean user E2E latency in legacy system.

Configuration	Experienced throughput	Mean E2E packet latency	Normalized bandwidth req
no caching, no relaying	5% CDF: 340.4 kbps 80% CDF: 1.9 Mbps	21.6 ms	2
L3 relaying	5% CDF: 278.8 kbps 80% CDF: 1.9 Mbps	22.3 ms	4
L2 FDD outband relaying	5% CDF: 301.3 Mbps 80% CDF: 1.9 Mbps	21.9 ms	4
caching	5% CDF: 408.0 kbps 80% CDF: 1.9 Mbps	18.7 ms	<4 (2.5)*
caching + L3 relaying	5% CDF: 286.8 kbps 80% CDF: 1.9 Mbps	19.0 ms	< 6 (4.5)*
L2 FDD inband half-duplex relaying	5% CDF: 138.1 kbps 80% CDF: 1.5 Mbps	24.6 ms	2
L2 TDD inband half-duplex relaying	5% CDF: 64.4 kbps 80% CDF: 985.5 kbps	30.0 ms	1
* Exact value depends on the bandwidth allocated to cache link. Realistic values indicated in parenthesis.			

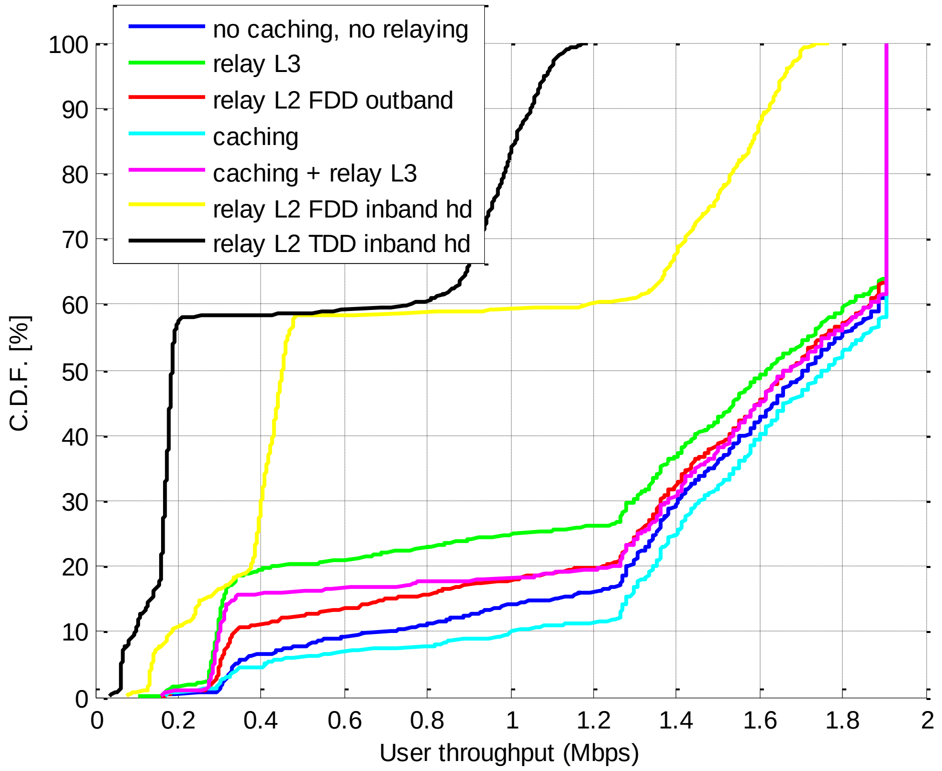

Figure A-72: CDFs of experienced user throughput.

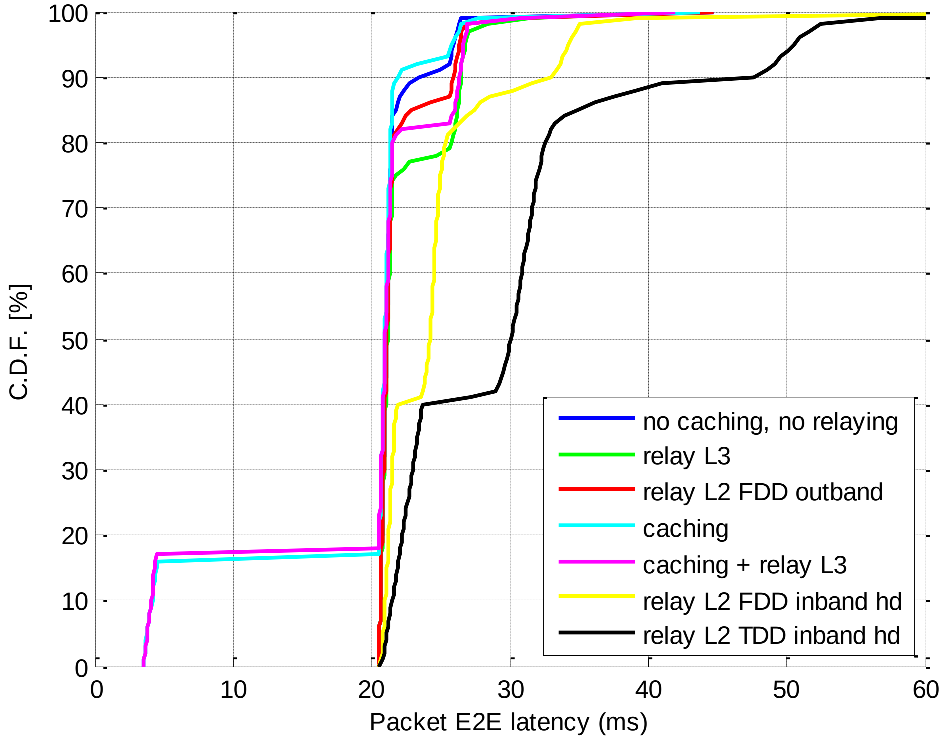

Figure A-73: CDFs of E2E packet latency.

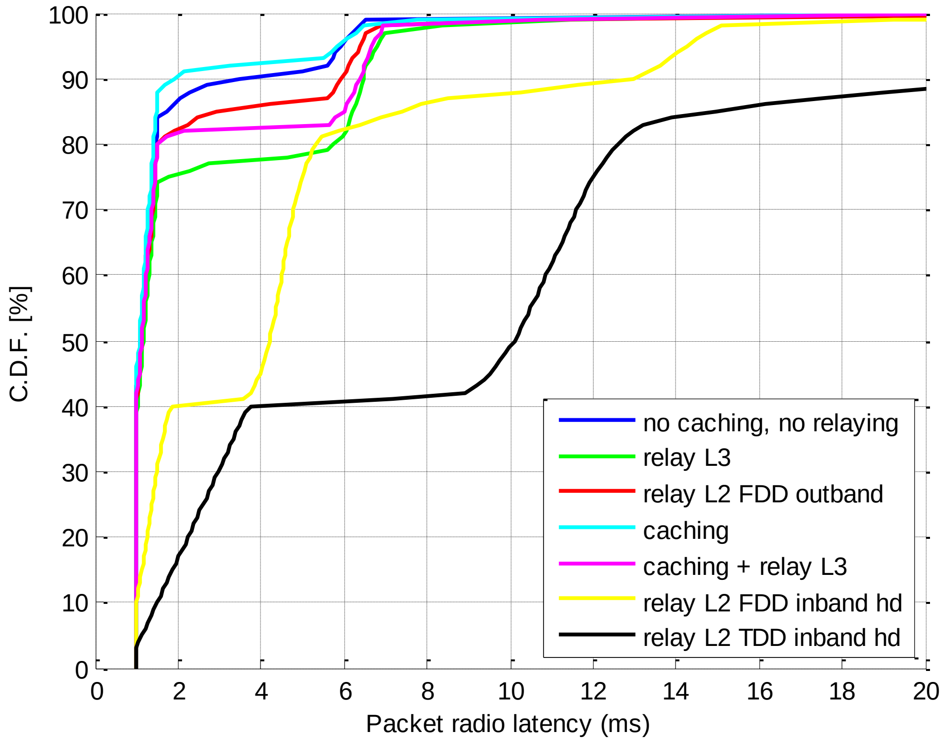

Figure A-74: CDFs of radio packet latency.

Simulation results have demonstrated that in this case mobile relaying does not improve the performance of the system. The reason is that this layout is close to an interference-limited scenario, and therefore the mobile relaying effect, more useful in noise-limited scenarios, is reduced.

Moreover, simulations have proven two positive effects of caching. First, caching reduces E2E latencies of cached users. See the lower percentiles of the cyan and magenta lines at Figure A-73.

The second positive effect of caching, as proposed in this assessment, is the offloading of traffic. About one fifth of the users are offloaded from the macro layers. See in Figure A-73 the range of latencies between 20 and 25 ms. Configurations with caching concentrate more users in the lower part of this range, precisely due to the offloading of the macrocells that have more resources to serve other users.

A.8 TC8 Real-time remote computing for mobile terminals

A.8.1 Description of the test case

Real-time remote computing for mobile terminals (TC8) focuses on provision of remote services in fast mobility scenarios. Information society of 2020 and beyond will demand a high performing data connection not only in stationary use cases (e.g. in the office or households), but also on-the-go at higher speeds, while using public transport or while traveling with a car. This requires a robust communications with very low latencies together with an availability that is close to 100%, while moving at high velocities.

In-vehicle users currently experience a limited QoS due to the channel aging, insufficient antenna capabilities and the penetration loss of the vehicle shell (especially for cars, trains and buses with metal-film windows the body penetration loss can reach up to 20 dB). All these challenges need to be addressed in order to provide a well performing solution for TC8.

A.8.2 Main KPI and requirements

Main KPIs of TC8 are summarized in the table below. More details on the definition of these KPIs can be found in [MET13-D11].

Table A-36: Main KPIs defined for TC8

Variable/parameter	Value
Performance targets	
Experienced user throughput	100 [Mbps] in downlink 20 [Mbps] in uplink
Traffic volume density	60 [Gbps/km^2] (for cars on a highway)
Latency	Less than 10 [ms] E2E latency
Availability	99% in space and time; Multi-operator solutions are required in order to serve users with different network operator contracts
Reliability	High reliability for real-time processing services; 95% of the packets shall be transmitted successfully within a maximum E2E latency of 10 [ms]
Constraints	
Energy efficiency (UE or other devices)	Significantly reduced battery consumption; UE transmit power should be constraint to the minimum
Cost (infrastructure)	Infrastructure cost should be kept on the same level per area as today.
Cost (UE or other devices)	No additional costs for UEs; solutions should be transparent for the devices
Test case definition	
User/device density	Less than 5 simultaneously active devices/car; approximately 100 cars per [km^2] (on a highway) Up to 50 user devices simultaneously active per bus Up to 300 user devices simultaneously active per train
User mobility	up to 350 [km/h]

A.8.3 Simulation models

A two-fold approach is proposed for TC8 with different simulation assumptions.

First approach focus on utilization of OFDMA based access in combination with flexible UL/DL TDD air interface and predictor antennas mounted on vehicles in order to cope with channel aging effects (channel aging limits the performance of closed loop MIMO schemes in legacy LTE-A). We refer further to this evaluation as OFDMA approach

Second approach exploits the benefits of SCMA and compares it with performance of OFDMA. In this approach, both SCMA and OFDMA simulations are carried out with the same simulation assumptions considering necessary changes for both access methods (e.g., receiver type or MCS tables). In sections related to TC8 evaluation we refer to the second approach jointly as an SCMA approach.

Environmental model

Evaluation of OFDMA approach is carried out in a dense urban environment of TC2 as described in [MET13-D61]. SCMA solution is simulated in a simplified Madrid Grid environment depicted in Figure A-75.

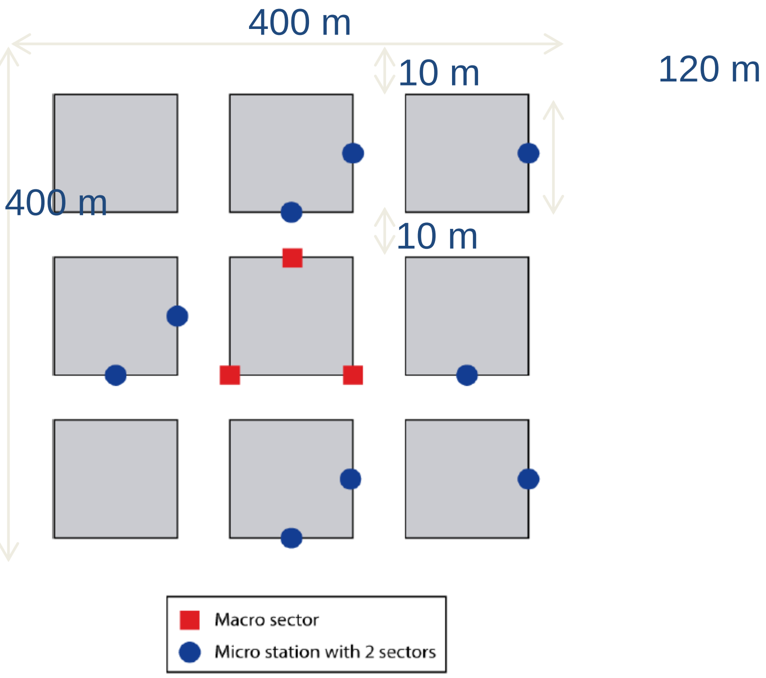

Figure A-75: Simplified Madrid Grid environment used for evaluation of SCMA approach for TC8.

In both approaches only outdoor environment is considered and no simulation of indoor environment is performed.

Deployment considerations

For the OFDMA approach, we've deployed a number of access nodes with the ISD of 20 m. Access nodes (small cells) are deployed on facades of the building 5 m above the ground level and are equipped with omnidirectional antennas. We are exploiting a moving relay nodes concept where vehicles (cars or buses) are equipped with two sets of antennas. The one mounted on the rooftop is used as a predictor and (candidate) reception antennas that enable an efficient wireless backhaul link. Second set of antennas is used to provide the connectivity inside the vehicles. This division is used to circumvent vehicular penetration losses and is an efficient solution as antenna systems on the rooftop of a vehicle can be more advanced comparing to the handheld devices. 4x4 MIMO transmission and IRC receivers are used.

In evaluation of SCMA approach for TC8, a micro station deployment as presented in Figure A-75 is used. Micro cells are equipped with 2 sector antennas resulting in 18 sectors in total, operating in an open loop 2x2 spatial multiplexing mode. Micro stations are transmitting with the maximum power of 28 dBm. Message Passing Algorithm (MPA) receivers are used for SCMA simulations and Maximum Likehood Detection (MLD) receivers are used for OFDMA simulation in SCMA approach. SCMA operates in multiple access mode meaning that SCMA layers are shared among multiple users over the same time-frequency and space resources.

Macro layer is not simulated in both approaches.

Propagation model

Propagation model for OFDMA simulations is PS#1 (micro O2O) as proposed in [MET13-D61]. Performance is evaluated for frequency of 40 MHz in 2.6 GHz band.

SCMA simulations were done using ITU-TU fading channel. Available bandwidth was 10 MHz at 2.6 GHz carrier frequency.

Traffic model

In the approach using OFDMA traffic model keeps similar traffic volume as defined for users in vehicles in TC2. Traffic pattern of TC2 is defined as FTP2 bursty traffic model [3GPP10-36814] with packet sizes of 20 MB and IAT of 167 s for 3873 users. To keep the similar traffic volume for 1464 (on average) users of TC8, this traffic was scaled to the transmission of 2.56 Mb every second, split with the ratio of 4:1 between DL and UL. Packet IAT is modelled with a Poisson process.

For SCMA approach a FTP2 bursty traffic model [3GPP10-36814] is used. Packets are generated according to a Poisson distribution with an average IAT of 0.1 s. Packet size is varying depending on the total load (total load was changing from 50 Mbps to 160 Mbps). Only DL transmission is simulated.

Mobility model

Figure A-76 depicts mobility traces used in OFDMA approach. Only users in vehicles are considered (pedestrians are excluded from this evaluation). In the simulated area there are 8 buses (with 1 to 50 users) and 420 cars (with 1 to 5 users) resulting in the average of 1464 users. Traffic traces were obtained using SUMO software and follow description in [MET13-D61]. Realistic mobility behaviour includes obeying traffic lights, turning, car dimensions, etc. Vehicles are allowed to move with the maximum speed of 50 km/h.

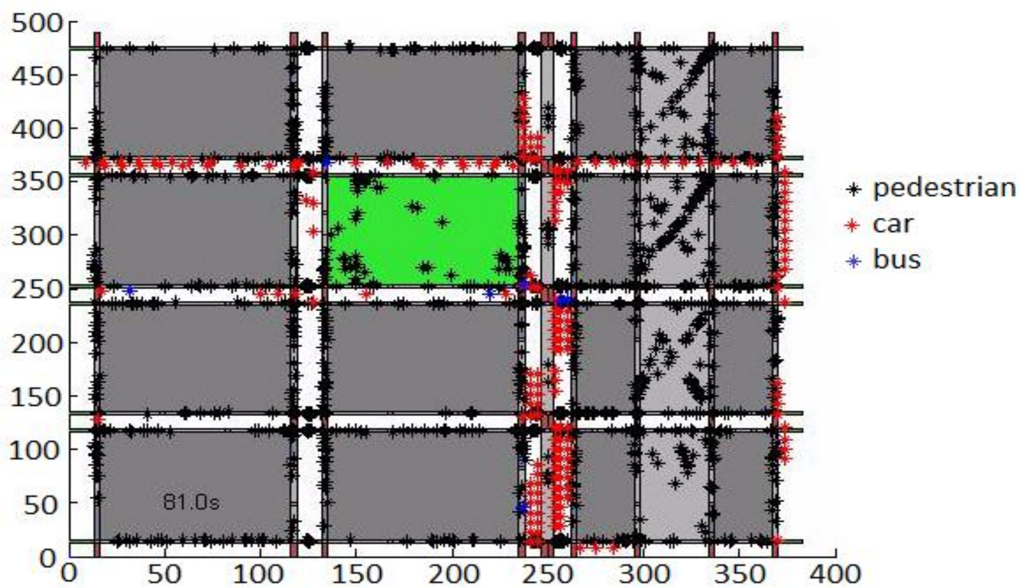

Figure A-76: Mobility traces in OFDMA approach [MET14-Web]. For the TC8 evaluation, pedestrians are not taken into account.

In SCMA approach a total number of 560 users are dropped uniformly in the streets. Users are static during simulation, but several user drops are averaged out to get final results. The fading channel changes over time to account for the Doppler effect (user mobility vector of 3 and 120 km/h).

A.8.4 Assumptions

For OFDMA approach several assumptions are made. Only performance of wireless link between the small cell and antenna set mounted on the rooftop of the vehicle is taken into account (cf. Figure A-77), as it is considered as the limiting factor. Users inside a vehicle are served by the antenna set connected to the one on the rooftop. Inside antennas are moving along with users, hence this link is not exposed to detrimental Doppler/channel aging effects. Traffic of the wireless backhaul is the sum of traffic processes of users inside the vehicle. Small cells are operating in the mode of decoupled control/user plane. Control plane is handled by macro that provides a seamless connectivity for fast moving vehicles, while the user plane is handled by the small cell in proximity. Several solutions based on this setup where proposed recently (e.g., phantom cell, soft cell) as it solves to problem of mobility and handovers (small cells are treated as transmission point and from the perspective of moving user it is perceived as being served by the same cell as long as the control plane is handled by the same macro). Performance of control plane is not explicitly studied.

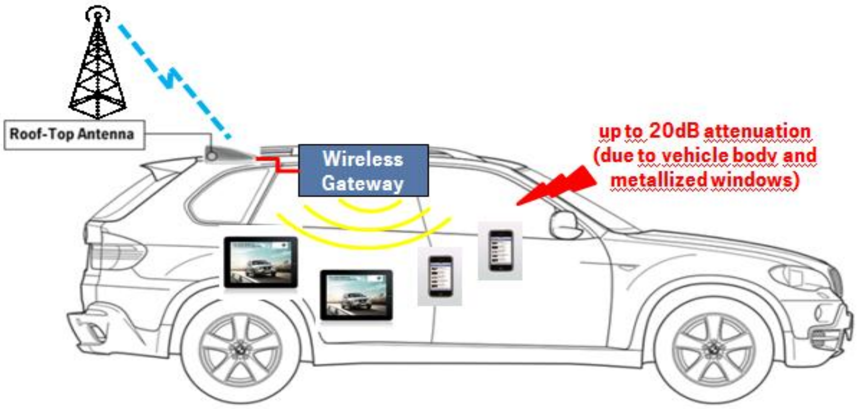

Figure A-77: Concept of dual set antennas for users on the move.

Additional assumptions for SCMA approach are captured in Table A-37.

Table A-37: Additional assumptions for SCMA approach.

Parameter	Value
Number of antennas at transmitter or receiver side	2 uncorrelated antennas
System bandwidth	10 MHz at 2.6 GHz carrier frequency
Channel type	ITU-TU fading channel
Transmission Mode	2×2 SM, open-loop
User speed	3 km/h or 120 km/h
HARQ	Incremental redundancy (IR) HARQ with up to 3 retransmissions
Scheduler	Proportional fair scheduler

RBG size for scheduling	50 RBs for wideband scheduling
Waveform	Multiuser SCMA (MU-SCMA), OFDMA
SCMA codeword dimension	4 OFDMA tones
SCMA receiver assumption	MPA joint detector PHY abstraction
OFDM receiver assumption	MLD PHY abstraction [MLK+12]
CQI feedback	Perfect CQI. Feedback report every 10 TTIs
OLLA	Enabled with 10% BLER for first transmission
MCS table	Follows LTE standard for OFDMA and specific MCS table for SCMA
MU-SCMA	Follows designed pairing algorithm , power allocation, and multi-user detection scheme
Mobility	Users are static during simulation but several user drops are averaged out to get final results. The fading channel changes over time according to Doppler frequency.

A.8.5 Technology components

In TC8 the main challenge is to provide a reliable, high data rate connection for the users that are on the move and traveling in vehicles such as cars or buses.

For the evaluation of the first of considered approaches based on OFDMA, in order to fully exploit the available spectrum we've used a dynamic TDD mode (WP2-TeCC1.2) that allows flexible UL and DL slot allocation, depending on the instantaneous traffic conditions. Frame structure as proposed in WP2-TeCC1.1 enable short latencies and efficient PHY signalling (control messages for UL and DL can be exchanged in every slot, regardless of the direction of the user's data transmission). As the focus in this TC is to provide a fast and reliable connection to the vehicles on the move we are also adapting predictor antennas as in T3.1-TeC6. In this setup predictor antennas are used to enable processing of signal in appropriate candidate antennas. This approach allows alleviating the detrimental effect of channel aging caused by moving at high velocities. Finally, a decentralized RRM scheme for flexible UL/DL TDD base air interface is used, as defined in T4.1-TeC6-A1.

In SCMA approach we've utilized solution proposed in WP2-TeCC11 and T4.2-TeC17. This SCMA based approach multiplex users in code domain, using limited knowledge in terms of CQI, and separate them at receiver side using MPA receivers. Such attempt allows avoiding the problem of CSI feedback as this scheme can be used as an open-loop scheme.

Table A-38: Main technology components evaluated in TC8 simulations.

WP/Taks	TeC	Name
OFDMA approach		
WP2	TeCC1.1	Air interface in dense deployment – Frame structure
WP2	TeCC1.2	Air interface in dense deployment – Dynamic TDD
T3.1	TeC6	Adaptive large MISO downlink with predictor antenna for fast moving vehicles
T4.1	TeC6-A1	Smart resource allocation in a UDN scenario (distributed RRM scheme part)
SCMA approach		
T2.3	TeCC11	Sparse Code Multiple Access (SCMA)
T4.2	TeC17	Downlink Multi-User SCMA for Mobility-Robust and High-Data Rate Moving Networks (MN-N)

A.8.6 Results

OFDMA approach

For the OFDMA scenario a case where small cells were deployed with 20 m ISD at the facades of the building was evaluated. Cells on the edge of Madrid Grid setup were excluded from the statistics and were used to create a realistic interference profile. Downlink and uplink packet delay's CDFs are depicted in Figure A-78. Worse UL performance is offset by 4 times lower packet size in case of UL transmission.

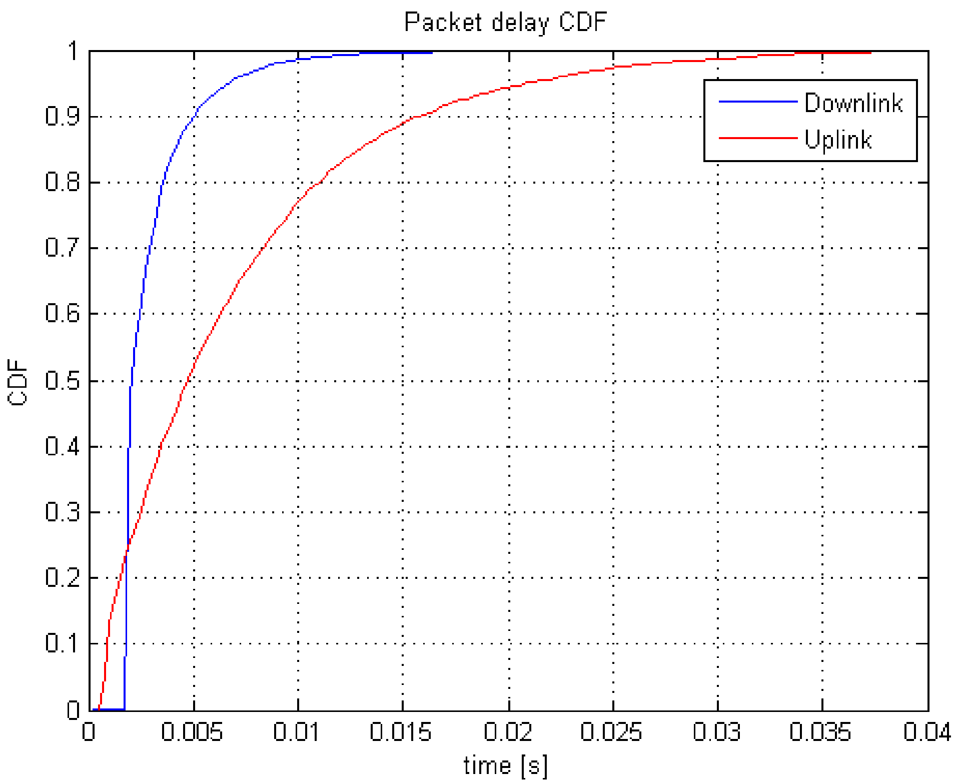

Figure A-78: CDF of downlink and uplink packet delay for OFDMA approach evaluation

With proposed setup we've managed to provide a high performing solution for urban scenario of TC8. High performance was achieved with reasonable fairness among the users. Performance of cell edge users is captured in Table A-39. We've managed to reach the required performance of at least 100 Mb in DL and 20 Mb in UL using 40 MHz of radio bandwidth. It is reasonable to assume that with an appropriate scheduler's settings (e.g. QoS aware scheduler) it would be quite straightforward to reach this performance with lower amount of bandwidth.

Table A-39: Individual user's packet throughput for the cell edge users in OFDMA approach.

Perceived throughput [Mbps]	DL	UL
5^{th} %	303.4	24.3
10^{th} %	422.5	32.5

Simulation's were carried out with 1464 users on average generating load of ≈18.2 Gbps/km^2, although as depicted in Figure A-79, traffic is limited to the streets and concentrated in Grand Via of TC2. This implies that in order to provide a well performing and cost effective system we also need to allow for a semi-dynamic shift of available radio resources to the congestion point, by means of e.g., dynamic activation/deactivation of access node and dynamic assignment of backhaul resources.

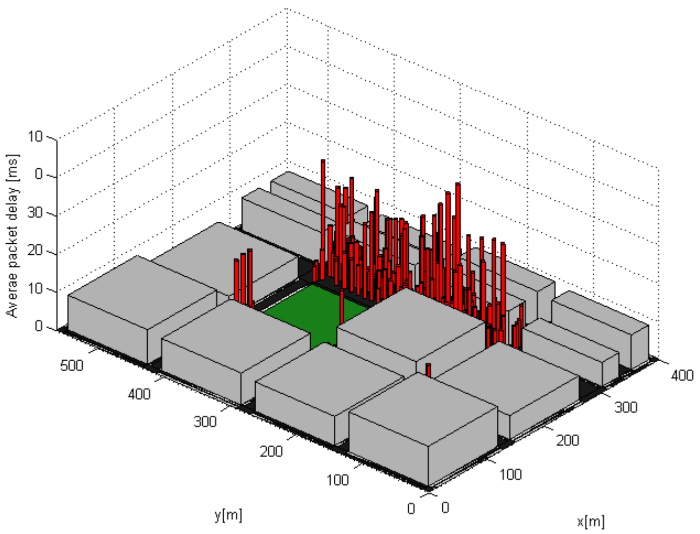

Figure A-79: Snapshot of a spatial distribution of an average packet delay of a user in OFDMA approach

SCMA approach

The second of considered approaches (SCMA approach) focuses on evaluation of MU-SCMA in comparison with OFDMA. Both approach utilizes 2x2 open loop spatial multiplexing MIMO. SCMA allows for code multiplexing of the users using SCMA codewords with length of 4 OFDM tones each. Multiple codewords are spanned over 10 MHz system bandwidth with 50 RBs. For OFDMA also a wideband scheduling (50 RBs) is assumed. Performance results are presented in Figure A-80 and Figure A-81.

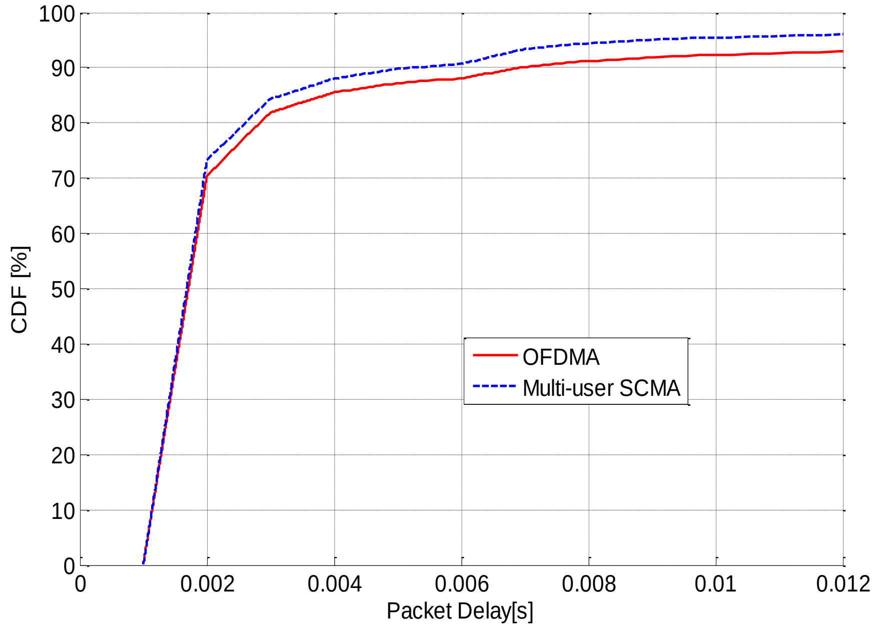

Figure A-80: Packet delay distribution at the speed of 3 km/h for the total load of 84 Mbps in SCMA approach with 10 MHz system bandwidth.

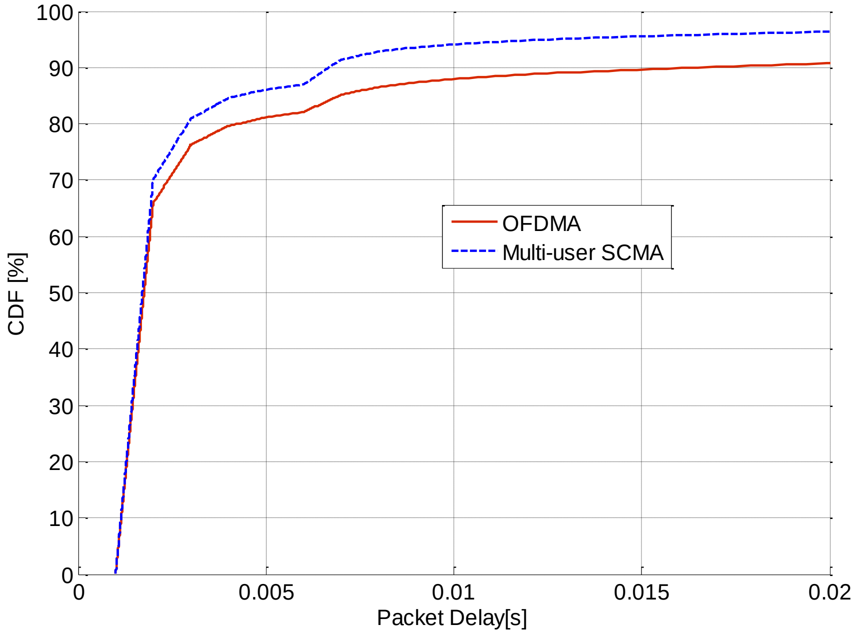

Figure A-81: Packet delay distribution at the speed of 120 km/h for the total load of 84 Mbps in SCMA approach with 10 MHz system bandwidth.

In considered setup MU-SCMA provided a significant gain over OFDMA which manifests in the cell edge performance. These results are captured in Table A-40.

Table A-40: Perceived throughput for the cell edge users in SCMA approach at the speed of 3 and 120 km/h

Perceived throughput [Mbps]	10th % 3 km/h	5th % 3 km/h	10th % 120 km/h	5th % 120 km/h
OFDMA	2.17	0.53	0.92	0.2
MU-SCMA	2.86	1.69	2.25	1.19
Gain	31.8%	217%	145%	495%

Figure A-82 and Figure A-83 depict the percentage of packets that can be delivered within 10 ms for different traffic loads. When taking the criterion of 95% of delivered packets, MU-SCMA can support ≈40% higher load comparing to OFDMA for both velocities of 3 and 120 km/h. When we relax this criterion to 90% of delivered packets, MU-SCMA supports 60% higher load for the velocities of 3 km/h and 70% higher load for the velocities of 120 km/h.

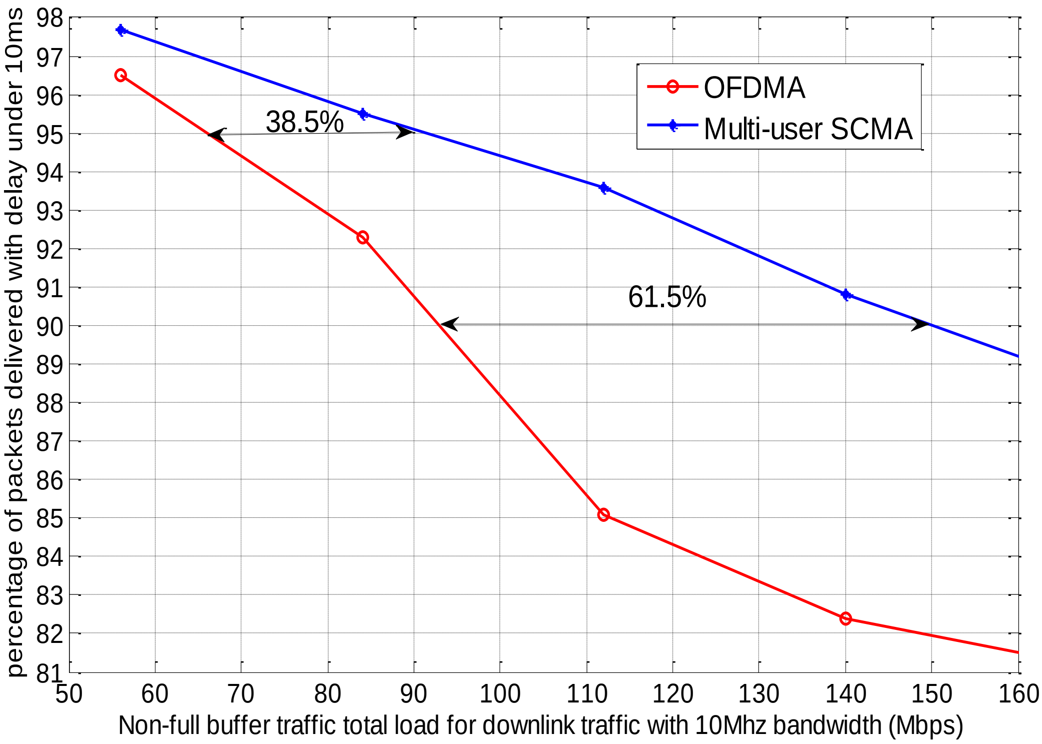

Figure A-82: Performance of MU-SCMA vs OFDMA for 3 km/h in SCMA approach.

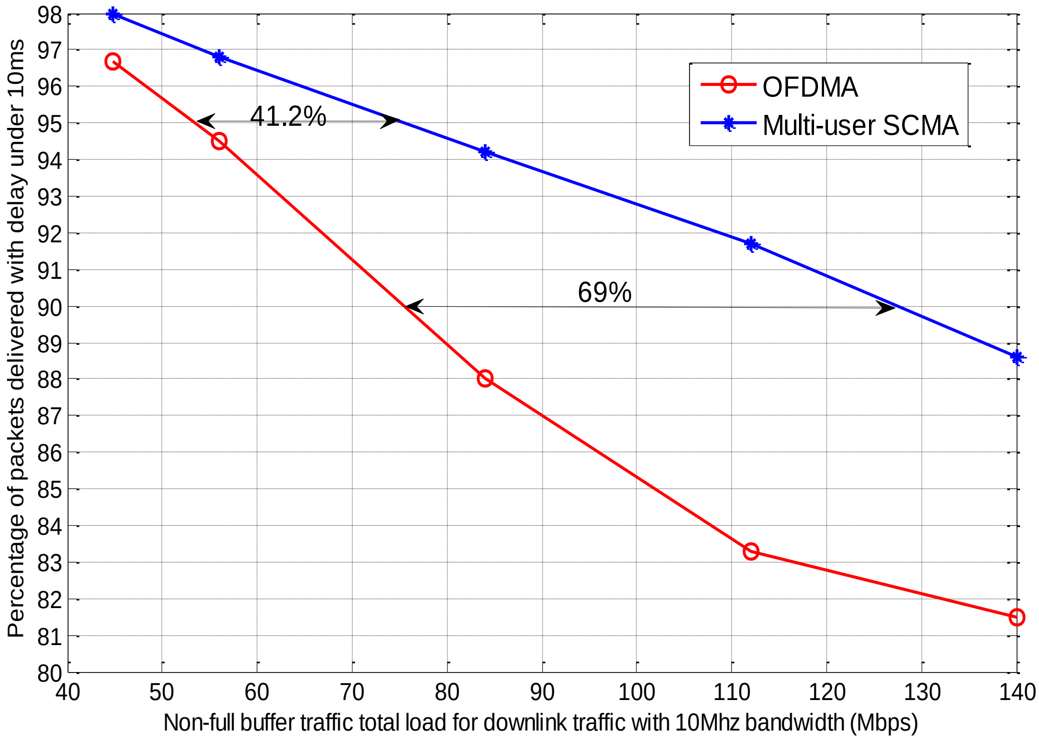

Figure A-83: Performance of MU-SCMA vs OFDM for 120 km/h in SCMA approach.

A.9 TC9: Open Area Festival

A.9.1 Description of the test case

Test Case 9 “Open Area Festival” models a small rural area, less than 1 km^2, which is visited by at least 100 000 visitors during a 4-day long multi-stage open air music festival. For example, the visitors want to be able to locate interactively, share real-time or recorded high definition video clips from the simultaneous ten stages, and to access the Internet at a high-speed that is greater than 30 Mbps, especially during the breaks between the performances. The high density of active users leads to a huge amount of aggregated data traffic about up to 900 $Gbps/km^2$. On the festival there are also thousands of trash bins, portable toilets, hundreds of vending machines, food stalls, and other service devices which rely on wireless communication to support their reliable and timely operation and maintenance. The security is ensured by good and reliable communication between headquarters, guards, medics, surveillance cameras, and a wide range of sensors. But normally in such remote area, only a small number of people exist, thus the mobile access network nodes are very sparsely deployed, i.e. the normal network is highly under dimensioned.

A motivation for this test case is to enhance the user experience of an extremely high density of active users/devices with a huge amount of aggregated traffic in terms of user throughput, availability, and reliability in an area where normally the mobile access network nodes are sparsely deployed, i.e. the normal network is highly under-dimensioned. The test case includes the challenges shown below that fit to the METIS overall goals that may require revolutionary approach.

- Accommodating a high density of users and devices substantially far beyond 1000 times compared to usual situation (only a very small amount of people (or almost no people) are present there during the rest of the year except the festival events in such a remote area).
- Although there are some existing solutions available, e.g. mobile eNB, they are far below the customers' satisfaction in terms of end-user throughput and latency currently. The challenge of the test case indicates the improvement in enhancing the user throughput by more than 10 times relative to the typical situation of today even in the very dense scenario like the test case.
- The test case implicates the challenge to simultaneously accommodate the diverse QoE requirements of conventional smartphone / handset users and machines / devices

The potential solutions of the test case may provide the operators or festival organizers the possibility to offer rich wireless communication services at lower deployment cost and energy consumption than with today's solutions. Thus, new players, e.g. temporal local network providers, may play an important role by making a contract with the festival organizers who like to provide better festival experiences to users. There is no fixed permanent infrastructure in the festival area.

From technical solutions point of view, access to new high frequency (cmW, mmW) spectrum is a must. Multi-antenna solutions like beamforming are needed to increase the areal spectral efficiency. Short wave lengths enable also fitting of high number of antennas in end user's device. Low mobility helps in CSI feedback signaling and beam tracking.

Opportunistic local data sharing via network controlled direct D2D is one key solution to offload the traffic locally as much as possible.

A.9.2 Main KPI and requirements

Main KPIs of TC9 are summarized in the table below. More details on the definition of these KPIs can be found in [MET13-D11].

Table A-41: Main KPIs defined for TC9 [MET13-D11].

KPI	Requirement
Traffic volume per subscriber	3.6 [Gbyte/subscriber] DL+UL during busy period of the festival
Average user data rate during busy period	9 [Mbps] (DL/UL)
Traffic volume per area	900 [Gbps/km^2] DL+UL
Experienced user data rate	30 [Mbps] (DL or UL) at 95% availability • Downlink: One packet size of 40 [Mbyte] generated per minute and user throughout of totally about 2 hours during the busy period of the festival event. Expected to be downloaded less than 10 [s] in 95% probability.

	• Uplink: In case of data sharing, same for downlink. In case of web-browsing and sensor, the required data rate can be much lower
Latency for machine traffic	Less than 1 [s] with 99% probability
Fixed permanent infrastructure	Not existing within the open area

A.9.3 Simulation models

Simulations follow simulation details included in [MET13-D61]. In the following, we include a short description of these models and deviations.

Environmental model

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

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

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

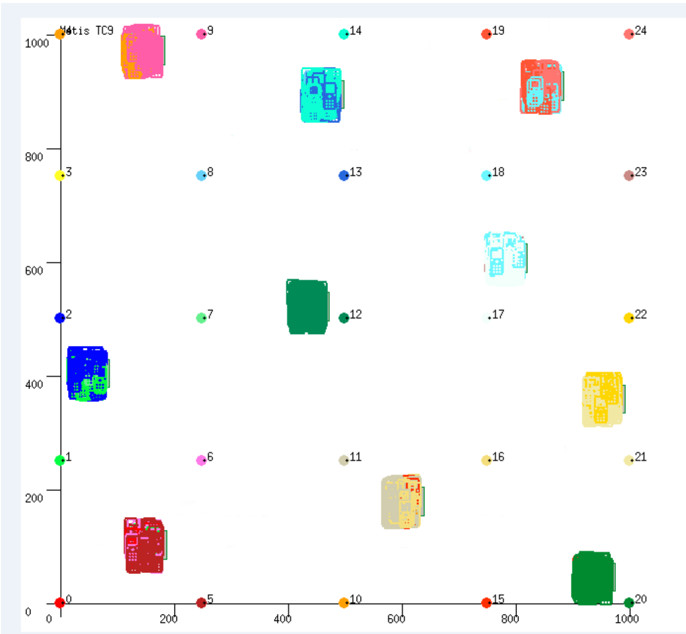

Figure A-84: TC9 scenario snapshot from the simulator.

In order to manage to run the simulations in reasonable time, we focus in simulations only to one stage area of 316 x 316 m^2. We assume that the inter-stage interference is negligible comparted to intra-stage interference. Furthermore, there is only very small user mobility between the stage areas.

Deployment considerations

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

A total of twenty five base stations deployed in a grid with a spacing of 250 m, as show in Figure A-84.

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

This scenario is assumed to be isolated from outside interferences

Both sub 6 GHz and mmW deployments are available. Highly directive antennas targeted to the audience on each stage area. The access points are connected via fibre to each other and might share one or more baseband units.

Propagation model

The propagation model for TC9 needs to take into account the Line of Sight (LOS) conditions. The cellular (non-D2D) links are modelled with ITU Rural Macro (ITU-R M.2135, as defined in [ITU08]) model with spatially correlated slow fading:

- LoS deviation 4 dB, NLoS deviation 8 dB
- correlation distance 50 m (ITU defines 40/120 m LoS/NLoS)
- LoS probability exp(-(d – 10) / 200), where d is the distance in meters

For propagation modelling of D2D links within the dense audience, there are no good existing models which take into account the effect of dense crowd body loss. That is why we use within the crowd an indoor model from 3GPP TR 36.843

- PL_LoS = 89.5 + 16.9 log10(R), R in km
- P_NLoS = 147.4 + 43.4 log10(R)
- Uncorrelated slow fading with 1 dB deviation
- LoS probability max(exp(-(d – 18) / 27, 0.5), where d is the distance in meters

Traffic model

The FTP-traffic model described in [METIS13-D61] is used, where users are downloading 30 Mbytes files) on average every 10 s (from exponential distribution), one in forward and one in reverse direction.

For the sensor traffic, each sensor device generates a 100 kB file in uplink once every 10 minutes. Offered system load will be 1.3 Mbps with 1 000 sensor.

Mobility model

The users are stationary for the duration of the simulation.

A.9.4 Assumptions

We are able to allocate total of 800 MHz spectrum on 20 GHz band in addition to 2.6 GHz 200 MHz cellular band, which is mostly used for sensor traffic. Antennas at base stations have 17 dBi gain.

For D2D communication, we use LTE type of pathloss compensation uplink power control in order to save UE power and reduce the interference. Before the communication, the devices check with help of the network whether they have possibility use opportunistic direct D2D or should they send the data to base station. The devices try to find D2D pair within the whole stage area.

D2D users are paired randomly across whole simulation area, but D2D is not used if the D2D link quality is not enough.

A.9.5 Technology components

The main characteristic of this TC is the huge amount of users per square meter.

As in TC1, there exists a central unit able of assuming the control of the whole system. This enables the cloud-RAN concept that is thoroughly investigated in a progressive manner, including SU-MIMO, MU-MIMO, coordinated MU-MIMO and cloud RAN.

On the other hand, working with beyond 6 GHz bands, the frame structure must be redefined following the results in WP2-TeCC1. In the case of cloud RAN with a massive availability of antennas, massive MIMO techniques will be used. The table below summarizes the TeCs included in the simulations.

Table A-42: Main technology components evaluated in TC9 simulations.

WP/Taks	TeC	Name
WP2	TeCC1.1	Air interface in dense deployments – Frame structure
WP2	TeCC1.3	Air interface in dense deployments – Harmonized OFDM
T3.1	TeC7	Massive MIMO Transmission Using Higher Frequency Bands
T3.1	TeC11	Heterogeneous Multi-cell, MU Massive-MIMO, massive SDMA

In addition, following TeCs are considered as useful, but they are not abstracted in the simulations:

- T4.2-TeC12 Context-based device grouping and signalling
    - This TeC would support massive amount of connected devices by coordinating e.g. RACH resources. Signalling overhead and average latency is expected to be reduced with this TeC
- WP2-TeC11.1.2 Sparse Coded Multiple Access (SCMA) could contribute especially to energy saving KPI on Uplink for machine type/user background traffic due to the higher multi-user detection reliability of SCMA receiver. This reduces the active time of devices due to retransmissions.
- T3.2-TeC3 "Distributed Precoding in multicell multiantenna systems with data sharing" could address the low-energy operation requirement for the downlink.

WP2-TeCC1 is taken into account as new numerology like wider bandwidth, higher carrier frequency and shorter TTI.

The main TeC for massive capacity increase is T3.1-TeC7 “Massive MIMO Transmission Using Higher Frequency Bands Based on Measured Channels with CSI Error and Hardware Impairments”. This TeC can also reduce complexity with hybrid analogue and digital beamforming.

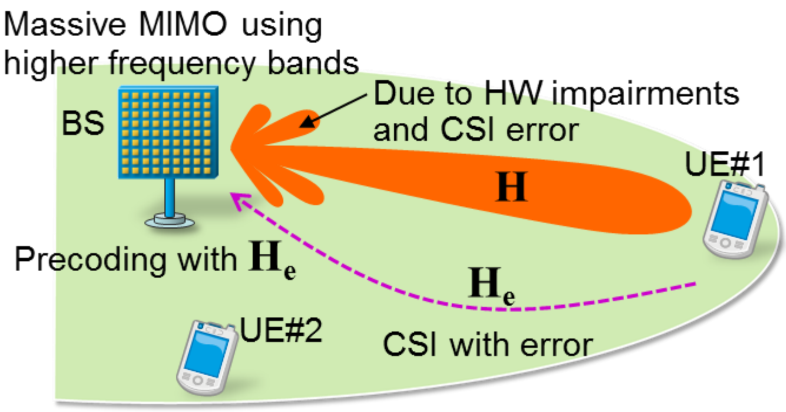

Figure A-85: Massive MIMO for TC9.

In the simulations, we assume 256 Tx antennas and 16 Rx antennas. In the simulations, we simply abstract the TeC by reading the gain from curves like in Figure A-86 with underlying assumptions given in [SSB+14].

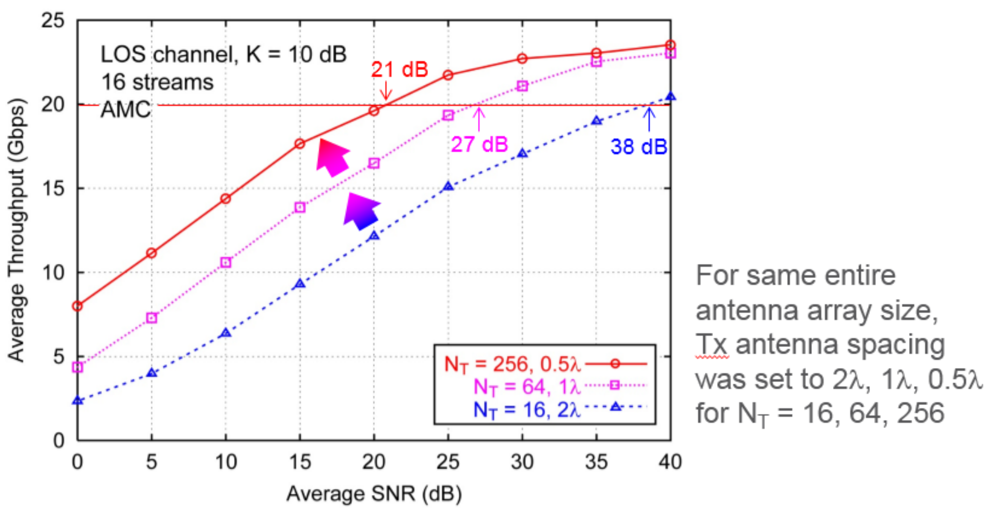

Figure A-86: Gain curves for T3.1-TeC7.

A.9.6 Results

We study separately the lower band performance and assume that sensor traffic is using that band. Finally, we target for highest capacity and do simulations in large allocation of cmW band using massive MIMO beamforming techniques.

Table A-43 shows the main simulation assumptions.

Table A-43: Main simulation assumptions.

Parameters	**Case 1: Cellular + sensor**	**Case 2: D2D**
Centre frequency and maximum available BW	High Band: (Up-to) 800 MHz at 20 GHz Low Band: 200 MHz at 2.6 GHz	(Up-to) 400 MHz at 20 GHz
Duplexing	TDD	TDD
Waveform	OFDMA (DL + UL)	OFDMA (DL + UL)
Antenna configuration	High Band: Massive MIMO beamforming 256 Tx, 16 Rx, 16 streams Low Band: 2Rx MRC	2Rx MRC
Modulations	QPSK, 16QAM, 64QAM	QPSK, 16QAM, 64QAM
Total simulation time	600 seconds	600 seconds

First, for the cellular lower band case, we checked the KPI of the uplink sensor traffic. The total offered system load with 1 000 sensor per stage area is very low, only 1.3 Mbps. Each sensor device generates a 100 kB file in uplink once every 10 minutes. It is assumed that the sensors are using low-cost radios (no MIMO, only simple 2-branch Rx diversity) and lower cellular band (2.6 GHz). On that same TDD band (totally 200 MHz) we are able to serve also some user traffic. The deployment is shown in next figure.

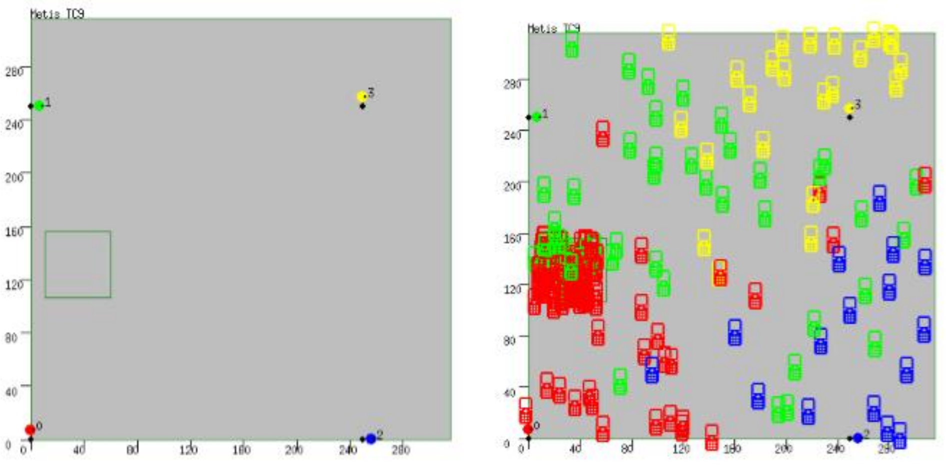

Figure A-87: Deployment for the lower cellular bands. Associated UEs shown on the right figure.

The lower cellular band is not able to provide enough capacity for the user traffic. But it can provide some capacity and very well the robust connectivity with the sensors as seen from Figure A-88. We can see that the sensor KPI is clearly fulfilled even in the presence of some user traffic. Note that the delay is not packet delay but the delay of the whole transmitted file.

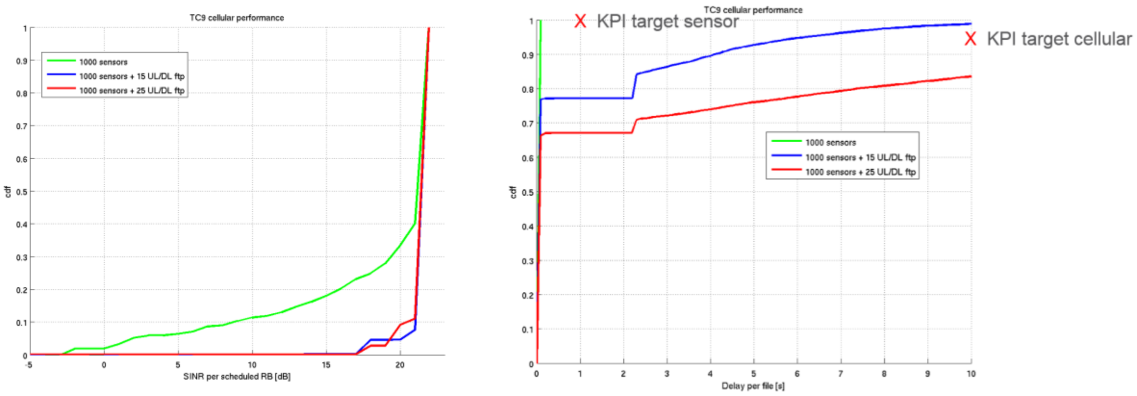

Figure A-88: Sensor and user traffic SINR (left) and file delay (right) on 2.6 GHz band.

Next, we take a look if we can provide the needed very high capacity when taking into use the upper 20GHz 5G band. We also assume opportunistic D2D transmissions being used whenever possible. A total of 800 MHz TDD spectrum is used and 400 MHz in D2D case. UE max Tx power was 21 dBm. Total simulated network time was 10 minutes.

Figure A-89 shows resource block SINR (left) and file delay (right) distribution for the case of 5000 users per stage area (the target is 10000). We can see that the KPI is fulfilled.

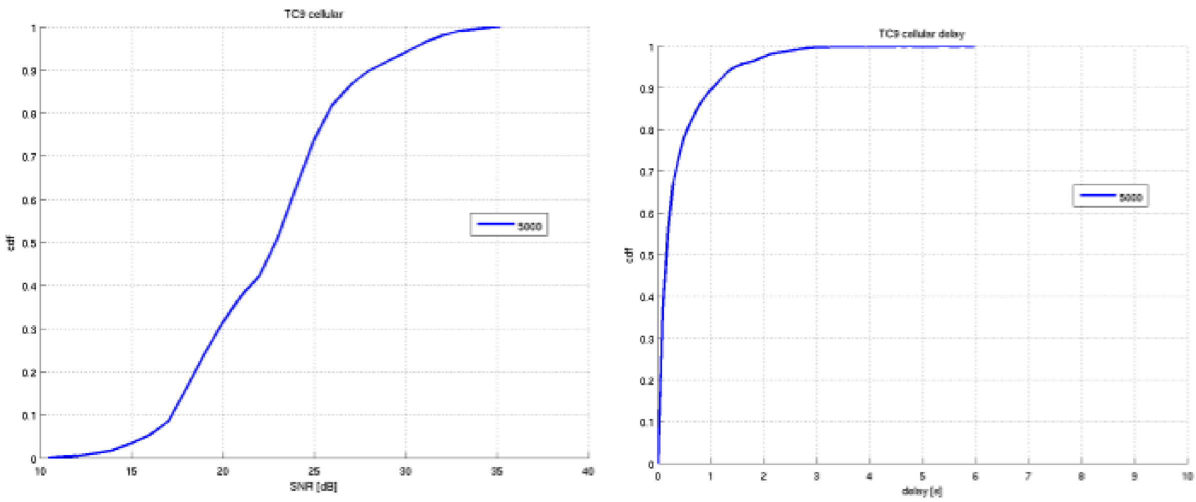

Figure A-89: User traffic SINR (left) and file delay (right) on 20 GHz band, 5000 users/stage.

After 5000 users, the delays start to accumulate quickly and performance collapses. User dropping (either by the end user or by network QoS control) is not modelled in the simulations which contributes to the phenomenon. The final capacity is about 5500 users.

Last, we study how much we can offload data with opportunistic D2D. Again, the high 20 GHz band is used, but no beamforming can be assumed between devices, just simple MRC 2-Rx diversity.

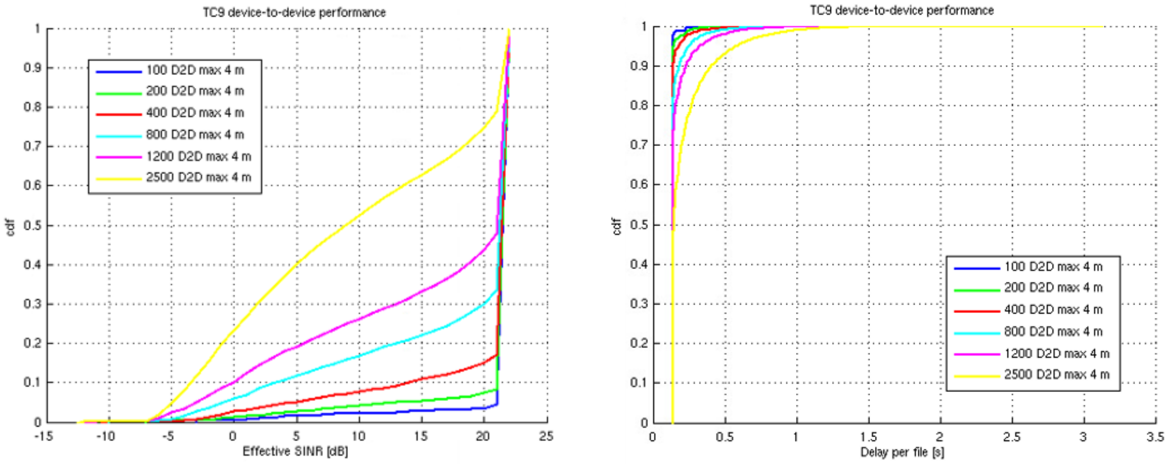

Figure A-90: D2D SINR (left) and file delay (right) on 20 GHz band, discovery range 4 m.

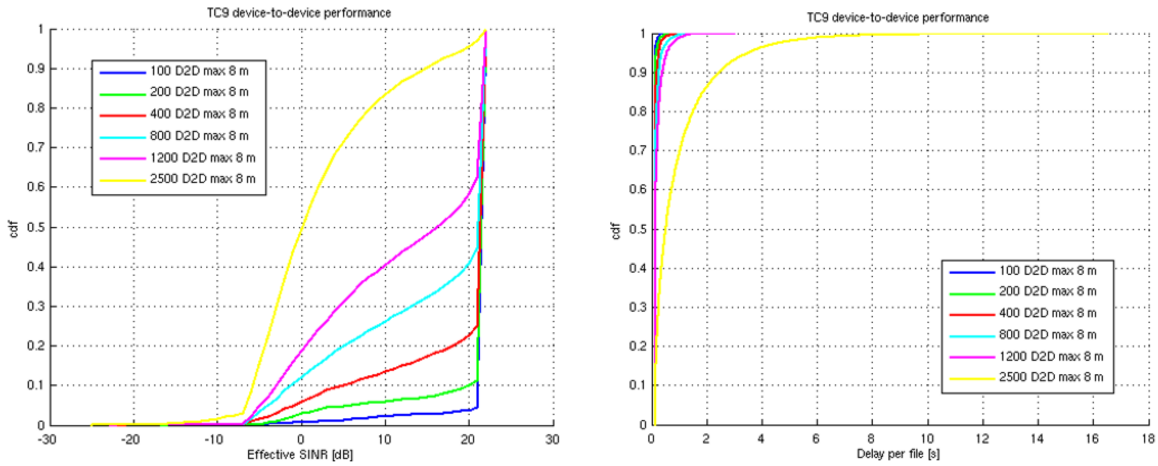

Figure A-91: D2D SINR (left) and file delay (right) on 20 GHz band, discovery range 8 m.

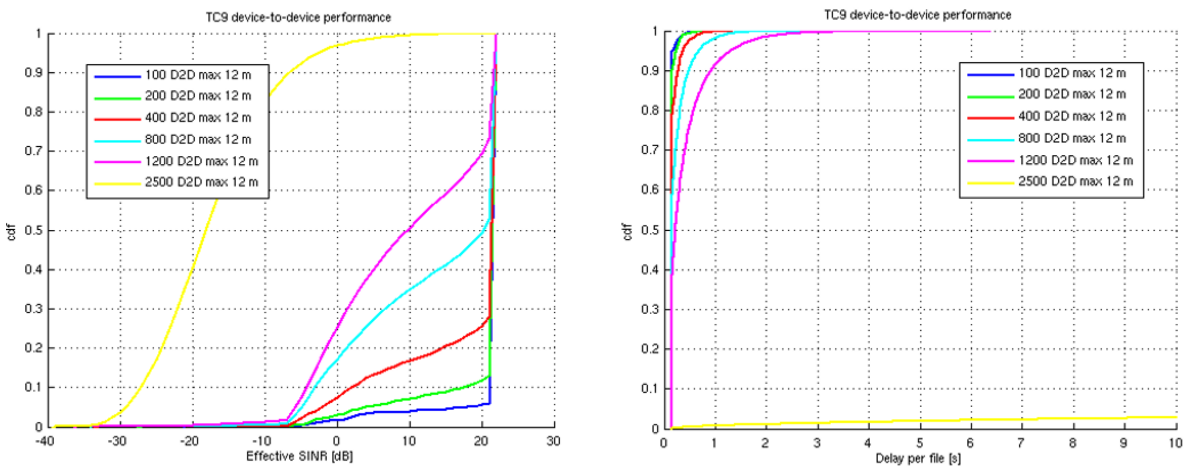

Figure A-92: D2D SINR (left) and file delay (right) on 20 GHz band, discovery range 12 m.

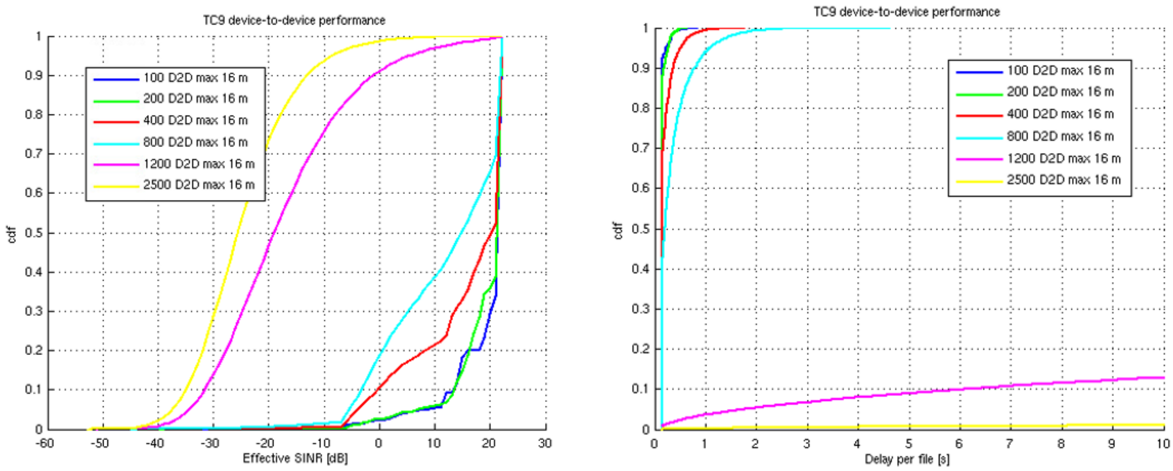

Figure A-93: D2D SINR (left) and file delay (right) on 20 GHz band, discovery range 16 m.

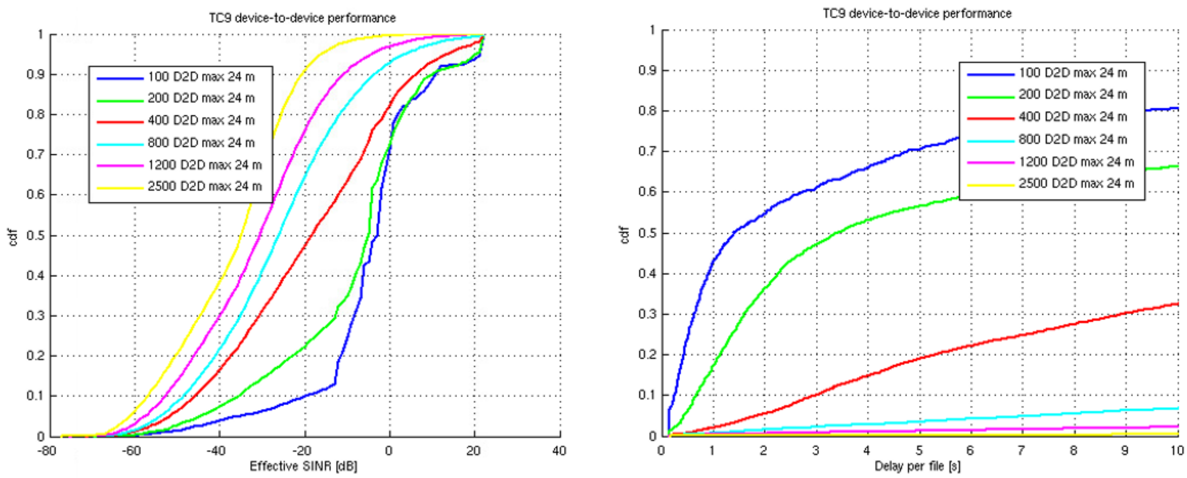

Figure A-94: D2D SINR (left) and file delay (right) on 20 GHz band, discovery range 24 m.

In the simulations, D2D pairs are formed assuming certain maximum distance between the devices (discovery range). We assume optimistically that 50% of the traffic can be offloaded via network assisted D2D. The scheduling is distributed and collision-aware in a way that if the throughput goes below certain threshold, random back-off is used to wait for the next transmission.

Figures (Figure A-90 - Figure A-94) above show the SINR and delay distributions for 6 different traffic loads from 100 to 2500 users per stage area. The results show that discovery range of 24 meters is already too large to have any sensible traffic. This is due to excessive amount of co-channel interference. Maximum capacity depends on the allowed discovery range as shown in Table A-44. The case with 4 m is not taken into account since it is seen as too restrictive.

Table A-44: Summary of capacity numbers.

Traffic	Spectrum needed (max)	Capacity/target
Sensor traffic	200 MHz at 2.6 GHz	1000/1000 = 100%
Cellular traffic	800 MHz at 20 GHz	5000/10000 = 50%
D2D traffic, range {8, 12, 16} m	400 MHz at 20 GHz	{>2500, ~2000, ~1000}
Sum: Cellular + D2D		(5000+2000)/10000 = 70%

As a summary, Table A-44 show the capacity estimates. For D2D, we take 12 m reference for the capacity, which is roughly 2000 users. When summing up the cellular and D2D capacity, we are able to support roughly 70% of the target.

A.10 TC10: Emergency communications

A.10.1 Description of the test case

The Emergency communications test case, TC10, is presenting a setting where a disaster has just taken place. In such a situation it is typically of highest importance to discover and communicate with the survivors, see Figure A-95.

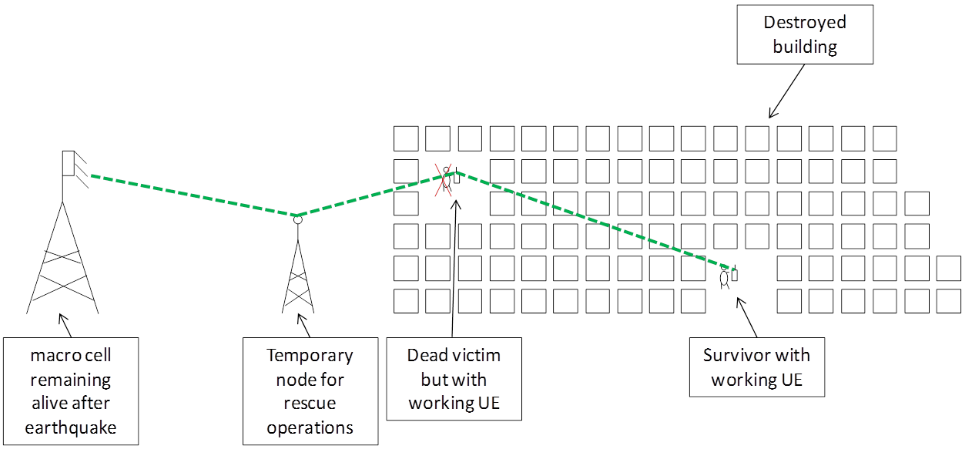

Figure A-95: Emergency communications. Discover and communicate with the survivors.

A.10.2 Main KPI and requirements

The main KPIs of TC10 are related to available and reliable setup combined with energy efficient communication procedures.

In terms of availability the discovery rate should reach 99.9% (less than 1 victim in 1000 should be missed) with a reliable setup time of less than 10 s and with a reliable call establishment after 1 s. In order to enable detection of survivors for as long as possible it is of high importance to put the energy consumption of the survivor's devices at a minimum. The target is that 5 days of operations should be supported in "emergency mode" with the battery backup designed for 1 day of operations in normal density (1 UE per 10 m^2) [MET13-D11].

A.10.3 Simulation models

Environmental model

The environmental model is the Madrid grid, defined in [MET-D61], after a natural disaster with out of coverage nodes. Temporary emergency base stations can be used to improve coverage.

Deployment model

Seven BSs positioned in a hexagonal grid with an ISD of 500 m for each BS (which gives a cell area of 0.65 km^2 for each BS) and the users are uniformly distributed inside the area.

Propagation model

The propagation conditions are specified in [MET13-D61], where the propagation model of cellular UEs is the O2I model (PS#2) and the propagation model of D2D UEs is the O2I model (PS#10).

Traffic model

The traffic model is Full buffer.

Mobility model

The simulation setting is assumed to be static, i.e. there is no mobility.

A.10.4 Assumptions

The bandwidth is 5 MHz (PRB bandwidth: 180 kHz) at 2 GHz carrier frequency. The CSI knowledge is assumed to be perfect. The transmit power of the UEs ranges from the maximum 23 dBm to the minimum -23 dBm. The density of users is 20 to 500 UEs/cell area in this evaluation, which gives a lower density of UEs than 1 UE per 10 m^2.

Two main aspects of this test case are the discovery part and the communication part. In the discovery part the discovery ratio and the power consumption used to enable detection is important parameters, whereas the communication part rather focuses even more on the low energy consumption aspects. Below, these two parts are explained more in detail.

Discovery

The neighbour discovery is a key for communication. Something needs first to discover all/or part of the neighbouring devices (before any rescue can take place). Under network coverage one can use network-centric mode, device-centric mode and a hybrid mode. If there instead is no or only partial network coverage then a fully distributed neighbour discovery algorithm can be applied, cluster-based discovery.

The cluster structure to build the D2D connection/network in out-of-NW-coverage is illustrated in Figure A-96. The node Cluster-Head (CH) will help in the network coverage extension, in the synchronization and with RRM for a group of devices.

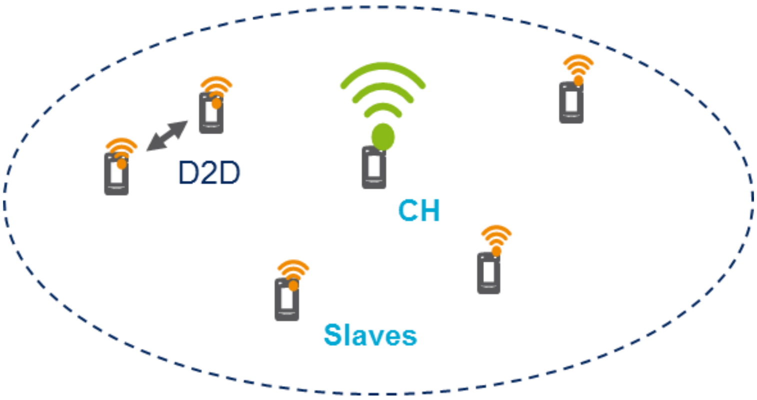

Figure A-96: The Cluster-Head (CH) extends the network coverage.

The system model contains two types of UEs. A type-1 UE (called cluster-head capable nodes) is first responder and serves as an eNB, i.e. temporary emergency BS. This type of nodes is initially allowed to transmit discovery beacons. A type-2 UE is a regular device and it can merely connect to the CHs.

Communication

The communication part focus is to operate on energy efficient mode rather than on spectrum efficient mode (on demand). The approach is to take advantage of the network assistance when it is available, but to also be able to operate autonomously in case of malfunctioning network infrastructure. Two-hop communication is possible. Utility-optimal distributed power control is used to increase the energy efficiency and to reduce outage probability.

Single-hop communication has two different communication modes:

- Cellular mode is a single hop communication between the UE and its BS.
- D2D mode is a single hop communication between two different UEs.

The two-hop D2D communications have two additional communication modes:

- Proximity communication mode takes place between two UEs, either in a direct single-hop communication or in a two-hop communication. The two-hop communication either goes via a relay or via the BS.
- Coverage extension mode takes place between the UE and its BS, either in a direct single-hop communication or in a two-hop communication via a relay.

The resource allocation scheme must fulfil the following constraints:

- A transmitter cannot have multiple receivers.
- A relay cannot receive and transmit on the same resource at the same time.
- The set of nodes transmitting to a BS must use orthogonal resources.

An allocation scheme has, while still fulfilling the constraints above, been randomized within the study below. In the allocation scheme it gets decided which devices that are supposed to communicate with each other. For single-hop devices this means that the resource allocation scheme has been found. For the BSs, UEs and relays that happen to either belong to Proximity communication mode or Coverage extension mode get their resource allocation schemes from Algorithm A-1 and Algorithm A-2.

Algorithm A-1: Harmonic Mode Selection (HMS) for Proximity communication.
If $G_{eq} \geq \max\{G_{TxRx}, G_{TxBS}\}$ **then**
Choose D2D two-hop communications.
else if $G_{TxRx} \geq G_{TxBS}$ **then**
Choose D2D single-hop communications.
else
Choose cellular mode (that is D2D Tx and Rx communication through the BS).
end if
where $G_{eq}^{-1} = G_{TxRe}^{-1} + G_{ReRx}^{-1}$.

Algorithm A-2: Harmonic Mode Selection (HMS) for Coverage extension.
If $G_{eq} \geq G_{TxBS}$ **then**
Choose D2D relay assisted communication.
else
Choose cellular mode (that is D2D Tx transmits directly to the BS).
end if
where $G_{eq}^{-1} = G_{TxRe}^{-1} + G_{ReBS}^{-1}$.

Given the resource allocation scheme, it remains to decide on suitable power levels. In this study three different power control algorithms are considered in uplink. In [3GPP07-26037] the two power control algorithms Open Loop (OL) and Fix are presented. The third power control approach considered is the Utility Maximization (UM) approach. These approaches are presented below.

The Open loop (OL) power control algorithm gives the power (in dBm):

$$P = 10 \log(1) - 78 + 0.8 \text{ PL},$$

where PL is the pathloss.

In the Fix power control algorithm the power P is given by the OL algorithm when the communication is cellular (i.e. from UE to BS). In the case that the communication is from UE to UE the power P = 23 dBm (which is the maximum UE transmit power).
The Utility maximization approach gives the Power P by solving an optimization problem for a chosen value on the scalar parameter ω. With the parameter ω one tunes the trade-off between spectral efficiency and energy efficiency. The optimization problem is given by:

$$\begin{array}{ll} \underset{\mathbf{P},\mathbf{s}}{\text{maximize}} & \sum_i u_i(s_i) - \omega \sum_{i=1}^{I} \sum_{h=1}^{f(i)} P_{\mathbf{t}(i,h)} \\ \text{subject to} & \tilde{\mathbf{R}}\mathbf{s} \preceq \sum_{q=1}^{Q} \mathbf{c}_q(\mathbf{P}), \quad \forall i, h, \\ & \mathbf{P}, \mathbf{s} \succeq 0 \end{array}$$

The joint method for SINR target setting and power control for D2D communications as formulated above maximizes the sum of utility functions u(.), where the summation runs through all communicating D2D pairs (D2D Tx and D2D Rx) and UE-to-BS pairs (cellular communication links). **P** is a vector that represents all transmit power levels and **s** is the vector of achieved rates along all communication routes (where a route can comprise a single hop or a two-hop connection). The index q runs through all resources (e.g. frequency channels of a frequency division system) [SFM14]. Finally, the matrix **R** is the so called routing matrix that associates (single or two hop) routes with links and resources and is assumed to be constructed by some appropriate relay and mode selection algorithm. The function f(i) returns the number of hops along the route i, and I denotes the total number of routes (that is the total number of communicating pairs, including D2D and cellular UE-BS pairs) in the system.

A.10.5 Technology components

Main technology components used in the evaluation of TC10 are:

- T4.1-TeC2: Unified resource allocation framework for D2D discovery,
- T4.1-TeC3-A1: Distributed Channel State Information (CSI) Based Mode Selection for D2D Communications,
- T4.1-TeC5-A1/A2: Joint Methods for SINR Target Setting and Power Control for D2D Communications.

In [MET15-D43] more details on these technology components are given.

Technology component T4.1-TeC2 is an was designed to work under partial network coverage where some part of the infrastructure is still available after a natural disaster as well as in the total out of coverage case where the total network infrastructure in destroyed. The Concept of the clustering allows the devices to connect to an existing part the infrastructure of to re-build a similar structure to the cellular networks. This TeC includes ways to prioritize the connection to a BS than to another neighboring device by given the CH role to the remaining BSs whenever this possible. It is also based on the fact that in an emergency situation, a UE does not have to discover every device around but only to the network or to a device carried with a responder.
In addition the structure built in particular with the threshold-based approach allows multiple levels of hierarchy, a CH device in one cluster can be a slave an connect to another CH or BS which could make it very easy at a later stage to set multi-hop communication from an isolated UE to the BS.

A.10.6 Results

The discovery ratio is given in Figure A-97.

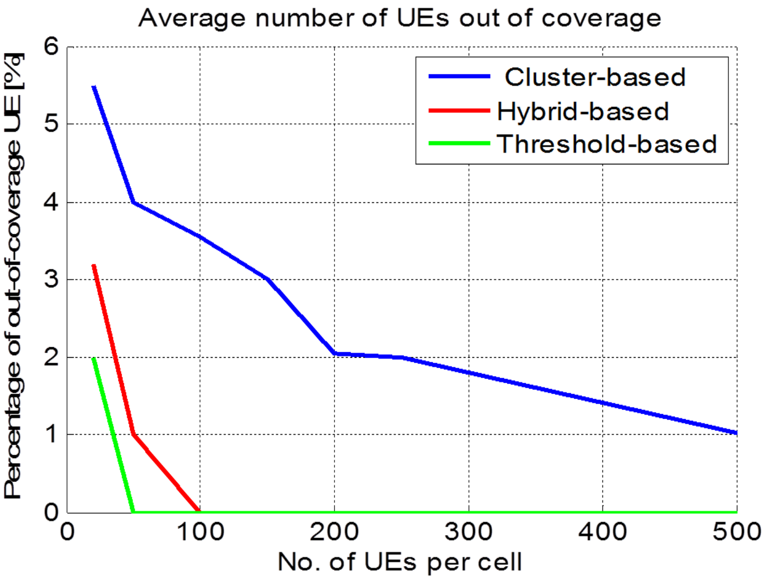

Figure A-97: The percentage of under coverage UEs, i.e. UEs that connect to one CH), as a function of the number of UEs per cell.

The Cluster-based approach merely has a few CHs which imply that a lower number of UEs can be covered. In the Hybrid-based approach all capable CHs do transmit their beacons which enable coverage of more UEs but at a cost of higher collision rate and detection failure. The Threshold-based approach is based on trade-offs between the number of CHs and the coverage ratio. The goal of 99.9% discovery rate is fulfilled for both the Hybrid-based and Threshold-based approaches given that the number of CH capable devices per cell is sufficiently large (e.g. more than 50 devices) and was enabled by T4.1-TeC2.

In Figure A-98 the discovery time is presented.

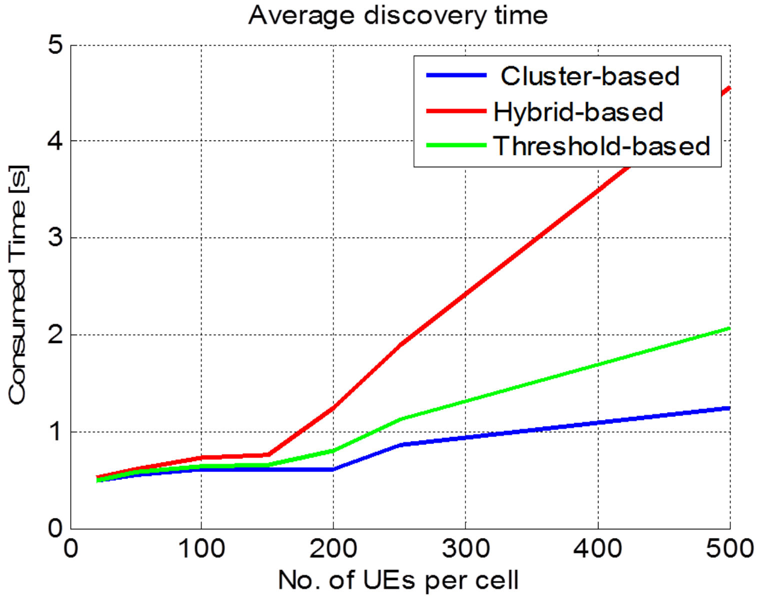

Figure A-98: The average consumed time to discover a UE as a function of the number of UEs per cell.

The Cluster-based approach has few CHs and thereby also low discovery ratio. In the Hybrid-based approach the discovery time is higher as all capable CHs do transmit their beacons. The Threshold-based approach uses trade-offs between the number of CHs and coverage ratio and thereby lies between the Cluster-based and Hybrid-based approach. The goal of an infrastructure setup time less than 10 s are fulfilled for the three approaches when considering the number of UEs per cell in the Figure A-98 which was enabled by T4.1-TeC2.

Figure A-99 shows the SINR distributions of cellular UEs and D2D pairs when employing the mode selection schemes, T4.1-TeC3-A1. In Cellular mode (Cmode) the UEs communicate via the BS. In D2D Mode Selection (DMS) the UEs can choose to either use Cmode or single-hop D2D. In Harmonic Mode Selection (HMS) the UEs can choose to either use a selection from DMS or two-hop communication via their relay.

From Figure A-99 it is evident that a more advanced scheme tends to provide an improved SINR together with reduced power consumption. HMS reaches higher SINR values than DMS with lower power consumption, and DMS reaches higher SINR values than Cmode with lower power consumption.

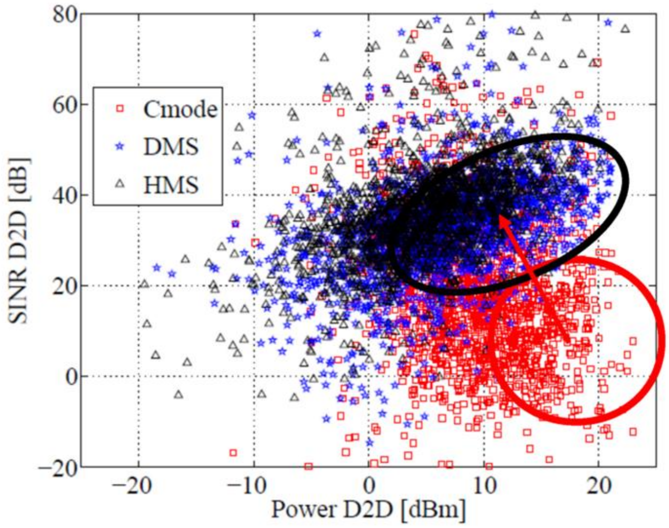

Figure A-99: SINR distributions of cellular UEs and D2D pairs when employing the mode selection schemes.

In a range extension setting (containing a random drop of 18 D2D triplets per cell) where the HMS approach is being used the three power control algorithms are evaluated. The Utility maximization (UM) approach is evaluated for the ω-values: 0.1, 1, 10 and 100. The results are presented in Figure A-100 and relates to T4.1-TeC5-A1/A2.

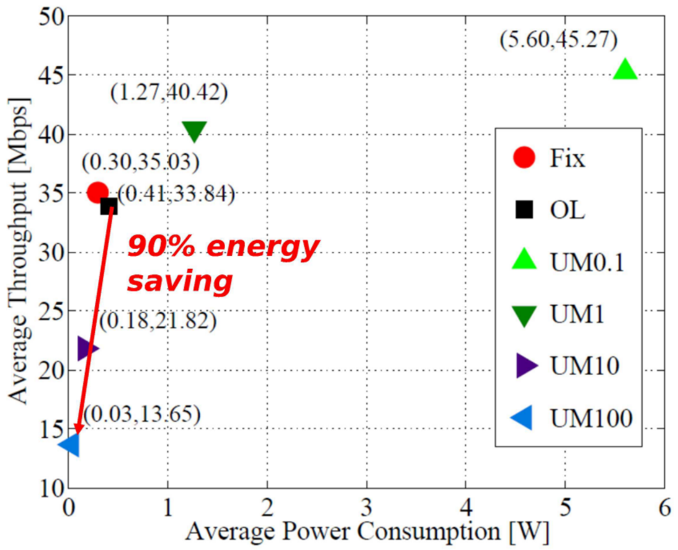

Figure A-100: Scatter plot of the total power consumption and average throughput achieved by the examined power control algorithms.

In Figure A-100 the trade-off between power consumption and throughput is given. The Fix and OL approaches seem to lie somewhere in between the ω-values 1 and 10 for the UM approach. Further details are provided in [SFM14].

A.11 TC11: Massive deployment of sensors and actuators

The structure of this section is somewhat different than for the other test cases in Annex A. The main reason for this is that several separate evaluations have been conducted for TC11 to cover a broad variety of potential components for this test case. The description of the test case is given in Section A.11.1 and the main KPI and requirements are presented in Section A.11.2. Thereafter, the investigated technology components and technology potentials are presented in Section A.11.3. The results from each of the TC11 evaluations, together with their corresponding simulation models and assumptions, are presented in Section A.11.4 to Section A.11.8.

The various aspects investigated in this test case are the following. In Section A.11.4 the impact of narrow bandwidth transmission and radio link efficiency is investigated. Section A.11.5 presents the findings of context-based device grouping and signalling, whereas Section A.11.6 highlights the SCMA relation to this test case. The energy consumption aspects are in focus in Section A.11.7 where battery gain trade-offs is being investigated. Finally, Section A.11.8 contains system evaluation results in a M2M sensor-relay setting. The evaluation details are given in each section.

A.11.1 Description of the test case

In this test case, the Massive deployment of sensors and actuators, smaller devices such as sensors and actuators are being considered. Typically these devices only transmit data occasionally, and when they do transmit it tend to be rather small packets. The foreseen massive number of such devices stresses the need for low cost and long battery life.

In [MET13-D62] three different ways for machines to communicate were illustrated by Figure A-101.

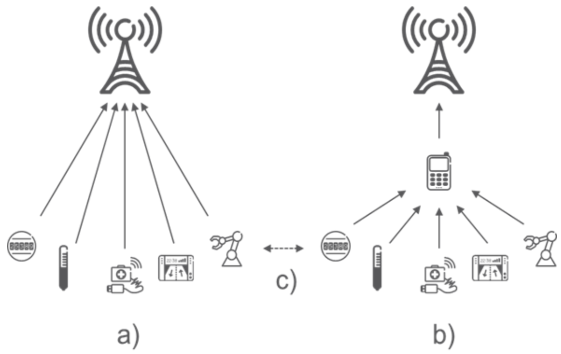

Figure A-101: a) Direct access; b) Accumulation point access; c) M2M access.

A.11.2 Main KPI and requirements

TC11 targets a higher number of connected devices, with longer battery life for these low power MMC devices at similar cost and energy consumption. The main KPI and requirements defined are given by the following requirements from [MET13-D11]:

- Energy efficiency: 0.015 μJ/bit for a data rate in the order of 1 kbps,
- Protocol scalability: 80% protocol efficiency at 300 000 devices per AN,
- Coverage: 99.9% to 99.99%,

together with the METIS goals of:

- 10x longer battery life,
- 10x-100x increased capacity.

A.11.3 Technology components

The narrow bandwidth transmission and radio link efficiency do improve coverage, capacity and the spectral efficiency. The presented results in Section A.11.4 are valid for a general narrow bandwidth transmission scheme, e.g. WP2-TeCC8.1. Other waveform related components are the WP2-TeCC1 components that do enable flexible OFDM, the context-based device grouping and signalling component, T4.2-TeC12, and the SCMA components WP2-TeC11.1.2 and T4.2-TeC16 that are used in Section A.11.5 to attain scalable MMC solutions.

A.11.4 Narrow bandwidth transmission and radio link efficiency

Narrow bandwidth transmissions have been considered to be suitable for machine type communication given the small payloads and high requirements on coverage [SIGFOX, Web12]. In a METIS context narrow band transmissions for MMC could be achieved both in FBMC and in OFDM based systems. The advantage with FBMC is that it does not require devices to be uplink synchronized. That is, as in the R11 LTE baseline case to perform a random access procedure to obtain a timing advance which is applied to uplink transmission in order for them to be received in sync. To have unsynchronized transmission in OFDM guard bands would have to be introduced which lower the spectral efficiency, which is no big issue for MMC itself having only moderate BW requirements but might be for other services in the same band. For a device in poor coverage a narrow band transmission with a long transmission time would be optimal but for a device in good coverage a wide band transmission with a very short transmission time would instead be optimal to achieve long battery life. Here results are presented showing the capacity and coverage gains associated with using a transmission bandwidth of a 15 kHz OFDM subcarrier as compared to a 180 kHz physical resource block in the baseline case of R11 LTE. The difference in bandwidth is illustrated in Figure A-102.

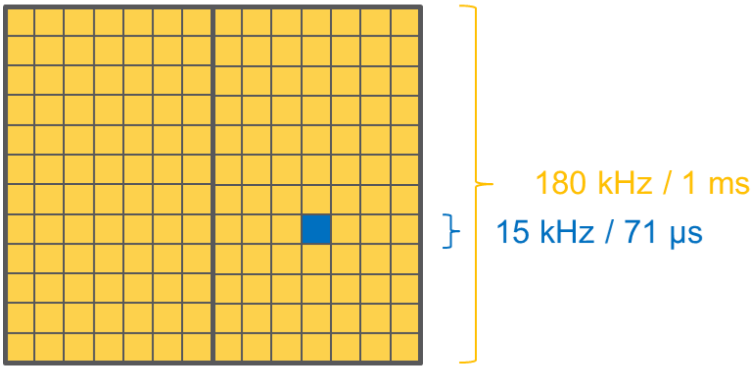

Figure A-102: Illustration of a resource element, RE, in relation to a pair of physical resource blocks, PRBs.

The model parameters are based on 3GPP values [3GPP13-36888] and are listed in Table A-45. Further users a uniformly distributed in an omnidirectional hexagonal cell as shown in Figure A-103. Note therefore that the results do not take intercell-interference in to account.

Table A-45: Model parameter values.

Parameter	Value
SNR impairment	10 dB
Thermal noise density	174 dBm/Hz
Noise figure	5 dB
Receiver gain	14 dB
Transmitter gain	-4 dB
Transmit power	23 dBm
logNorm component	8 dB standard deviation and mean 0
Out-of-coverage data rate limit	250 bps
Pathloss	120.9 + 37.6·log10(d)

Further, indoor and basement devices are modelled by the inclusion of either +20 dB or +40 dB additional pathloss. The resulting coupling loss is shown in Figure A-104.

For each user the data rate is calculated from the Shannon expression for the channel capacity, $r = bw \cdot \log_2(1+SNR)$, where *bw* is the transmission bandwidth and *SNR* the signal to noise ratio. The uplink payload is 125 Byte with a 50% control signal overhead added on top. The resource consumption is calculated as the number of scheduling units required to cover the transmission time. The system capacity is then calculated as the number of messages that can be transmitted in the system bandwidth per hour. Further, QPSK and 64QAM modulation is included as an upper limit on the user data rate.

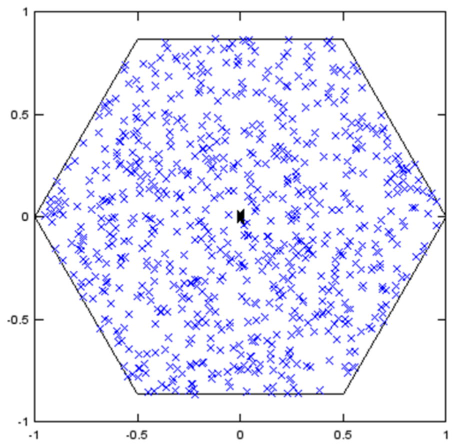

Figure A-103: Uniform user distribution in hexagonal cell.

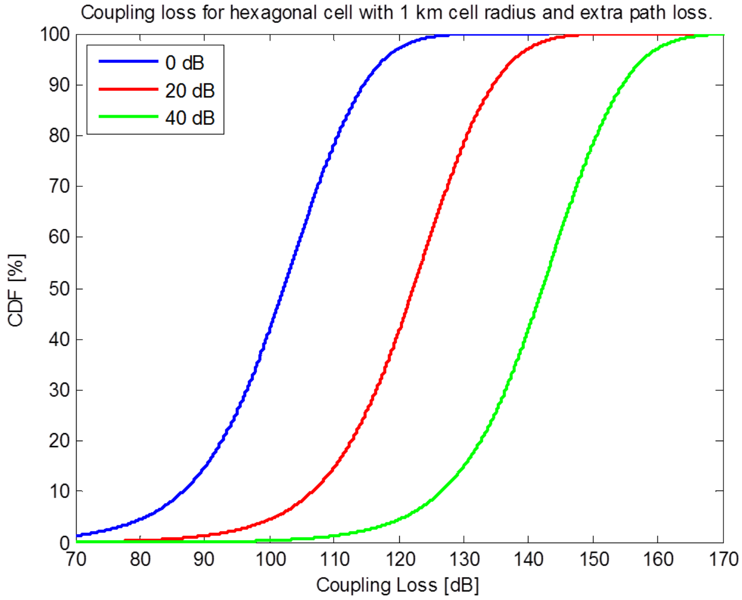

Figure A-104: Coupling loss distribution for uniformly distributed users.

In Figure A-105 the capacity, in terms of served messages per hour is shown as a function of the cell radius. System band-widths in the range from 0.5 MHz to 10 MHz have been calculated and it is seen that the 1.4 MHz system bandwidth in Figure A-106 will meet the TC11 capacity requirements. That is, the capacity is over $3.6{\cdot}10^6$ messages of 125 Bytes per hour, which is indicated by the horizontal dotted black line.

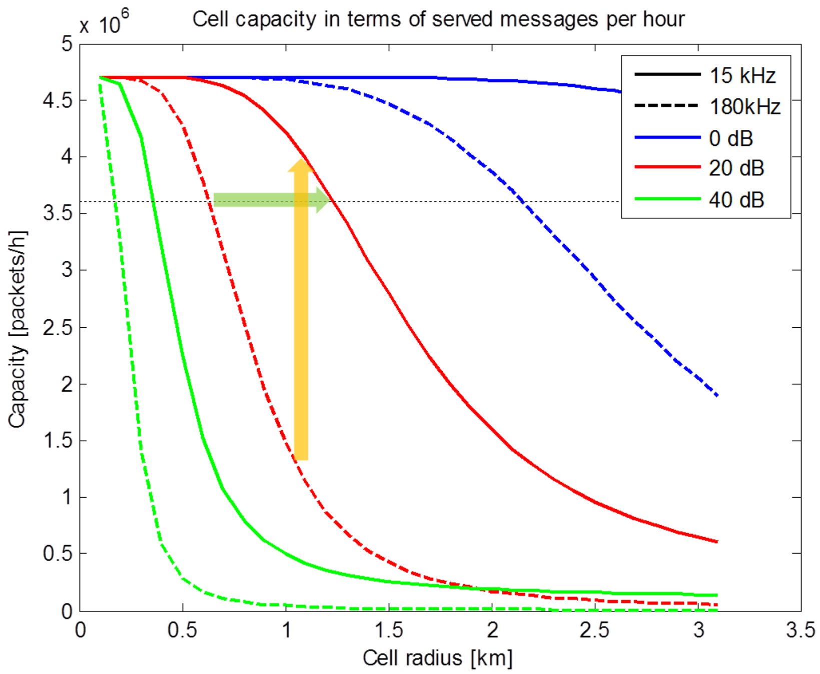

Figure A-105: UL capacity with 1.4 MHz system bandwidth and QPSK rate limitation.

Focusing on indoor MMC devices (+20 dB path loss curve), using a narrow band-width transmission of 15 kHz allocation would at a cell radius of 1.1 km give an absolute increase in capacity of $2.8{\cdot}10^6$ messages per hour (indicated by the vertical orange arrow in the Figure A-105). That is 78% of the traffic requirement of TC11.

Alternatively, at the METIS TC11 traffic requirement of $3.6 \cdot 10^6$ messages/h, the 15 kHz narrow-band width transmission would increase the cell radius by 98% (as indicated by the green horizontal line in Figure A-105). In terms of area that means 290% larger cell sizes for the narrow-band transmissions. The outdoor and basement cases (+0 and +40 dB additional pathloss respectively) show the same gains, a doubling of the cell radius at the METIS capacity requirement and a the same capacity increase. The only difference is that they occur at a different cell radius. These results are under the constraint of a maximum user data rate dictated by QPSK. If devices with good channels are instead allowed to use a higher modulation of up to 64QAM, a system bandwidth of 0.5 MHz would be sufficient to meet the TC11 traffic requirements. This case is shown in Figure A-106.

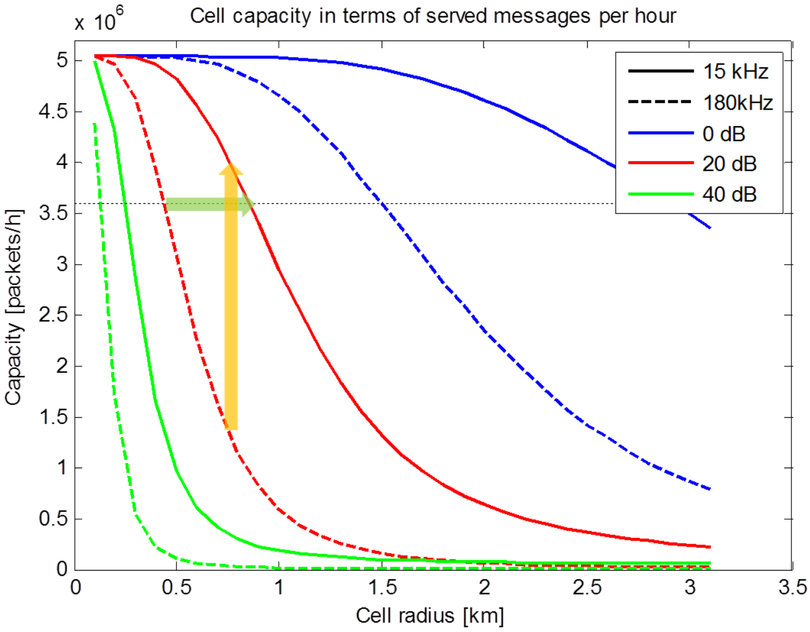

Figure A-106: UL capacity with 0.5 MHz system bandwidth and 64QAM rate limitation.

In the same way the 15 kHz narrow bandwidth transmissions here increases the cell radius by 94% at the METIS TC11 traffic requirement, or at a fixed cell radius increase the uplink capacity by $2.7 \cdot 10^6$ messages/h which is 75% of the same requirement (for the indoor +20 dB additional path loss case).

Plotting the relative capacity increase of the 15 kHz transmissions relative to the capacity of the 180 kHz transmission case in Figure A-107 it is more clearly seen the maximal gain is the same for the indoor, outdoor and basement cases, it is just achieved at different cell radius. Overall, the gain is almost as large as twelve times, which then meets the METIS goal of increasing the capacity ten times. Note that this is for the uplink capacity and that a power spectral density boosting is not achieved in the same way in the downlink.

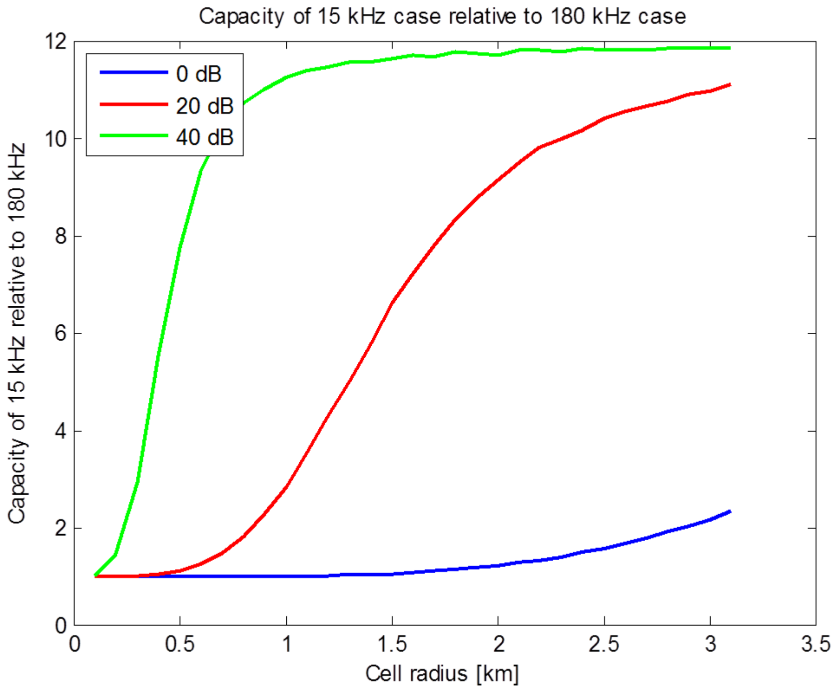

Figure A-107: Relative uplink capacity increase of 15 kHz relative to 180 kHz.

The smallest schedulable unit in baseline LTE is a pair of PRBs, i.e. 1 ms in time and 180 kHz in frequency. It has been investigated whether this unit is too large for the small payloads of MTC under good channel conditions by comparing to scheduling of REs. Normal cyclic prefix is considered such that a RE is $0.5 \cdot 10^{-3}/7 = 71.4$ µs in time and 15 kHz wide. Note that in the following it is rarely the case that only a few REs are used for transmission, rather the potential gains come from the finer granularity and better adoption to the data payload. (In practice if only a few REs were to be used the baseline scheduling procedure with uplink grants would become unfeasible and one would have to rely on contention-based transmission or some sort of semi-persistent scheduling). The number of used time resources in this model is simply the number needed to cover the transmission time. The scheduling resource efficiency is defined as the percentage of unused resources in terms of transmission time. Coding is not considered here for simplicity and a packet sizes are normally distributed around the considered packet sizes of 10 B, 100 B and 1 kB to avoid artificial dependencies and better statistical results (standard deviation of 150 bits). 50% control signalling is added on top of the payloads as before. In Figure A-108 the scheduling efficiency is shown as a function of the cell radius for the case user data rates are upwards limited by QPSK modulation.

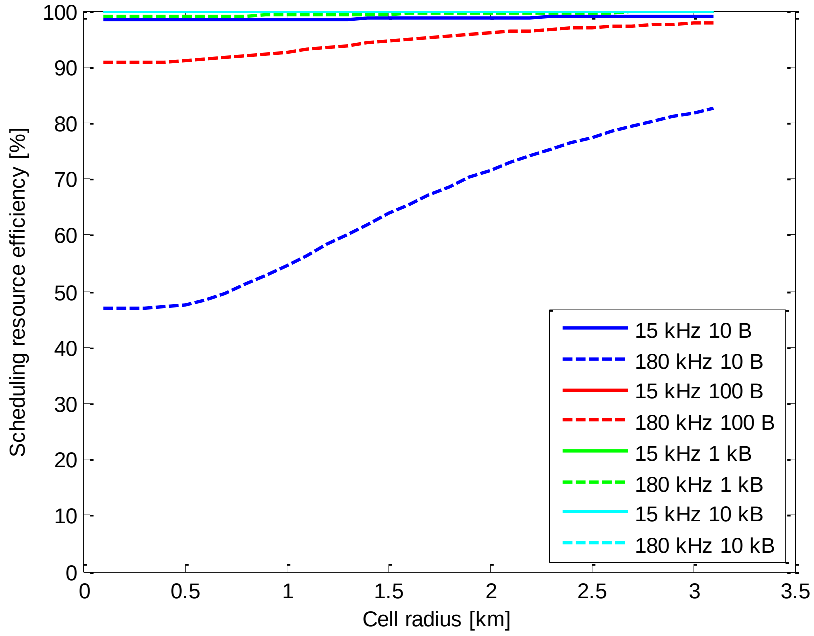

Figure A-108: Scheduling efficiency for the QPSK rate limited case.

It is seen that for devices with good channels and for small cells the scheduling efficiency is down to 91% for 100 Byte payloads and down to 47% for small 10 Byte payloads with the baseline PRB scheduling unit (indicated as ‘180 kHz’ in Figure A-108). With the finer scheduling granularity of the REs (indicated as ‘15 kHz’ in Figure A-109) the scheduling efficiency is close to 100% for all the considered cases. This is also the case for PRB scheduling of payloads of 1 kB or larger. Further, these results are for the indoor case with +20 dB of additional path loss. For the outdoor case the low scheduling efficiency would be the case for the majority of devices and also for very large cells.

Under good channel conditions the radio link can be better utilized by the higher modulation of 64QAM the scheduling inefficiency of the larger baseline PRB scheduling unit is even lower as shown in Figure A-109.

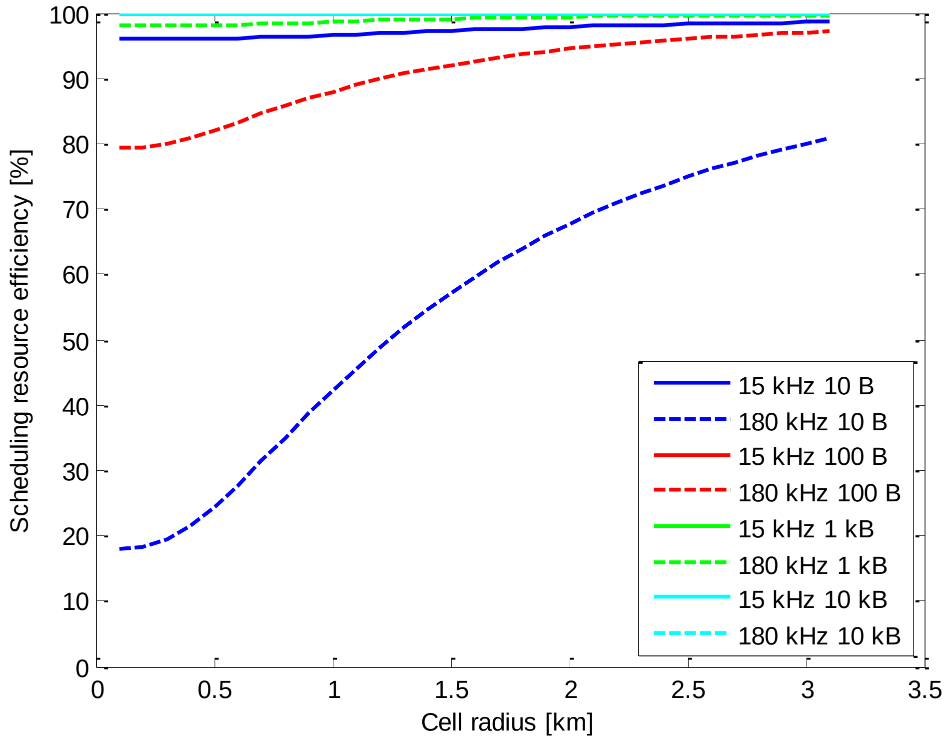

Figure A-109: Scheduling efficiency for the 64QAM rate limited case.

In this case the scheduling efficiency is as down to 79% for 100 Byte payloads and 18% for 10 Byte payloads for the baseline case. Overall there are therefore large potential gains in terms of increased spectral efficiency associated with the finer RE scheduling granularity for the small data payloads of MMC. The gains are naturally largest for devices in good coverage, in this model at small distance or devices located outdoors.

To conclude, the 15 kHz RE scheduling is beneficial for MMC compared to baseline 180 kHz PRB scheduling regarding the following:

- Coverage: At any fixed capacity requirement, and at any additional path-loss, the cell radius is effectively doubled.
- Capacity: Uplink capacity is increased up to almost twelve times for larger cell sizes.
- Spectral efficiency: The low scheduling efficiency of down to 18% for the baseline case for the small MMC payloads is synonymous to a huge waste of resources but this can be solved by the finer RE scheduling granularity.

15 kHz narrow band transmissions with RE scheduling granularity therefore meets the METIS goals for capacity in the uplink and on improving the coverage.

A.11.5 Context-based device grouping and signalling

The gains from T4.2-TeC12 are attributed to three parts:

- Scheme 1: Inhibition of fully redundant messages
- Scheme 2: Coordination and scheduling of RACH resources
- Scheme 3: Cross-device compression of messages

In the first scheme the transmission of an entire message can be omitted if, for example, it can be determined that the same measurement report has been reported by another sensor in a group. The second scheme, the gains are due to a group of MMC devices being allocated a certain PRACH preamble which is used in a turned based manner before handing it back to the network. The third scheme achieves gains by compression of the control signalling overhead when there are commonalities between messages.

The baseline for the evaluation is LTE R11 with the normal random access procedure and transmissions scheduled by uplink grants. A full list of parameter values are found in Table A-46. The evaluations are mainly on the random access procedure and control signalling parts, the data transmission part is included only in terms on resource consumption.

Table A-46: Baseline parameter values.

Parameters	Settings
Cell bandwidth	10 MHz
PRACH configuration index	6
Preamble format	0
Total number of preambles	54
Maximum number of preamble transmission	10
RA response window size	5 ms
Back-off indicator	100 ms
Traffic Model	Beta distributed arrivals with IAT of 10 seconds
Number of MTC devices	Up to 30000
Packet access (packet TX) failures	Due to RACH collisions only; No signal detection errors were assumed for non-collision access and signal transmissions at the receiver

The modelling of the T4.2-TeC12 is as follows. Devices are divided in to groups of either 50 or 100 units which are considered to have the same ‘service type’. To model scheme1, when packets are generated in the traffic model 30% of them (or 50%) are labelled as ‘redundant’ (all modelling parameters are listed in Table A-47). When transmitting the message and there has been a ‘redundant’ message transmitted by another device in the group within the last 20 ms, this is considered to model that e.g. the same sensor reading has already been sent by another device and the transmission is omitted all together. If there has been no other ‘redundant’ message within the last 20 ms the message is transmitted at usual. Scheme 2 is modelled by that some of the devices in a group are assumed to be pre-scheduled and have been assigned a certain order (idealistically modelled). The messages generated at these pre-scheduled devices are marked as 'diverse message', which carries distinct measurement values and is barely compressible. When there is an event and devices in a group want to transmit data, the network will poll the first device among the scheduled devices in the group and append a collision-free preamble (either 4/54 or 6/54 dedicated preambles set aside for this purpose). The first device will use the dedicated preamble and the rest of the scheduled devices in the group will listen for the random access response, and when it is heard by the second scheduled device the preamble are used by it and so on. This way, completely collision free random access is achieved for the scheduled devices as long as there are enough dedicated preambles. When the last device in the group has used the preamble it is returned to the network. Note that no other device can use the preamble in the meantime and that the solution is suitable for stationary devices such that preambles can be allocated.

Table A-47: Modelling parameters.

Parameters	Settings
Network layout	One cell with BS in the centre
Inter-site distance	500 m
Channel estimation	Perfect
Traffic pattern	Packet size of 20 bytes. Beta distributed packet arrival with IAT of 10 seconds
Number of UL grants per RAR	6
ARQ Ack feedback time	4 ms
Random back-off window for retransmissions	Uniformly distributed between 1 to 4 ms
η: Percentage of redundant information	30%, 50%
ng: Group size	50, 100
ρ: Amount of pre-assigned preambles for group representatives	4/54, 6/54

If packets are either not labelled as 'redundant' or if there is no valid 'redundant' message stored they will be transmitted, or they are not pre-scheduled by the base station. In this case we can observe some similarities in the measurement values reported by devices from the same group, and the control signalling overhead can be compressed there are similarities with other messages. In the system evaluations ≈ 30% of the control signalling is assumed to be compressed.

In Figure A-110 the improvement for the number of preamble transmissions per packet transmission is shown. By reducing the collision rate by the sequential use of pre-allocated preambles and omitting redundant transmissions the median number of preamble transmissions per device can be reduced from 2 in the baseline case to 0.8-1.2 depending of the assumptions for the fraction of omitted packets, group size and number of reserved preambles. (Note that omitted transmissions are included in the results – that is why results less than 1 are possible).

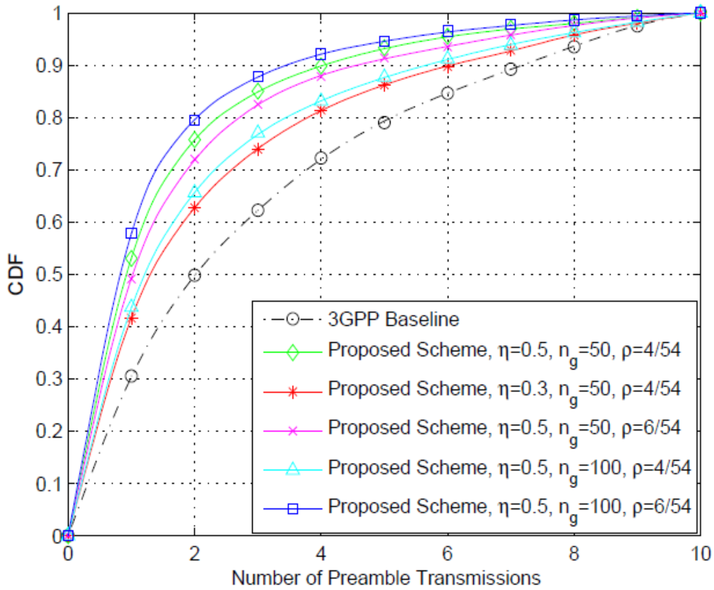

Figure A-110: The cumulative distribution function of the number of preamble transmissions per data packet with 30000 deployment devices in a cell.

In the system evaluations of T4.2-TeC12 the traffic model is an event trigger model which means that the devices in a group transmit data in a synchronized manner. The gains of scheme 1 and 2 rely on this, in the first case since 'the same' packets must have been sent within the last 20 ms and in the second case since the second data must have data to send when the first device receives its random access response. The third scheme could however give gains also for unsynchronized access since the compression can work more on long term statistics.

In Figure A-111 the signalling overhead of the T4.2-TeC12, including all three schemes, is compared to that of the baseline. It is seen that the fully redundant messages are removed (scheme 1), the partially redundant messages are compressed (scheme 3) and also random access retransmissions are reduced (scheme 2). The conclusion is the for groups with synchronous access and the same service class, i.e. a 30%/50% probability of reporting the same measurement value and also having commonalities in the control signalling, the control signalling can be reduces by up to 35% for 10 000 devices/cell and by up to 54% for 30 000 devices/cell.

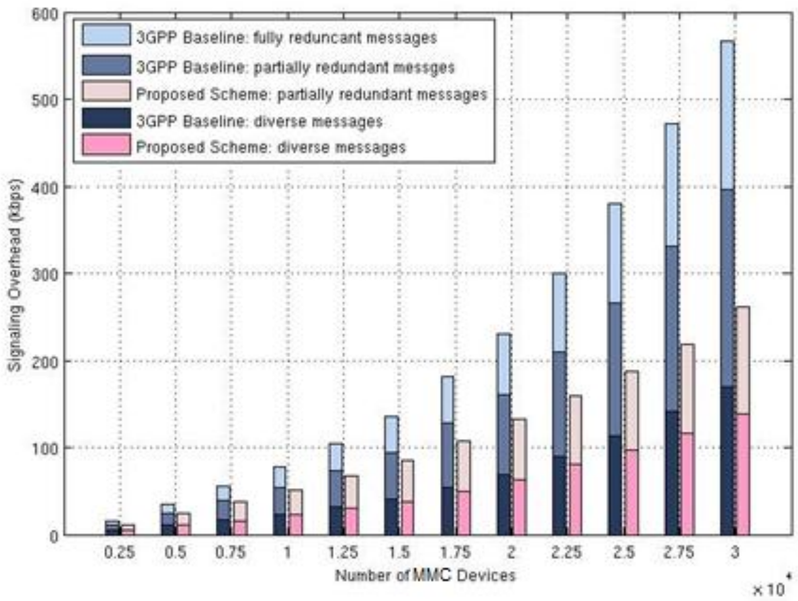

Figure A-111: Control signalling reduction as a function of the number of MMC devices.

This addressed the MMC KPIs protocol efficiency, since collision and retransmission lead to increase control overhead, and also to increased uplink capacity since more devices can be served at a certain fixed collision probability.

A.11.6 Sparse Code Multiple Access

In the R11 LTE baseline the entire RA, contention resolution, and RRC connection setups are included. The Sparse Code Multiple Access (SCMA) evaluation is done for contention-based transmission of data, that devices immediately transmit their data payload on common physical resources at the risk of collision. The presented gains of SCMA are therefore twofold, one part is due to the contention-based transmission and a second part is due to the actual SCMA overloading of the physical resources. Contention-based transmission of data is possible with any type of wave form, but is advantageous for FBMC where no uplink synchronization is required. SCMA and OFDM require uplink synchronization and would have to rely on for example reusing a previous timing advance for stationary devices. A grant-free contention based transmission mechanism with SCMA can tolerate more simultaneous uplink data transmissions due to the fact that SCMA blind detection with MPA receiver can detect multiple active users and their signals with reasonable complexity.

The codebook configuration contains six codebooks, spread over 4 frequency resources. Each user is pre-assigned a codebook. Every two encoded bits are mapped to one code-word. The Poisson arrivals have IAT of 300 seconds [3GPP11-37868].

Table A-48: Modelling parameters.

Parameters	Settings
Network layout	19 cells with 3 sectors per cell
Inter-site distance	500 m
Channel	Flat Rayleigh fading
Antenna config	SIMO 1x2, uncorrelated antennas
Modulation and coding	Codebook size of 6, Spreading factor 4 with 2 non-zero elements, code rate ½ for SCMA
Channel estimation	Perfect
Traffic pattern	Packet size of 20 and 125 bytes. Poisson packet arrival with a mean of 300 s; configurable number of active users in each sector
OL Power control	$\alpha = 0.95$, P_0 = -93 dBm
Receiver model	SCMA multiuser detection with Message Parsing Algorithm (MPA)
ARQ Ack Feedback time	4 ms
Random back-off window for retransmissions	Uniformly distributed between 1 to 4 ms

In Table A-49 the MMC capacity is investigated for LTE baseline and SCMA with non-delay-sensitive applications, i.e. up to three retransmissions for failed packets are allowed. Both for the LTE baseline and SCMA the non-delay-sensitive applications are considered, where up to three retransmissions are allowed for failed packets.

Table A-49: MMC capacity in terms of the number of devices per MHz of bandwidth at 1% packet failure rate.

	Packet size 20 bytes	Packet size 125 bytes
LTE baseline	95 000	80 000
SCMA	1 010 000	168 000

The number of devices supported per MHz of bandwidth is evaluated for packet sizes of 20 and 125 bytes. It is shown that SCMA supports around 10 times more devices for 20-byte packet and 2 times more devices for 125-byte packet in a given bandwidth.

The gain in Table A-49 increases as the packet size becomes smaller. In general, packet size is larger if current LTE connection setup control signaling overhead is included for every packet transmission. However, packet size can be smaller in the future when such overhead is not sent in every contention-based transmission for machine type applications. The gains are a combination of contention-based transmission and the SCMA overloading of the physical resources. This is facilitated by blind detection with reasonable complexity due to SCMA codebook design with low projection codebook, the sparseness of codewords and MPA receiver. Details of SCMA can be found in [MET15-D24, MET15-D43] and references therein.

A.11.7 Battery gains

One of the key requirements to realize MMC is the prolonging the device battery life such that frequent charging is not required. To achieve this, reduced on-time is the key factor. Many TeCs in METIS achieve this by so called contention-based transmission of data, in which the data payload is sent immediately on common resources at the risk of collision. This is in comparison to the baseline R11 LTE procedure where a RA procedure including contention resolution phase is used after which devices can transmit their data payload on dedicated resources. An improved version of the baseline operation has also been included as a third alternative in the evaluations, which is basically contention-based transmission of data for wave forms which require uplink synchronization. In this alternative the contention resolution phase is skipped for a more fair comparison such that RA is only used to obtain the timing advance (i.e. the contention resolution phase including msg3 and msg4 is not required to obtain uplink sync). In this alternative the random access is transmitted with a fixed timing such that DRX/DTX can be applied. RRC connection setup signalling is not considered in any of the cases and devices are assumed to start from a connected mode. The device energy consumption is calculated based on the model in [TLS+13]. The parameters are given in Table A-50.

Table A-50: Parameters for device consumption.

P_{tx}	P_{rx}	P_{base}	P_{clock}	t_{rx}	t_{tx}	t_{sync}	B	Payload
300 mW	100 mW	10 µW	10 mW	10 ms	50 ms	10 ms	5.04 Wh	125 Byte

The differences are a smaller payload of 125 Bytes (with a 50% control signalling overhead on top), according to TC11, and a better battery (2 AA batteries instead of 1 AAA battery) and that the procedure to obtain uplink synchronization is taken in to account. In the model the device listens to paging according to a DRX cycle and transmit periodical uplink payload. The initial state is a connected state. Warm up, sync times and data transmission times are assumed to be the same for all three solutions. In the contention-based procedure no actions are required prior to data transmission, whereas 3 subframes are required for transmission plus 17 subframes for reception in the baseline case, and 1 subframe for transmission plus 1 subframe for reception in the improved alternative. Note that if contention-based transmission is used for wave forms that require uplink synchronization, the timing advance must be obtained and the battery life would be the same as for the improved alternative. (This is valid for all wave forms considered in METIS except FBMC/UFMC which are enabling TA-less transmission or unless the timing advance could be accurately estimated from previously used values etc.). Furthermore, collisions are not considered here so the results are valid for low load situations. Due to the cost saving related to reduced device band-width [3GPP13-36888] the devices are scheduled on at most 6 PRBs, and here always benefit from doing so which means that the gains for power limited devices would in practice be smaller than the ones presented here.

Considering first a typical cell-edge bitrate of 23 kbps, the battery-life times for the three alternatives are presented in Figure A-112. The battery life is plotted as a function of the sleeping cycle length for various uplink traffic reporting periodicities.

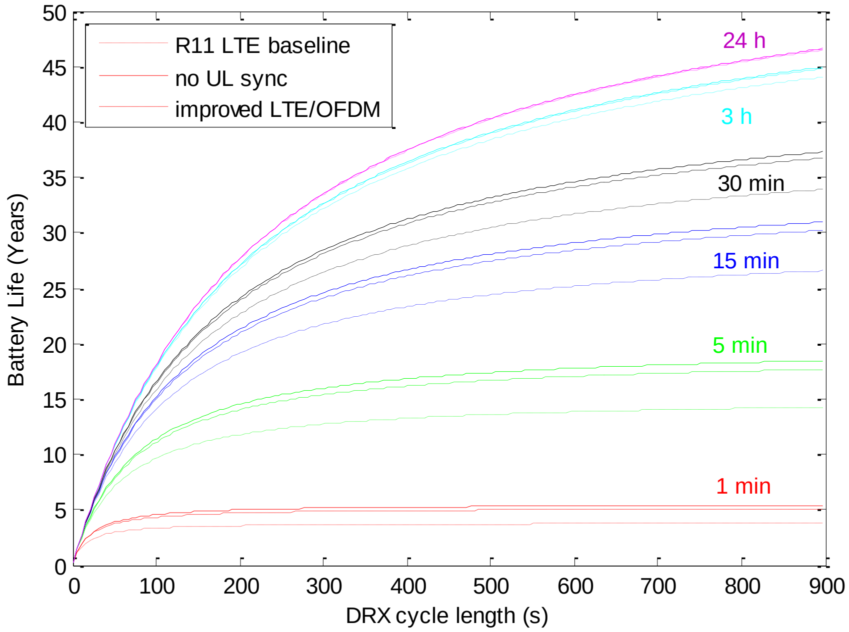

Figure A-112: Battery life as a function of sleeping cycle length for various inter-arrival times.

It can be seen that a battery life longer than 10 years is not possible with an uplink reporting periodicity shorter than 5 min. Further, it is seen that the effect of contention-based transmission is second to the effects of the DRX cycle and the reporting periodicity. In Figure A-113, the gains over the baseline performance are shown and it is seen that the gain can be as large as 29%. However, the improved alternative can achieve a 24% gain, which is the major part of the gain. Further, the gains are also the largest for relatively frequent traffic, in this case with a 5 min reporting interval, for other reporting intervals the gain is considerably smaller.

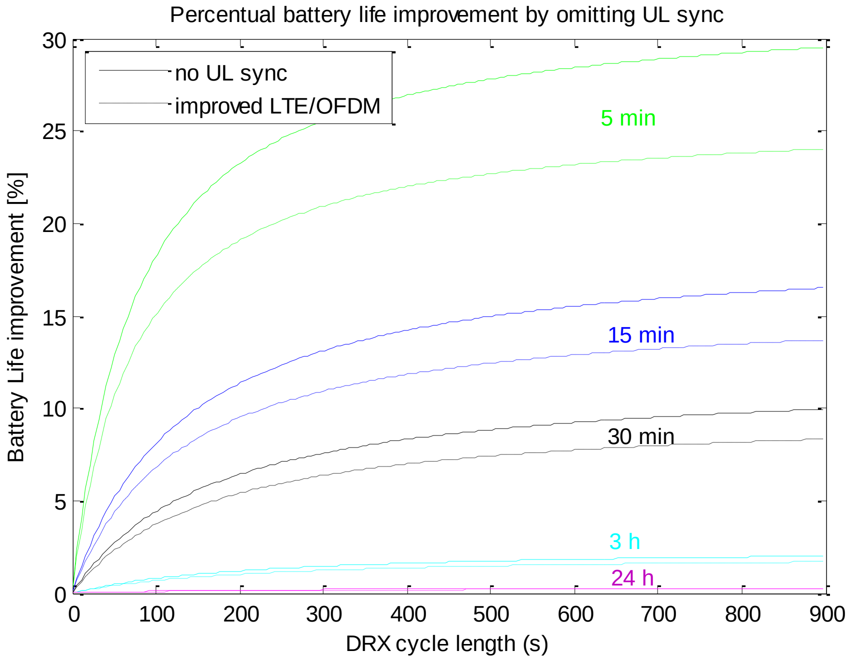

Figure A-113: Battery life improvement in percent over baseline for a user throughput of 23 kbps.

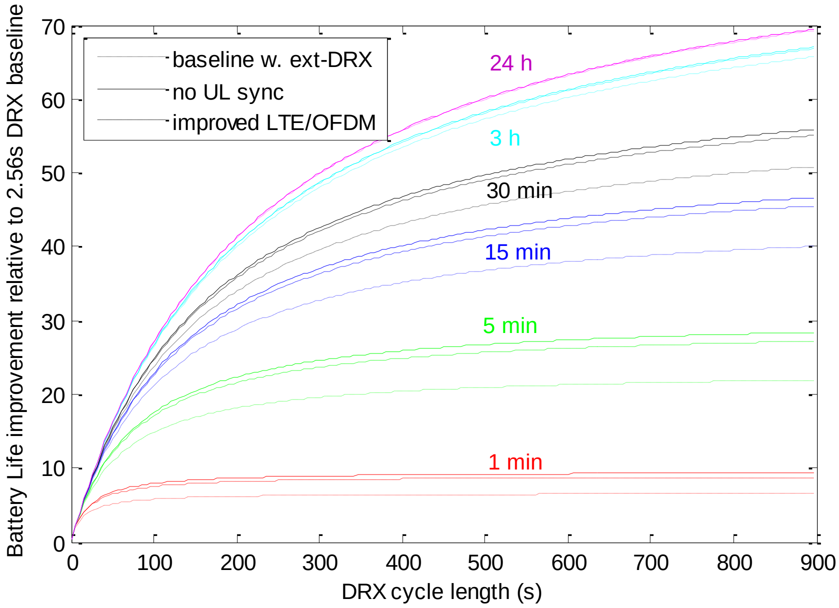

Figure A-114: Battery life gain (as a factor) relative to LTE baseline with DRX cycle of 2.56 s.

In the R11 LTE baseline the longest possible DRX cycle is however 2.56 s so for evaluating the METIS gains this should be the reference. The extension of the DRX sleeping cycles is therefore part of the solution and these gains are plotted in Figure A-114.

It is seen that no solution can provide battery life longer than 10 years for reporting interval of 1 min for the uplink payload and that this constitutes a fundamental limit. For the 5 min reporting interval stated for TC11, extending the DRX cycle to 300 s gives a x20 battery life time gain. This can be further improved by the contention-based techniques; omitting UL sync gives x25 and the x24 for the improved alternative.

According to the TC11 specifications the energy consumption should however be evaluated at a user throughput of 1 kbps. The same graphs are shown below in Figure A-115 and Figure A-116 for this lower bitrate.

The transmission time of the data payload is now much longer relative to the initial control signalling which is what differs between the considered solutions. In effect the gains almost vanish; the gains for the longer reporting intervals are around 1% or less. It is also seen that a battery life of more than 10 years is not possible for reporting intervals of 30 min or shorter.

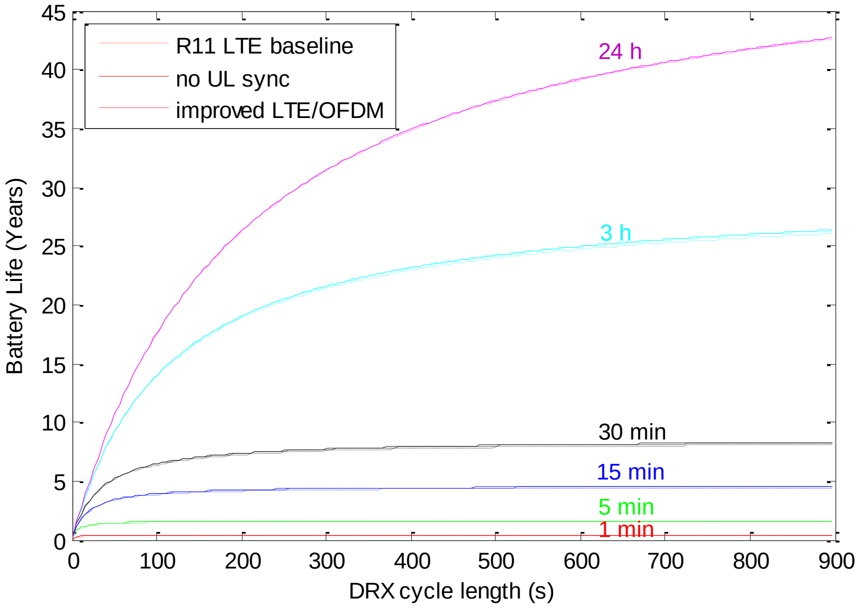

Figure A-115: Battery life as a function of sleeping cycle length for various inter-arrival times of periodic UL traffic at a user throughput of 1 kbps.

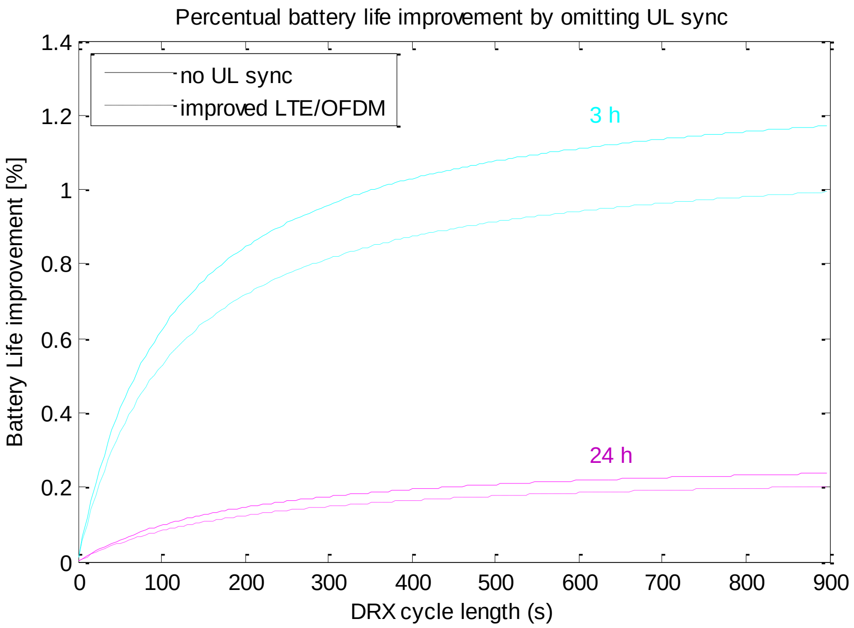

Figure A-116: Battery life improvement in percent over baseline for a user throughput of 1 kbps.

Plotting the METIS gains as for the 23 kbps user data rate case is very similar to previous results, only periodical reporting intervals of 30 min or more can obtain the desired gain of more than x10 (see Figure A-115). Therefore a x10 battery lifetime improvement at the TC11 stated reporting period of 5 min is fundamentally not possible with the modelled power consumption values for transmission, reception and sleep.

The conclusion is therefore that the contention-based access or the improved alternative can give good gains for relatively high user throughputs (or equivalently smaller payloads than considered for TC11). However, system design must be made in such a way that the cell-edge devices meet the requirements. If 1 kbps devices are to be supported for MMC the gains from the proposed solutions will be marginal. Further, in these results it is assumed that devices can always transmit over 1 MHz BW (6 PRBs), gains are smaller for more narrow BW transmissions. This is independent of if it is the selected MMC solutions or if it is for devices in poor coverage which do not benefit in terms of throughput when transmitting over a full 1 MHz band-width. In the 23 kbps case the maximal gain is reduced to 7% for the contention-based transmission and to 6% for the improved alternative if the devices are transmitting over 1 PRB.

A.11.8 M2M relaying

In M2M relaying the machines (sensors) are assumed to have the ability to serve as relays. The relaying capability enables the possibility to improve coverage by helping the weaker users, which also may improve the capacity (via reduced interference) and improve the battery life (via shorter transmission times and reduced energy per transmitted bit). The sensors have direct access and accumulation point access capabilities.

Simulation models

The simulation model for this evaluation is presented below.

The environment of TC11 is the same as for TC2, i.e. the Madrid grid originally defined in [MET13-D61]. Three times three copies of the Madrid grid are considered to avoid border effects. Wrap around is also applied.

The considered deployment of the Madrid grid for M2M relaying was defined in [MET14-D63], and is illustrated in Figure A-117. In this evaluation we consider the macro stations (in pink) together with the users and relays (in blue). In total 9 macro stations with 3 sectors each are considered. The user distribution is such that 75% of the users are located indoors and 25% are located outdoors.

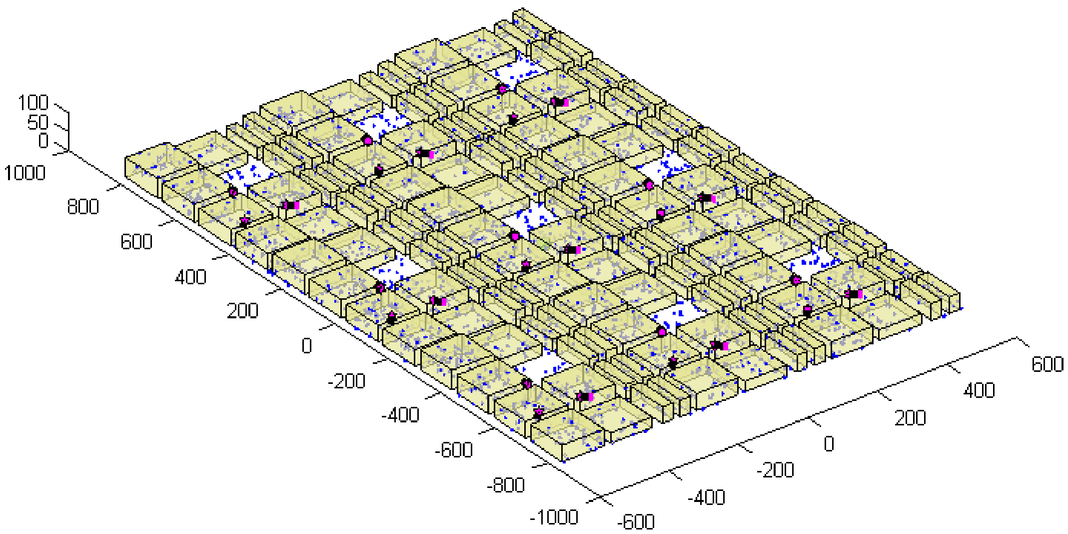

Figure A-117: The Madrid grid. Buildings (yellow); streets and parks (white); macros (pink); sensors/users (blue).

The propagation models used are publicly available at [MET14-Web] and have been obtained via ray-tracing simulations. Both the macro stations and the relay-sensors are using the same bandwidth, 1 MHz, at the carrier frequency 2 GHz (i.e. as a sensor is admitted to serve as a relay it is given the same amount of bandwidth as the macro stations already have). The minimum allowed bit rate is 250 bps. The considered setting is half-duplex with the same frequency between source and relay as between relay and destination. 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 as the maximum Tx power, see [MET13-D61] and [MET14-D63]). Regarding the traffic model, each sensor has monthly quota of data and how often it needs to transmit to fill this quota determines the sensor's activity level. Further, the simulator is static and mobility is not considered for the machine devices. 4000 user positions are considered and multiple devices are modelled in the same position to be able to reach the high number of devices required.

Evaluation technique

The evaluation technique has already been described in Section A.2.1 of [MET14-D63]. For completeness it is shortly summarized below.

The evaluated technique introduces 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. This technique is foremost targeting to improve coverage for devices in poor coverage that otherwise would have non-existing possibilities to communicate or would need long transmission times, causing bad battery life and increased interference levels.

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.

Further, repetition coding is introduced to enable data transmissions for devices that would otherwise have too low SINR. In practice this results in longer transmission times and shows the gains with the M2M relaying for battery life, otherwise gains would mostly be seen as reduced drop rate (devices would be dropped before experiencing poor battery life).

The battery consumption model is based on [TLS+13] and in addition to the uplink payload sensors listen for paging every 300 s.

Results

The evaluations have been conducted separately in downlink and in uplink. In the downlink, machine devices in 6% of the user positions serve as relays (in total 249 out of 4000), and devices in 47% of the user positions are connected to the relays (in total 1880 out of 4000). In Figure A-112 the utilization of the macro stations and the sensor-relays respectively are being presented as a function of the total served traffic in the system.

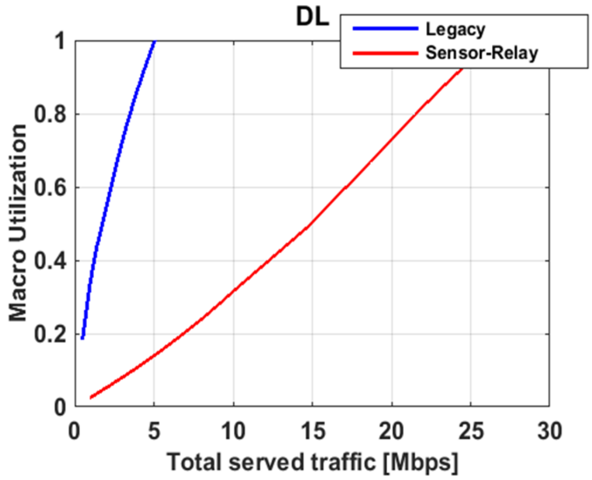

Figure A-118: The macro utilization, for the set of all users, is presented as a function of the total served traffic for the legacy system and the sensor-relay system.

From Figure A-118 it is evident that the sensor-relays are able increase the capacity of the system. In a fully loaded system the legacy system provides a total served traffic of 5 Mbps while the corresponding sensor-relay system provides 25 Mbps.

In Figure A-119 the drop rate is presented and it is seen there is a significant improvement for the sensor-relays compared to the legacy system.

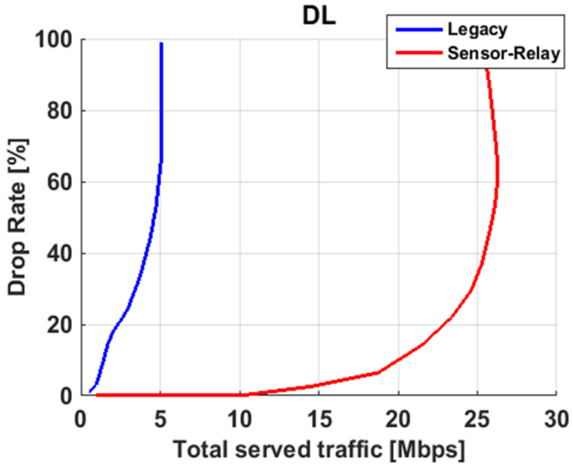

Figure A-119: The drop rate, for the set of users that benefit from the sensor-relays, is presented as a function of the total served traffic for the legacy system and the sensor-relay system.

It is seen that the drop-rate is very dependent on the capacity limit in Figure A-119. In a realistic network there would be a highest acceptable drop rate. Assuming this is for example 4%, the baseline case could handle a total traffic of up 1 Mbps whereas with the introduction of sensor-relays this is increased to 16 Mbps. This meets the METIS overall goal of x10 to x100 capacity increase.

In Figure A-120 the average battery lifetime for the set of users that benefit from the relays is presented (i.e. in the 47% of 4000 user positions that are connected to the relays).

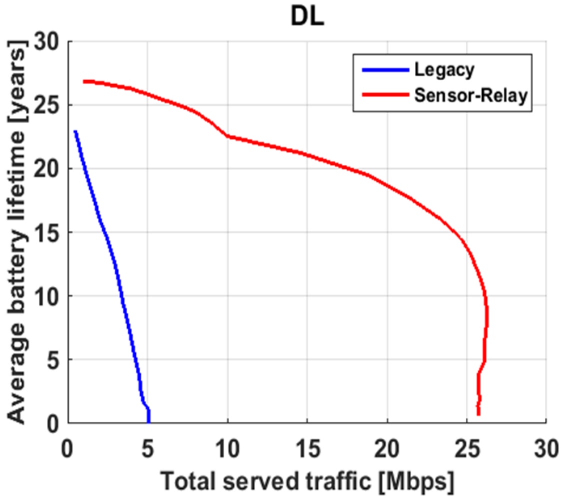

Figure A-120: The average battery lifetime, for the set of users that benefit from the sensor-relays, as a function of the total served traffic.

As can be seen, the sensor-relay case significantly outperforms the legacy system for a given total served traffic that one wants to attain in the system. The capacity requirement of TC11 is 2 Mbps, i.e. derived from 300 000 devices per cell transmitting 125 Byte (with a 50% overhead) every 5 min. At this fixed total served traffic the battery life increases from 16 years to 27 years by the introduction of sensor-relays. This does in this case meet the METIS overall goals of 10x battery life but this is due to that capacity and coverage is improved significantly at the same time. If however the condition of dropping users below a certain user throughput was removed, no users would be dropped and there would be significantly higher gains of the battery life side since there would be no coverage gains.

In the uplink, machine devices in 1% of the user positions serve as relays (in total 35 relays out of 4000), and devices in 18% of the user positions are connected to the relays (in total 72 out of 4000 users).

Results for the uplink are similar to the downlink. In Figure A-121 the utilization of the macro stations is as a function of the total served traffic in the system. The maximal total traffic is in this case is increased by x2.6 which is less than for the downlink case of x5 and this is due to that fewer are aided by relays.

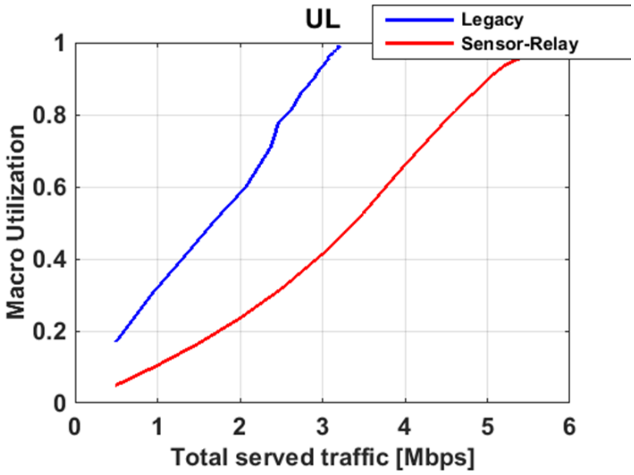

Figure A-121: The macro utilization, for the set of all users, is presented as a function of the total served traffic for the legacy system and the sensor-relay system.

The uplink drop rate is presented in Figure A-122 and again shows large gains from using sensor-relays.

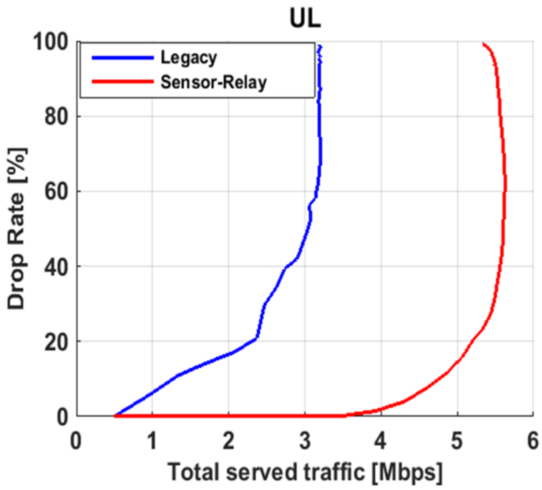

Figure A-122: The drop rate, for the set of users that benefit from the sensor-relays, is presented as a function of the total served traffic for the legacy system and the sensor-relay system.

If maximum acceptable drop rate of 4% is considered as before, the capacity improvement is from 0.8 Mbps for the baseline to 4.3 Mbps for the sensor-relay case, or 5x capacity improvement.

In Figure A-123 the average battery lifetime for the set of users that benefit from the relays is presented (i.e. the 18% of 4000 user positions that are connected to the relays).

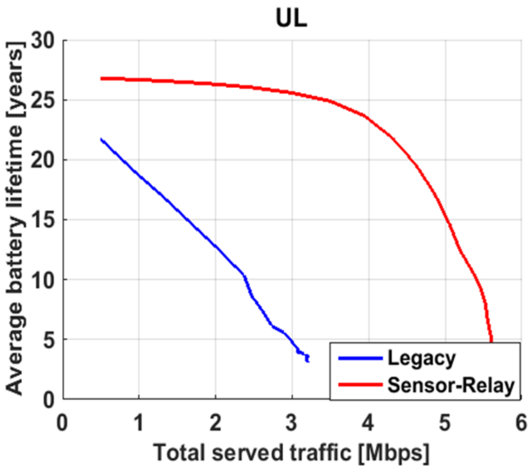

Figure A-123: The average battery lifetime, for the set of users that benefit from the sensor-relays, is presented as a function of the total served traffic for the legacy system and the sensor-relay system.

The sensor-relay case again outperforms the legacy system for a given total served traffic. Considering the TC11 traffic requirement of 2 Mbps also for the uplink, it is found that the battery life increases from 12 years for the baseline to 26 years.

Regarding the coverage goal of METIS, improving coverage is about increasing the received energy and typically there is a trade-off in doing so. A common solution is to allow for longer transmission times in which case the battery consumption will suffer. Therefore it is worth noting that M2M relaying improves coverage (reduces drop rate), capacity and battery life at the same time. For the scenario considered there, these simultaneous gains are summarized in Table A-51.

Table A-51: Results at 300000 devices/cell with 125 B payload with 50% overhead every 5 min.

		Baseline	M2M Relay
Battery life:	DL:	16 years	27 years
	UL:	12 years	26 years
Drop rate:	DL:	18 %	0 %
	UL:	17 %	0 %
Capacity (4%):	DL:	1 Mbps	16 Mbps
	UL:	1 Mbps	5 Mbps

It is also worth noting that the gains are very scenario dependent. The TC2 propagation map is for a very dense, urban scenario, more challenging in terms of interference than in coverage. To increase the number of power limited devices, an additional +20 dB pathloss was also studied which approximately makes outdoor devices to indoor devices and indoor devices to basement devices[4]. This results in that a higher number of the devices transmit via sensor relays, around 80%. In this case the downlink capacity is increased by x217 and the uplink capacity by 81x (in this case at a maximum acceptable drop rate of 14% since baseline drop rate is larger than 4% even at the lowest load). The conclusion is therefore that, unsurprisingly, M2M relaying shows the biggest gains for power limited devices in scenarios with challenging coverage.

[4] Note that in this case 20 MHz system bandwidth was used rather than 1 MHz.

A.12 TC12: Traffic efficiency and safety

A.12.1 Description of the test case

In Europe alone, some 40 000 people die and 1.7 million are injured annually in traffic accidents. At the same time, traffic increases on our roads leading to traffic jams, increased travel time, fuel consumption and increased pollution. Cooperative intelligent traffic systems (C-ITS) can address these problems. Cooperative active safety systems can warn drivers of dangerous situations and intervene through automatic braking or steering if the driver is unable to avoid an accident. Cooperative driving applications, such as platooning (road-trains) and highly automated driving can reduce travel time, fuel consumption, and CO_2 emissions and also increase road safety and traffic efficiency. Moreover, not only cooperation between vehicles or between vehicles and infrastructure is required, but also the cooperation between vehicles and vulnerable road users, e.g. pedestrians and cyclists, through their mobile devices, such as smartphone and tablets, will be an important key element to improve traffic safety. C-ITS systems rely on timely and reliable exchange of information. Common to most applications are real-time requirements, and strict requirements on reliability and availability, especially when considering high mobility and large message sizes. End-to-end latency requirements of less than 5 ms for message sizes of about 1600 byte need to be guaranteed for all V2X transmissions. Data is sent either event-driven or periodically with a rate of about 10 Hz. Relative speeds of up to 500 km/h are possible on high-speed highways. [MET13-D11]

Information exchange among vehicles will enable the provision of safety hints to the driver or warnings about the road status, e.g. constructions, weather conditions, road hazards. Consider a vehicle arriving into an intersection with low visibility; in order to aid the driver and avoid the occurrence of an accident, the vehicle could signal to the driver the direction and velocity of any moving vehicle that approaches the intersection. Additionally, the vehicle could communicate with other vehicles and actively intervene in order to avoid accidents. An example could be the autonomous intervention of the vehicle (e.g. emergency braking), based on the notification of the presence of another vehicle, to avoid an accident. [MET13-D11]

Besides providing a safer driving environment, information exchange between vehicles can also enhance traffic efficiency. This refers to increasing traffic flows and reducing fuel consumption and emissions. [MET13-D11]

A.12.2 Main KPI and requirements

The main KPIs and requirement for this test case in Urban Scenario are shown in Table A-52. This test case shows main challenges in the required reliability, availability, and latency of automotive safety services.

Table A-52: KPIs and requirement for TC12.

KPI	Requirement for Urban scenario
Latency, end-to-end (including detection delay) for receivers within the target range	Less than 5 ms for 99.999% of the transmissions
Relative velocity	60 km/h
Detection range	Up to 300 m

A.12.3 Simulation models

Environmental model

This test case should work in any road environment, independent from whether it is urban, rural, or highway scenario. In this work, system performance is investigated in a dense urban environment. We give special consideration to this environment since vehicles are distributed in a 2D map compared with 1D of highway with a higher density compared with rural area. Besides, due to high building density in this environment, vehicles distributed in this 2D map encounter more complicate channel propagation model than another two scenarios.

As shown in Figure A-124, environmental model defined in TC2 is reused here. In this model, a 3D visualization of Madrid grid is depicted. In order to avoid cell border effect, totally nine replicas of Madrid grid are exploited but only performance of vehicles located in the central Madrid grid (as shown at right hand side of Figure A-124) are inspected to derive system performance. Dimensions for one Madrid grid is 387 m (east west) and 552 m (south north) assuming only one sidewalk, parking lane and road lane between edge buildings and the layout border. The building height is uniformly distributed between 8 and 15 floors with 3.5 m per floor. Detailed description of this model can be found in [MET13-D61].

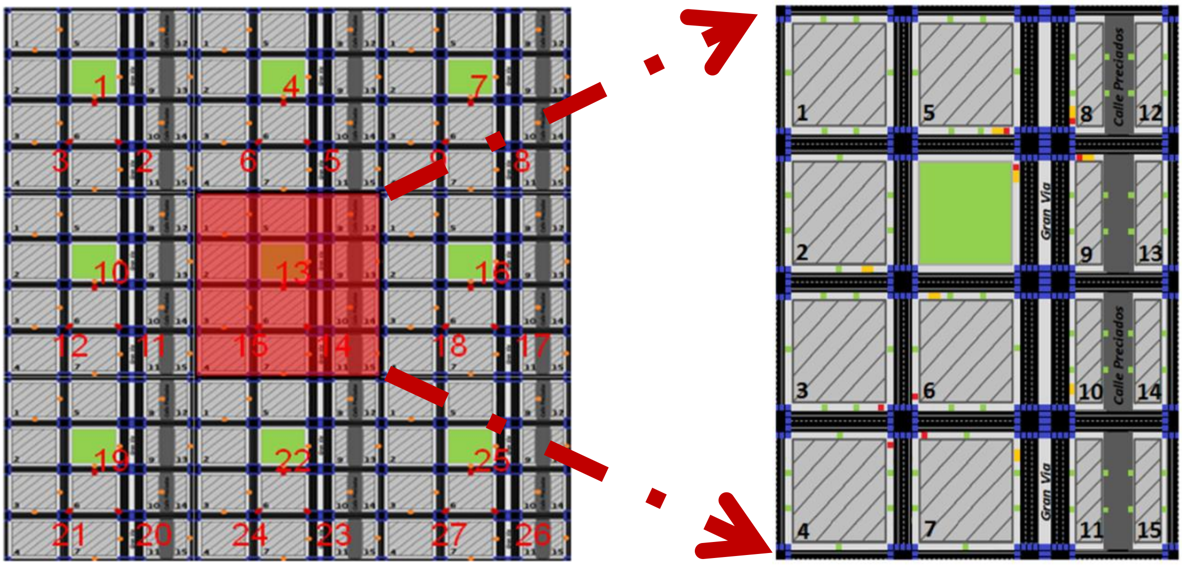

Figure A-124: Environmental model.

Deployment model

As shown in Figure A-125, default infrastructure deployment is aligned with TC2 description in [MET13-D61]. Network consists of a single macro station operating in 3 sectors. And the macro cells are complemented with 12 micro/pico cells.

Vehicles are distributed on road with a density of 1000 vehicles per square kilometre. And isotropic antennas are installed on each vehicle at 1.5 meter height. 1×2 antennas configuration (receiver diversity) is exploited for V2V communications in this work. Each transmitting vehicle has a constant transmitting power of 24 dBm in each 10 MHz bandwidth, corresponding to a power spectrum density of -46 dBm/Hz.

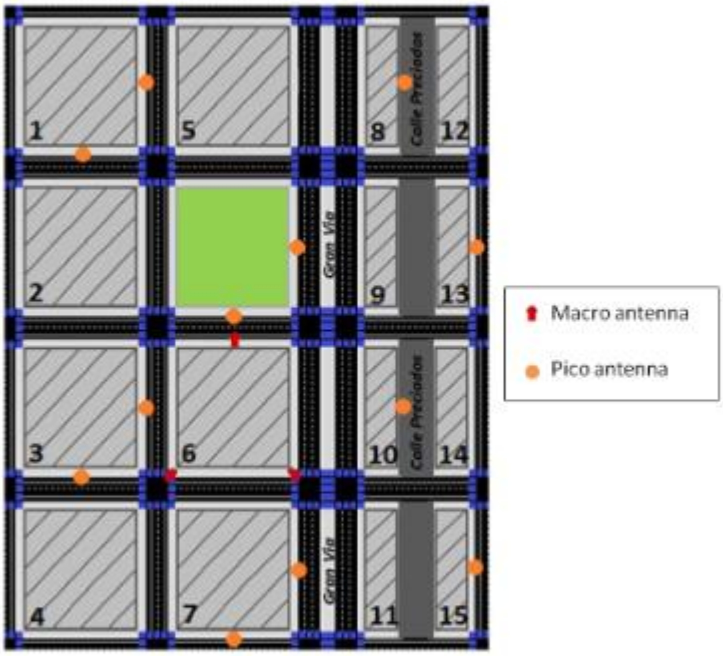

Figure A-125: Deployment model.

Propagation model regarding V2V communications

The LOS path loss for V2V communications in decibels is calculated according to:

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

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

$$h'_{tx} = h_{tx} - 1, h'_{rx} = h_{rx} - 1$$

where h_{tx} and h_{rx} are actual heights of transmitter and receiver antennas.

The NLOS path loss for V2V communications in decibels as shown in Figure A-126 [TOH11], is calculated according to [TOH11]:

$$PL_{los} = C + i_s L_{SU} + 10log_{10}((\frac{{d_t}^{E_T}}{(x_t w_r)^{E_S}} \frac{4\pi d_r}{\lambda})^{E_l})$$

where $C = CurveShift,\ L_{SU} = SubUrbanLoss, E_l = LossExponent,$ $E_s = StreetExp, E_T = TxDistExp.$

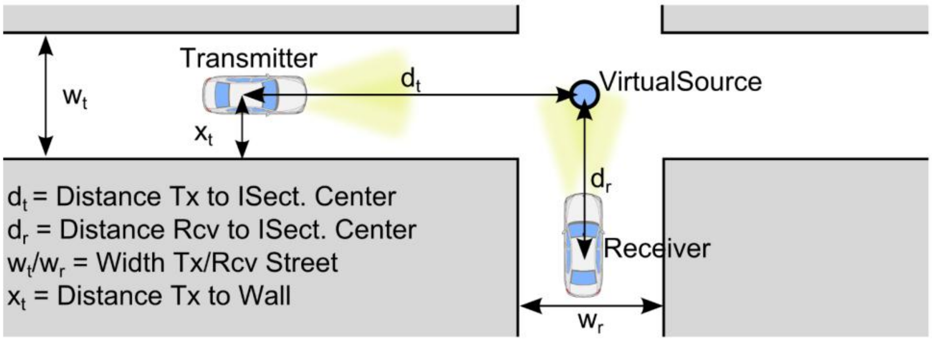

Figure A-126: NLOS path loss model for V2V.

Traffic model

Package of 1600 bytes is periodic broadcasted with 10 Hz per vehicle for V2V communication.

Mobility model

Each vehicle has a velocity of 60 km/h.

A.12.4 Evaluation methodology regarding V2V communication

RAN architecture

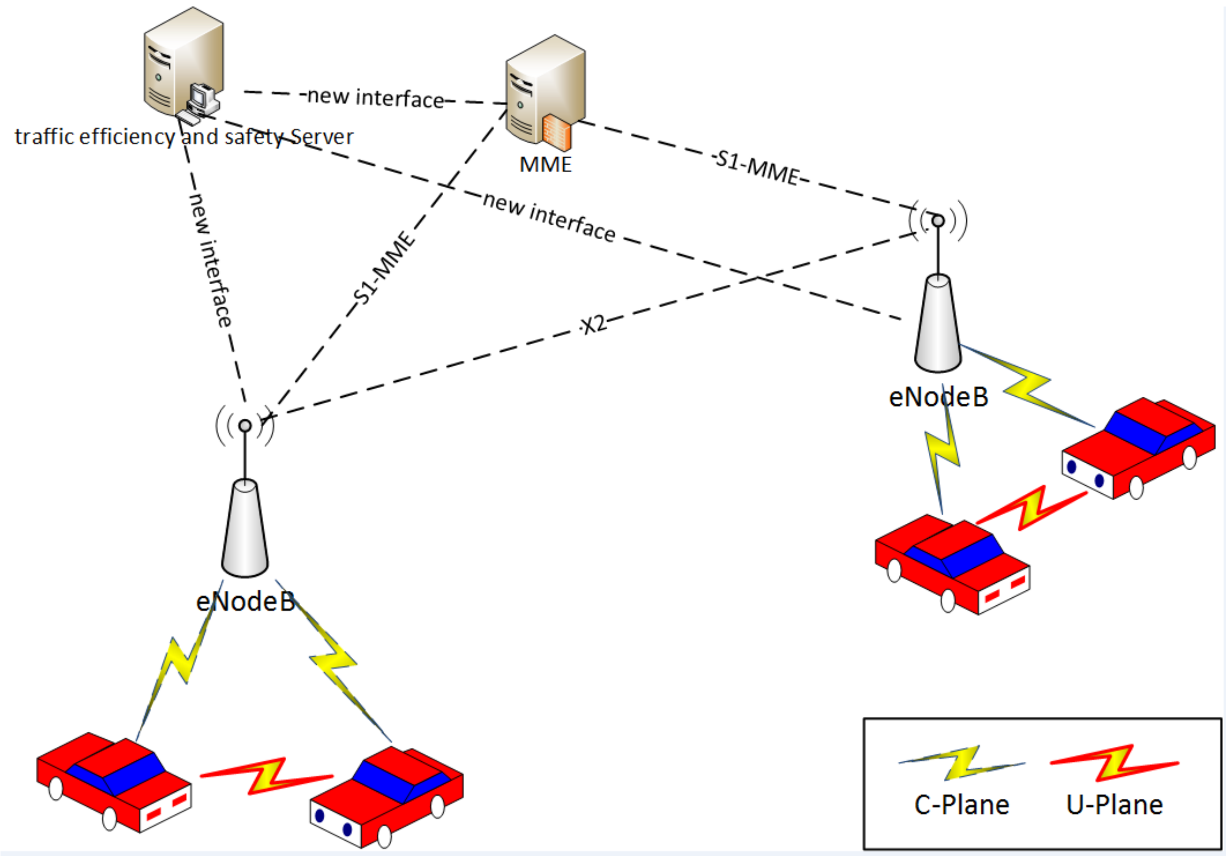

Figure A-127: RAN architecture.

In this work, network controlled V2V communication is exploited for package transmission. In this sense, as shown in Figure A-127, all vehicles are connected to operator network in C-plane. Meanwhile, U-plane traffic communicates directly in between vehicle transmitter and receivers where receivers are located in the proxy of the transmitter. Therefore, user data transmission carries out in a manner of direct V2V communication instead of going through network infrastructure.

In order to provide network controlled V2V communication, we assume a traffic efficiency and safety (TES) server is installed in the core network of a mobile network operator and certain functionalities can be provided by this new server.

- TES server can exchange location information with the mobility management entity (MME) which receives regularly location update messages from vehicles.
- Based on location information of each vehicle, this server can allocate RBs for V2V transmission.
- Based on real time network environment and performance, TES server can adapt network settings for V2V operation.

Delay component assumptions

Table A-53: Delay component assumption.

Delay component	Value in a unit of TTI
frame alignment (FA)	0.5 TTI
TTI per package (TP)	Package specific (depending on available spectrum resource)
receiver processing delay (RPD)	1 TTI
transmission of NACK feedback from receiver to BS (FB)	1 TTI
minimal scheduling delay in server (SD)	1 TTI
transmission of retransmission command from BS to Txs (TRC)	1 TTI

In order to evaluate U-plane E2E latency, delay components shown in Table A-53 are considered in this work. All delay components are assumed with unit of TTI with a value of 1ms in legacy LTE network.

As can be seen from this table, the minimal E2E latency happens when the first trial of package transmission is successful. At the same time this package transmission (TP) should cost only 1 TTI. Thus, a minimal E2E latency has a value of:

$$\text{minimal E2E latency} = 0.5\ (\text{FA}) + 1\ (\text{TP}) + 1\ (\text{RPD}) = 2.5\ \text{TTIs}.$$

In the case where first package transmission is not successful and retransmission is required, the minimal E2E latency can be calculated as:

$$\begin{aligned}\text{minimal E2E latency of retransmission} \\ &= 0.5\ (\text{FA}) + 1\ (\text{TP}) + 1\ (\text{RPD}) + 1\ (\text{FB}) + 1\ (\text{SD}) + 1\ (\text{TRC}) + 1\ (\text{TP}) \\ &+ 1\ (\text{RPD}) = 7.5\ \text{TTIs}.\end{aligned}$$

Resource allocation between first transmission and retransmission

In order to support V2V traffic with 10 Hz periodic transmission of package of 1600bytes, each package transmission is assigned by TES server with a certain time and frequency domain resource. An efficient way to assign resource can be done in a centralized manner, where TES server pre-allocates resource to all vehicles and inform vehicles in broadcast channel. The basic principles for resource allocation are as follows:

- For first package transmission: each Tx is scheduled by TES server with a set of RBs, and it generates its packet in the TTI just before its own transmission starts.
- For retransmission: RBs are uniformly distributed among all RBs.

One example is shown in Figure A-128 in order to express above resource allocation procedure more clearly. In this example, six users (U1,U2, …, U6) should be served by one BS in 100 ms (duration time of one period with 10 Hz periodicity) and we assume that first transmission of each packet occupies 10 ms of time resource, where in reality this time length is related with packet length, coding and modulation rate, and also available transmission bandwidth. Meanwhile, since retransmission might use a lower coding and modulation rate in order to achieve a better link robustness, we assume each retransmission requires a longer time resource of 20 ms, compared with the first transmission. Thus, two blocks for retransmission are available in this time duration of 100 ms and they are uniformly distributed in this work.

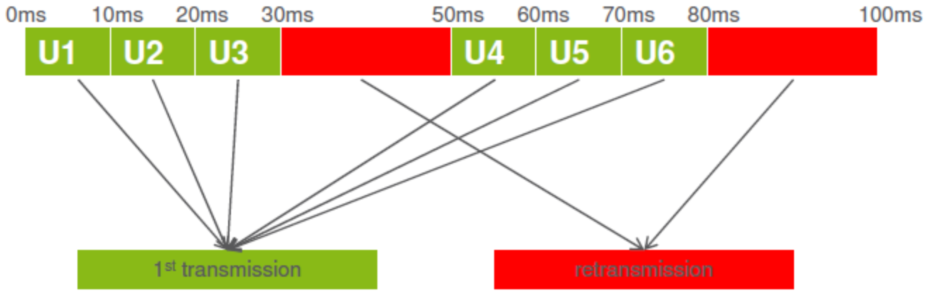

Figure A-128: Resource allocation between first transmission and retransmission.

Methodology

The methodology used to evaluate package E2E latency is shown in the following.

1) A packet of 1600 Bytes (12800 bits) is generated at one vehicle. In 100 ms, packets are generated in the TTI just before its own transmission should start. The transmission time for each vehicle is pre-allocated and broadcasted by TES server and BSs.
2) Perform transport block cyclic redundancy code (CRC) attachment and code block segmentation (24 bits for each block and with a maximum information block size of 6144 bits).
3) Perform coding and modulation w.r.t. a specific coding and modulation rate (0.377bits/Hz now).
4) Block error rate (BLER) is derived from SINR value of each link.
5) TES server determines how many RBs*TTIs are allocated for each packet. (since it is a fixed packet size and fixed coding and modulation rate, this value of RBs*TTIs is same for all links)

6) If a packet is not received correctly w.r.t. BLER of step 4), we inspect on whether ARQ retransmission is scheduled and successful for this packet. If it is not successful, the packet delay is considered as infinity.

It should be noticed, as we introduced in section before, first transmission and retransmission might apply different coding and modulation rate. Therefore, RBs*TTIs in step 5) is a fixed value for all vehicles which try to transmit a new data package, and another one fixed value for all vehicles which try to retransmit a package.

A.12.5 Technology components

Table A-54: Main technology components evaluated in TC12 simulations.

WP/Taks	TeC	Name
WP2	TeCC8.1	FBMC
WP2	TeCC9.2	Advanced coding and decoding
T4.2	TeC2	Context awareness through prediction of next cell
T4.2	TeC7	Context aware mobility handover optimization using Fuzzy Q-learning
T4.2	TeC10	Signalling for trajectory prediction
T4.3	TeC1-A1	New management interfaces between the operator and the service provider
T4.3	TeC1-A2	New management interfaces for information exchange and action enforcement

Under the scope of METIS project, many TeCs are developed in order to enhance communication reliability and approach the strict requirement of V2V communications. In this work, several TeCs are selected in order to proof their benefits for V2V communications. The selected TeCs are listed in Table A-54. In the following, we give some overview of the selected TeCs and how they contribute to V2V communications.

WP2-TeCC8.1 *FBMC* and WP2-TeCC8.2 *UFMC* can provide better waveforms to improve the robustness of multicarrier transmission against the Doppler spreading effect. At the same time, they can also relax the synchronization constraint in V2V communications where it is difficult to synchronize among all potential vehicles in the high mobility scenario. WP2-TeCC9 *advanced coding and decoding* can improve the link performance by overcoming the influence of fast fading. These three TeCs from WP2 enable an improved robustness and therefore a robust modulation scheme with constant data rate can be achieved.

T4.2-TeC2 *context awareness through prediction of next cell* enables to predict user trajectory and the next cell for transition. In this work, together with T4.2-TeC7 *context aware mobility handover optimization using Fuzzy Q-learning* and T4.2-TeC10 *signalling for trajectory prediction*, it is assumed that moving users are always connected to their serving BSs in a corrected seamless manner.

Two TeCs: T4.3-TeC1-A1 *new management interfaces between the operator and the service provider* and T4.3-TeC1-A2 *new management interfaces for information exchange and action enforcement*, can enable critical functionalities of V2V communications by providing necessary interfaces and support interaction between TES server with V2V communication network in control plane.

A.12.6 Results

Draft solution analysis

In order to enable traffic safety and efficiency, information of each vehicle should be collected by all vehicles in its proximity, e.g. constructions, weather conditions, road hazards. Thus, to broadcast information of each vehicle is an efficient way for information exchange between vehicles. In this manner, all vehicles which are in proximity of the transmitter vehicle should listen to the broadcasted package simultaneously. This communication process corresponds to a point-to-multipoint communication where several receivers try to receive the same package coming from one transmitter.

One issue for above point-to-multipoint communication is to adapt each transmission with an appropriate modulation and coding scheme (MCS). Due to the near-far effect, different links between transmitter and receivers experience different channel states. Therefore it is critical that links experiencing worse channel states should adapt to a MCS with a more robust link performance. Meanwhile, real time CSI is difficult to be collected in high mobility scenario at transmitter side. In the case where no CSI is available at transmitter side, a more robust transmission simply means a lower coding and modulation ratio. However, such a MCS requires more frequency and time resource to transmit one package. Therefore, the MCS used for each transmission should be adjusted by TES server based on real time system load. In the following, we give a basic analysis for our urban dense scenario.

In our simulated area, a user density of 1000 vehicles/km^2 with a dimension of 387 m (west-east) * 552 m (north-south) are assumed. Thus, total number of vehicles in the considered area is:

$$N_V = 1000 * (0.387 \times 0.552) \approx 213 \text{ vehicles}.$$

Every transmitted package has a size of 1600 Bytes with 10 Hz periodicity, thus the overall date volume is:

$$1600 \text{ Byte} \times 8\text{bits/Byte} \times 10\text{Hz} \times 213 \text{ vehicles} \approx 27.3\text{Mbps}.$$

When 100 MHz bandwidth is used for V2V communication, the minimal coding and modulation ratio should provide a spectral efficiency of 0.273 bps/Hz. Legacy LTE network has 15 MCSs with different spectral efficiency. With above calculated minimal spectral efficiency, the level three MCS with a spectral efficiency of 0.377 bit/Hz should be used for first transmission and this scheme provides a low block error rate (BLER) to links which experience SINR values larger than -3dB. For the links with SINR values lower than -3 dB, due to high BLER value, retransmission is required.

Detailed simulation results and analysis

In Figure A-129, CDF of SINR values in our scenario is plotted with a V2V communication range up to 200 meter. In this case SINR values of all receiving vehicles inside a radius of 200 meter from each transmitting vehicle are considered to generate this plot. Besides, transmitters located in the central Madrid grid are considered as desired package transmitter and transmitters located in the other eight Madrid grids are used to generate interference for the desired link. When we choose a MCS with a spectral efficiency of 0.377 bits/Hz, receivers experiencing SINR values lower than -3 dB normally require retransmissions due to their high BLER. It can be seen from this plot, approximately 15 percent of receivers have SINR values lower than -3 dB and require retransmission. Therefore, the set of receivers requiring retransmissions are inspected and SINR values of retransmissions are also plotted in Figure A-129. Among all retransmitted packages, it can be seen that more than 30 percent of them still experience SINR values lower than -3 dB.

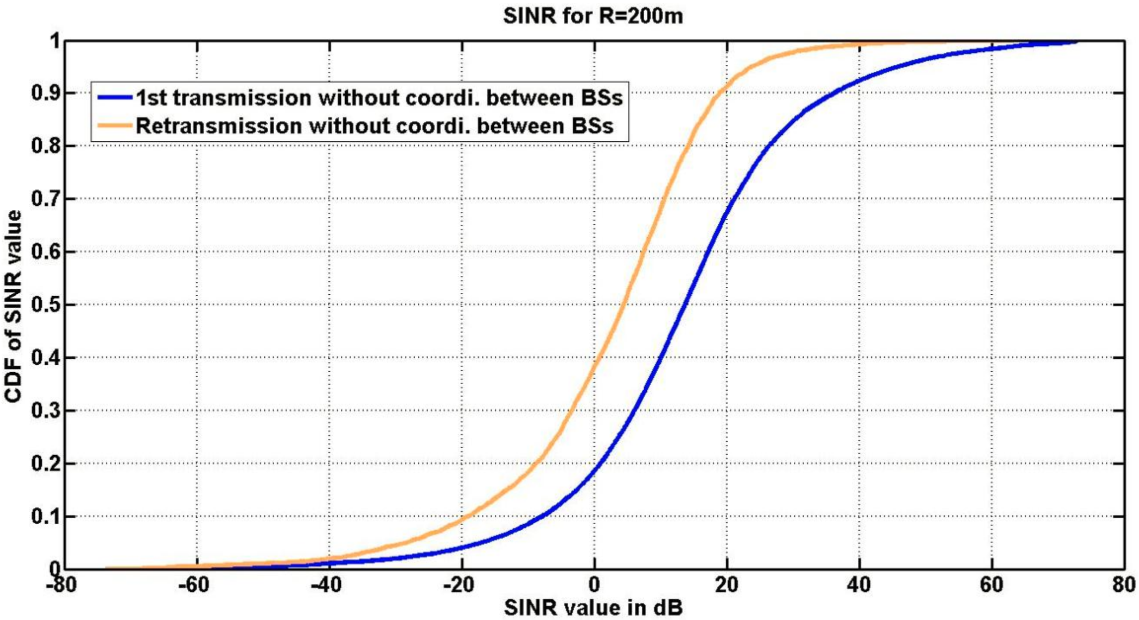

Figure A-129: SINR for communication range of 200 m.

Previously, there is no coordination between different BSs since vehicles in the other eight Madrid grids are randomly selected as interference generators. In this scenario, every BS has no awareness of situation in neighbouring cells and thus two issues are presented:

- Without any awareness of interference coming from neighbouring cells, receiver may experience strong interference.
- When one receiver located in the cell border, it might locate in the proximity of another transmitter served by neighbouring cell, thus package collision may occur.

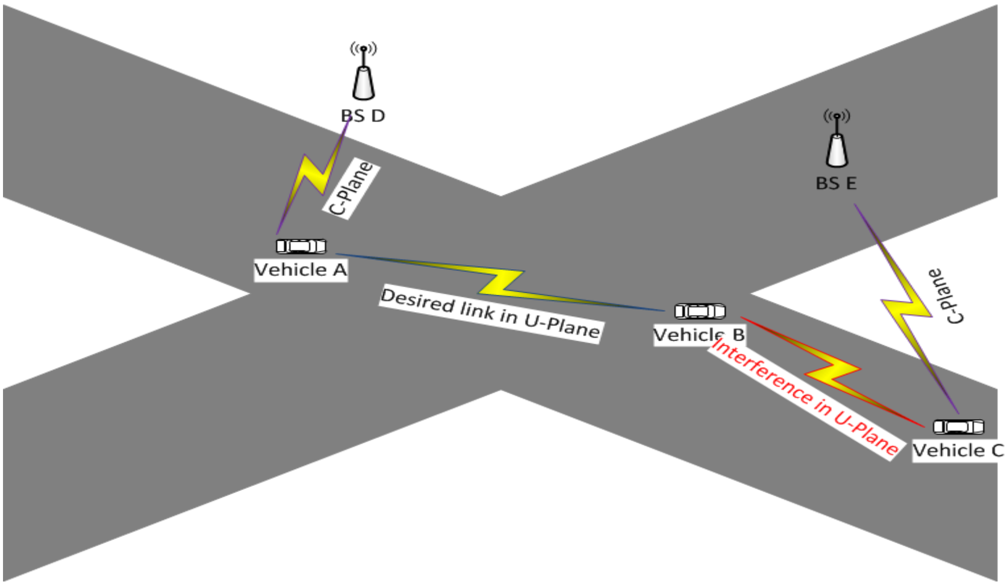

Figure A-130: Example to show disadvantages without coordination.

Figure A-130 gives one example to show above issues. Vehicle A and vehicle C are two transmitters controlled by different base stations D and E. Meanwhile, Vehicle B locates in the communication range of both vehicles A and C. Without cooperation in between different BSs, Vehicles A and C can transmit their packages simultaneously. Thus, these two packages collide at vehicle B and a high interference can be experienced.

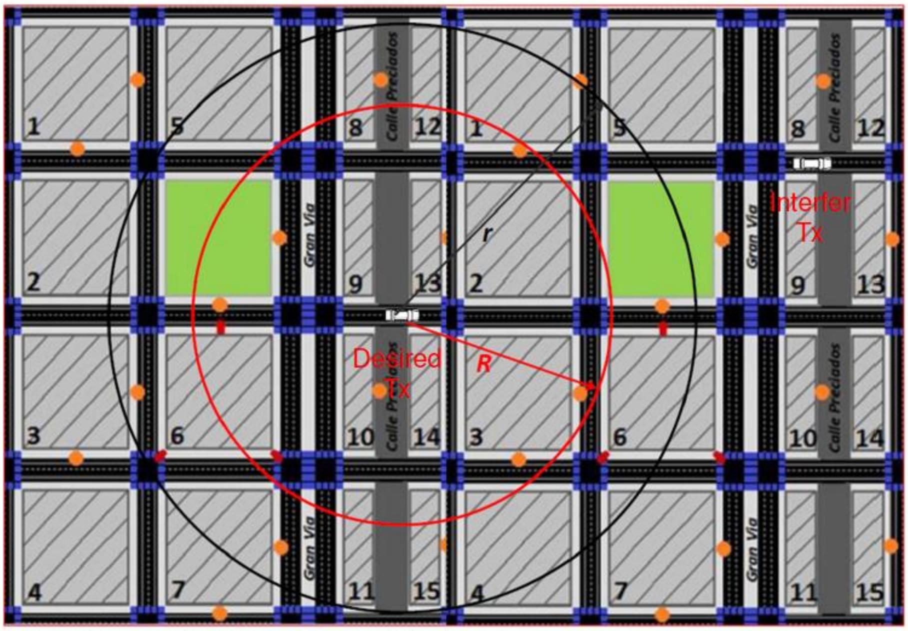

Figure A-131: Context-aware coordination between BSs.

In order to solve above issues, coordination between BSs should be used. In Figure A-131, context-aware coordination scheme is applied where location information of vehicles in between neighbouring cells are exploited at TES. The principle here is to allocate same radio resource to transmitters served by different BSs when these transmitters have an inter-transmitter distance *R* larger than a threshold value *r.* And in our work, the value of *r* is set with a value which is two times of the communication range *R* in order to avoid packet collision.

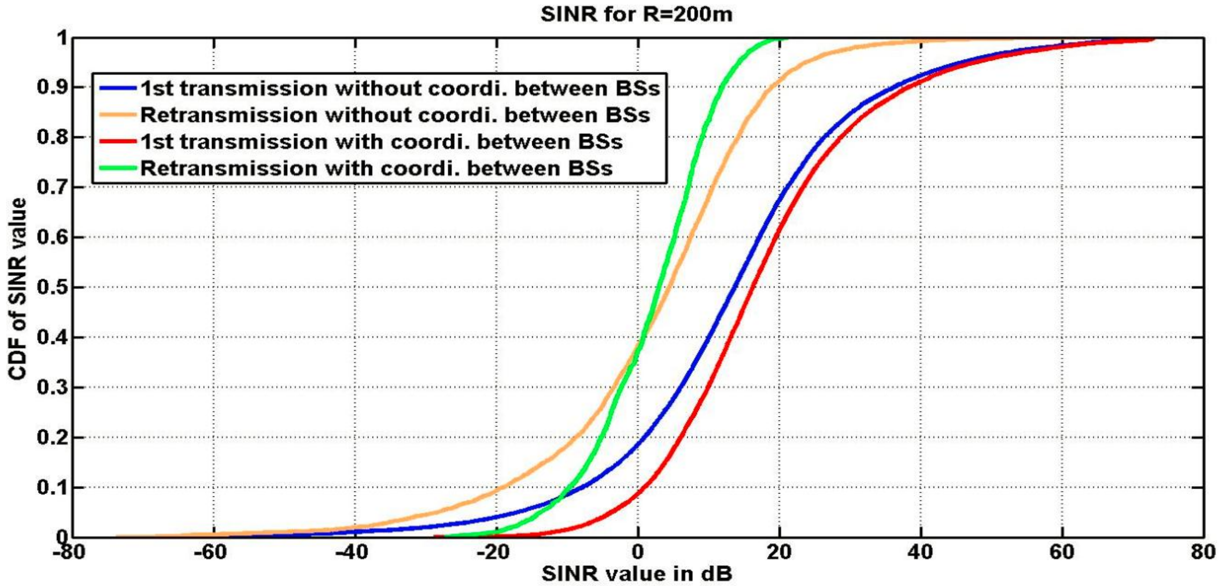

Figure A-132: SINR plot for comparison of different schemes.

In order to see the performance improvement compared with the non-coordination scheme, CDF of SINR values are plotted in Figure A-132 when coordination between BSs is exploited. It can be seen from this figure that around 9% gain in SINR CDF can be achieved when successful ratio of the first transmission is considered as KPI.

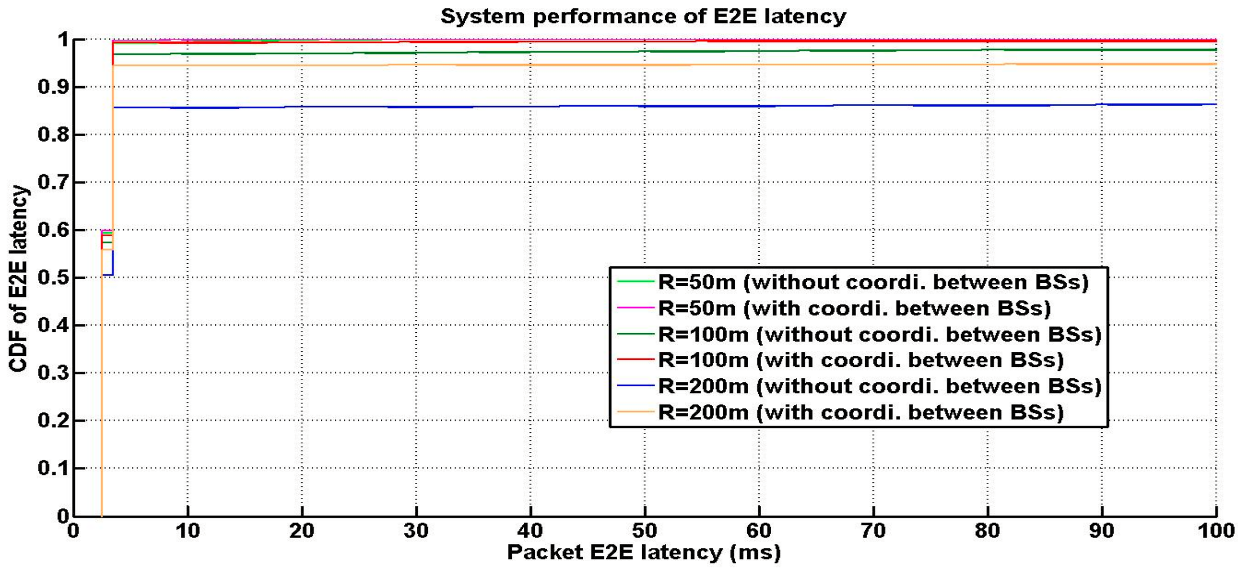

Figure A-133: System performance w.r.t. different coordination schemes.

Table A-55: Detailed number regarding KPIs.

range	R=50m		R=100m		R=200m	
	No Coordi.	Coordi.	No Coordi.	Coordi.	No Coordi.	Coordi.
Successful ratio	99.93%	99.99%	97.71%	99.56%	86.26%	94.73%
5ms E2E latency ratio	99.10%	99.83%	96.82%	99.18%	85.59%	94.45%

In Figure A-133, the CDF of package E2E latency is plotted and the relative numbers of Successful ratio as well as of 5ms E2E latency ratio are given in Table A-55. It is further assumed in this simulation that each TTI has time duration of 1ms. Besides, MCSs with spectral efficiency of 0.377 bits/Hz and 0.1523 bits/Hz are used for first transmission and retransmission respectively. A MCS with lower spectral efficiency is used for retransmission to achieve a more robust link. Successful ratio and 5ms E2E latency ratio are two KPIs used in the table with definitions as:

$$\text{Successful ratio} = \frac{\text{number of successful packet transmissions}}{\text{number of packets which should be transmitted}},$$

$$\text{5ms E2E latency ratio} = \frac{\text{number of successful packet transmissions with a E2E latency smaller or equal to 5ms}}{\text{number of packets which should be transmitted}}.$$

As we can see from Figure A-133 and Table A-55, a performance improvement can be achieved when coordination between BSs is applied, and system performance deteriorates with an increased communication range. As we analysed before, when each TTI has time duration of 1ms, then minimal latency of retransmitted package has a value of 7.5 ms. It means the packages received by retransmission cannot contribute to 5 ms E2E latency ratio but only to successful ratio. We can see from Figure A-132 and Figure A-133 that around 80% of retransmission can have SINR values larger than -7 dB in the case with coordination between BSs. Though retransmissions contribute to the difference between successful ratio and 5ms E2E latency ratio, Table A-55 demonstrates only a small improvement gained by retransmissions. The reason is that 94 percent of successful first transmission ratio does not mean that 94 percent of packages do not need to be retransmitted, but 94 percent of receivers successfully received their packages. This property comes from the point to multipoint communication mode. In Figure A-134, one example is given to illustrate this issue. In this figure, vehicle Tx broadcasts two packages to nearby 10 vehicles, vehicles Rx#9 and Rx#10 experience bad channel condition and fail in receiving first and second package transmissions respectively. Thus, a successful first transmission ratio of 90% is encountered here but both of the transmitted packages need to be retransmitted. Therefore, we can see that a larger number of packages need to be retransmitted in broadcast mode compared with unicast mode.

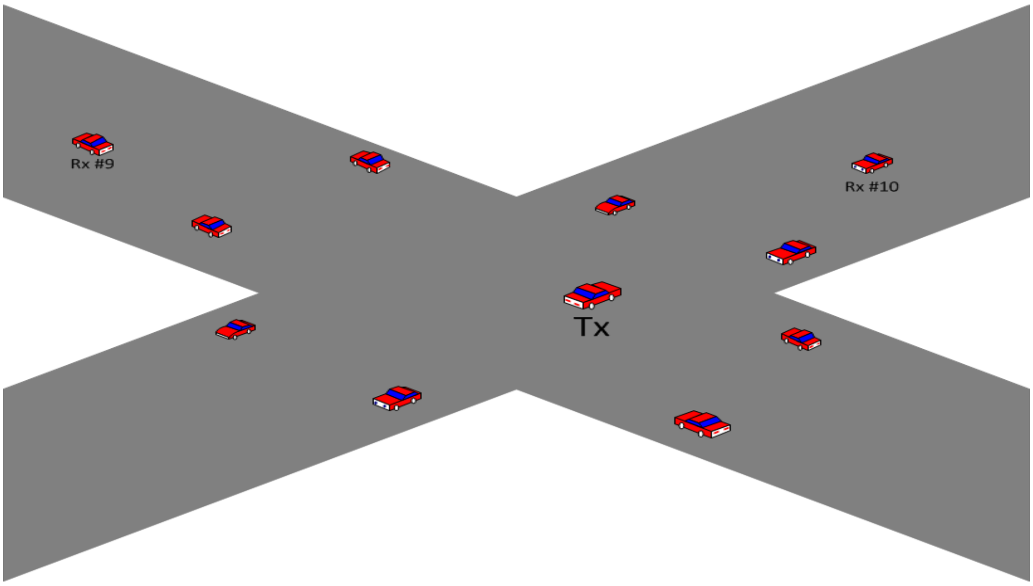

Figure A-134: Clarification of retransmission in broadcast mode.

In order to provide a larger amount of resource for retransmission attempt, we increase system bandwidth from 100 MHz to 200 MHz from now on. In Figure A-135, CDF of E2E latency is plotted and Table A-56 gives most relative numbers there. In this simulation, MCS with spectral efficiency of 0.377bits/Hz is used for the first transmission. In order to see the influence of retransmission scheme on system performance, two different MCSs are used here for package retransmission. In one case MCS with spectral efficiency of 0.377 bits/Hz is used and in the other case retransmission exploits MCS with spectral efficiency of 0.1523 bits/Hz. Besides, coordination between BSs is used to mitigate interference in both cases. With a communication range *R* up to 200 meters, we can see that a retransmission scheme with spectral efficiency of 0.377 bits/Hz has a larger successful ratio compared with the other scheme with spectral efficiency of 0.1523 bits/Hz. Even though the scheme with spectral efficiency of 0.1523 bits/Hz can provide retransmissions with better robustness compared with another scheme, it also requires more resource for each transmission due to the low efficiency. Therefore, with an overall system bandwidth of 200 MHz in dense urban scenario, MCS with worse robustness but higher efficiency for retransmission introduces a better system performance comparing with MCS with better robustness and lower efficiency. Above observation shows that TES server should adapt MCS based on available resource to achieve a compromise between efficiency and link robustness.

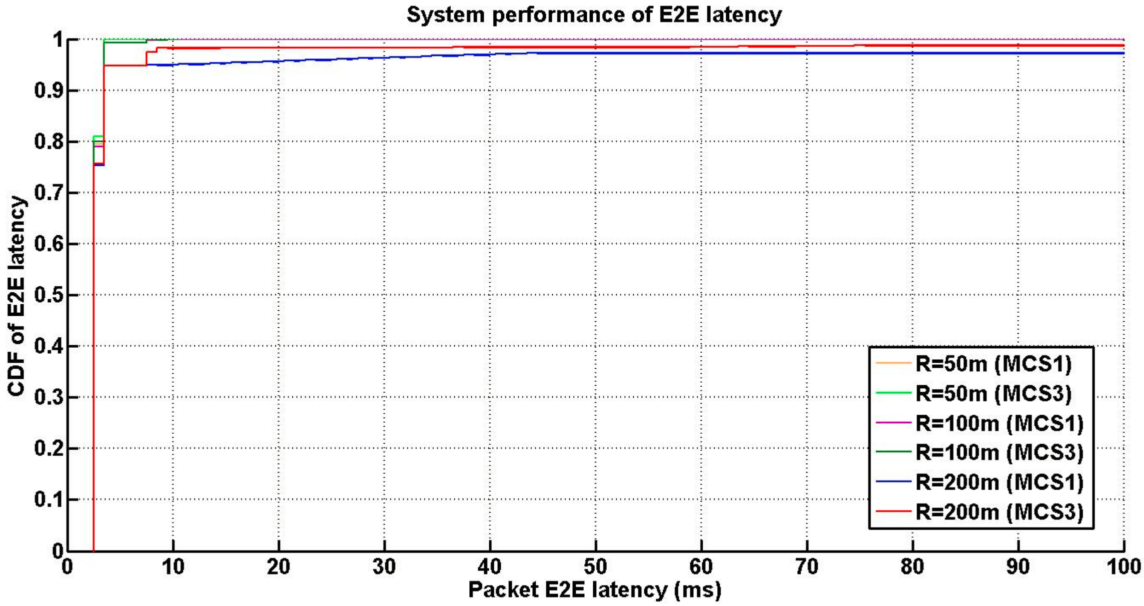

Figure A-135: System performance w.r.t. different MCSs.

Table A-56: Detailed number regarding KPIs.

range	R=50m		R=100m		R=200m	
	Retrans. with rate 0.1523 bits/Hz	Retrans. with rate 0.377 bits/Hz	Retrans. with rate 0.1523 bits/Hz	Retrans. with rate 0.377 bits/Hz	Retrans. with rate 0.1523 bits/Hz	Retrans. with rate 0.377 bits/Hz
Successful ratio	100%	100%	99.98%	100%	97.25%	98.50%
5 ms E2E latency ratio	99.83%		99.18%		94.45%	

Furthermore, by comparing Table A-55 and Table A-56, it can be seen that successful ratio increases due to more frequency resource available for retransmission. But the performance of 5 ms E2E latency ratio is not improved. As mentioned before, with per TTI duration of 1 ms, it introduces a minimal E2E latency of 7.5 ms for retransmitted packet. Therefore, packets successfully transmitted in retransmission attempt will not be counted as a contribution to 5 ms E2E latency. One potential solution is to decrease TTI duration from 1ms to a smaller value.

In Figure A-136, CDF of E2E latency is plotted w.r.t. different TTI duration time and the most relative numbers are given in Table A-57. As we can see from both of the figures and tables, with a decreased duration time of each TTI, successful retransmission can therefore further contribute to 5 ms E2E latency ratio.

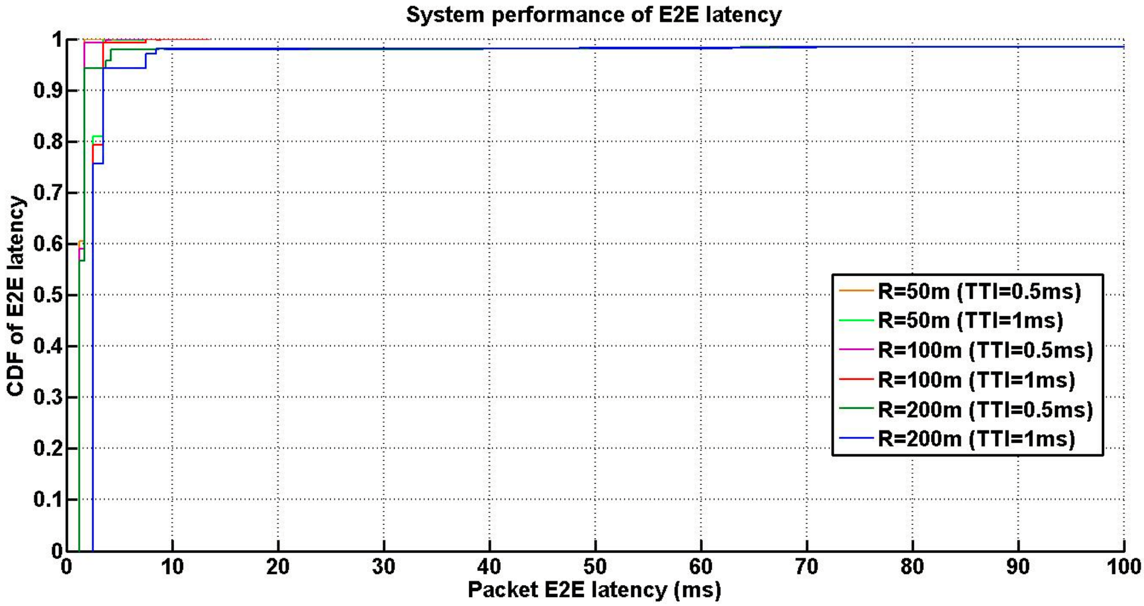

Figure A-136: System performance w.r.t. different TTI duration.

Table A-57: Detailed number regarding KPIs.

range	R = 50 m		R = 100 m		R = 200 m	
	TTI=0.5 ms	TTI=1 ms	TTI=0.5 ms	TTI=1 ms	TTI=0.5 ms	TTI=1 ms
Successful ratio	100%	100%	100%	100%	98.50%	98.50%
5ms E2E latency ratio	100%	99.83%	99.98%	99.18%	97.98%	94.25%

Annex B

B. Use of Technology Components

This annex contains the list of TeCs used in the simulations, with a brief description and an indication on the impact of this TeC in the different test cases and METIS goals. In the final D6.6 (within section 6), this list will be updated including other TeCs already identified in parallel activities within METIS.

B.1 WP2

- ***WP2-TeCC1 (WP2-TeCC1.1, WP2-TeCC1.2 and WP2-TeCC1.3) – Air interface in dense deployments:*** This TeCs cluster provides optimised solutions for short distance communication up to 200 m. The cluster investigates new design for frame structure, applicability of dynamic TDD, and harmonized OFDM / PHY layer numerology from 3 GHz to 90 GHz, cmW and mmW bands. The solution gives support for robust and fast control plane, fast network synchronization, short physical layer latency (data RTT latency), flexible data direction switching (for wireless backhauling, network controlled small cells), PHY layer enablers for interference handling by cross-link interference mitigation capabilities and support of OFDM-based MIMO solutions including high-gain beam-forming. Relevant for **TC1, TC2, TC3, TC4, TC5, TC8 and TC9**. In order to fully exploit available spectrum WP2-TeCC1.2 enables the dynamic TDD mode, which allows flexible UL and DL slots depending on the instantaneous traffic conditions. On the other hand, frame structure as proposed in WP2-TeCC1.1 enables short latencies and efficient PHY signalling (control messages for UL and DL can be exchanged in every slot regardless of the direction of the user data transmission). [MET15-D24 Section 4.1]
- ***WP2-TeC8.1 – FBMC and TeC8.2 – UFMC-OFDM**:* The two approaches proposed by these TeCs have the potential to improve the transmission robustness against signal distortions in high mobility scenarios by adapting the waveform to the UE characteristics and the propagation scenario. Synchronization requirements can be significantly relaxed, thanks to higher robustness against sync errors in time and frequency. In particular, no timing advance is needed, which is exploited in TC6 and TC11. Furthermore, it is also possible to enable the concurrent support of multiple speed classes within one contiguous band without the need for compromising between the different device and mobility classes. The adaptation between different speed classes is possible on a per sub-band level (e.g. a single PRB in LTE terminology) enabling the system to be highly scalable. As a result of the improved robustness against synchronization errors in time and frequency, both TeCs are considered for increasing capacity and allowing the soft inclusion of machine-type communications. Furthermore, the two waveforms enable the concept of dynamic RAN, since they provide additional flexibility and spectral efficiency in fragmented spectrum scenarios as well as for spectrum sharing including inter-operator sharing. These TeCs are also relevant for massive machine communications, as they enable a flexible scaling of the data rate and facilitate coexistence of multiple low-rate devices with high-rate devices. FBMC has been evaluated in Annex A for **TC5, TC6, TC11 and TC12**. Other TC where these TeCs could provide benefits are **TC8, TC9 and TC10**. [MET15-D24 Section 4.8]

- ***WP2-TeCC9.2 – Advanced coding and decoding**:* Iterative MIMO detection offers significant improvement in error-rate performance for a reduced SNR ratio at the cost of additional baseband complexity. However, the conducted analyses with various system parameters and channel conditions have shown that important gains can be achieved by adequate receiver design. Unfortunately, often a compromise has to be made between performance and complexity. It goes farther than the choice of the reduced complexity algorithm to the large number of receiver parameters. In fact, the conducted performance analyses on possible complexity-performance trade-offs can be exploited to design multi-mode adaptive-complexity MIMO detector supporting both MMSE and LSD with variable list size. In such a flexible detector, selection between the executed algorithm and choice of the main parameters should be based on channel conditions and targeted performance. Relevant for **TC6 and TC12** since these TeCs can improve the link performance by overcoming the influence of fast fading. They enable an improved robustness and therefore a robust modulation scheme with constant data rate can be achieved. [MET15-D24 Section 4.9]
- ***WP2-TeCC11 – Sparse coded multiple-access (SCMA)**:* This TeC investigates the multiplexing of users in the code/power domains by means of multi-dimensional sparse codewords. No accurate channel information is required in order to multiplex users on the transmitter side, and therefore, with low signalling overhead, the TeC can boost the network capacity for pedestrian and vehicular users within the context of mobile broadband communications**.** In addition, by means of blind detection techniques, SCMA can enable uplink contention-based access with low latency, low energy consumption, and low signalling overhead which is relevant for machine-type communications. Relevant for **TC2, 5, 6, 8, 9, and 11** where reduced latency and higher user multiplexing has been observed**.** [MET15-D24 Section 7.11]
- ***WP2-TeCC12.3 – MAC for UDN and mmW:*** High gain beam forming is an important component in UDN at mmW bands which is also challenging or the MAC design due to occurring hidden node problem with very narrow beams. A hybrid MAC approach is considered to leverage the advantages and avoid the disadvantages of the contention based and the scheduled based protocols for UDN at mmW band. Important for increasing the capacity of the system**.** Relevant for **TC3**, in which a dense deployment in the mmW band is evaluated. [MET15-D24 Section 8.2]

B.2 WP3

- ***T3.1-TeC6 – Adaptive Large MISO Downlink with Predictor Antenna Array for very fast moving vehicles**:* The TeC investigates the use of predictor antenna arrays as presented in WP2-TeCC6.4 in order to enable the use of massive MIMO and CoMP techniques in vehicular scenarios. The utilization of massive MIMO and CoMP can boost network and link performance for vehicular users in the context of mobile broadband connectivity. It is relevant for **TC8,** which focus in providing a fast and reliable connection to the vehicles on the move. In this case, predictor antennas are used to enable processing of signal in appropriate candidate antennas. This approach allows alleviating the detrimental effect of channel aging caused by moving at high velocities. [MET15-D33 Section 7.8]

- ***T3.1-TeC7 – Massive MIMO transmission using higher frequency bands based on measured channels with CSI error and hardware impairments****:* Performance evaluation of Massive-MIMO transmission using higher frequency bands based on the measured channels is performed by computer simulations, and requirements of both CSI error and hardware impairments are clarified. From these investigations, novel precoding and compensation methods will be proposed so as to satisfy the requirements for Massive-MIMO using higher frequency bands. Relevant for **TC4 and TC9** where massive MIMO is used for short and medium distances respectively. [MET15-D33 Section 7.9]
- ***T3.1-TeC11 – Massive SDMA with a Large Scale Antenna System:*** Massive spatial division multiple access in cooperation with a large scale antennas system using interference aware precoding and user clustering. Relevant for **TC4 and TC9** where massive MIMO is evaluated**.** [MET15-D33 Section 7.14]
- ***T3.2-TeC3 – Distributed Precoding in multicell multiantenna systems with data sharing:*** The concept of precoders utilizing data sharing (e.g., by caching) and local channel knowledge. The main goal has been to enable a form of "light" coordinated multi-point (CoMP) transmission, by significantly reducing the requirements on the backhaul links' latencies. The proposed scheme benefits from the envisaged possibility of smart end-user data sharing/caching in future wireless access networks. It is relevant for **TC2** for broadcasting information and for **TC9** for the low-energy operation requirement on the downlink. [MET15-D33 Section 8.6]
- ***T3.2-TeC7 – Dynamic clustering with multiple receive antennas in downlink CoMP systems:*** This TeC considers a downlink CoMP-JP scenario, i.e., a scenario where CSI and data to be sent to the UEs are shared among the BS. The TeC is relevant for dynamic scenarios with varying load and different types of devices in the network especially with different amount of antennas. It is relevant for **TC2** in dense urban outdoor environment. [MET15-D33 Section 8.11]
- ***T3.2-TeC8 – Non-orthogonal multiple access (NOMA) with multi-antenna nodes and multi-site extensions:*** This TeC investigates the multiplexing of users in the power domains and utilising advanced cancelation techniques. Due to the required minimum number of user in the NOMA system TeC can be utilized from access in crowd scenarios or wireless back haul as support for UDN deployments. Relevant for **TC2,** to increase system capacity in outdoor scenarios. [MET15-D33 Section 8.12]
- ***T3.2-TeC13 – Extension of IMF-A interference mitigation framework to small cell scenarios and Massive-MIMO****:* The main idea is to combine massive MIMO with the IMF-A interference mitigation framework and enhance it with small cells to significantly improve the main observed limitations of the IMF-A framework, i.e. low SNR for a significant part of the indoor UEs and limited channel rank per cell. It is relevant for ultra-dense networks, like **TC1 and TC4**, where this technology is evaluation with and without massive MIMO availability. [MET15-D33 Section 8.17]
- ***T3.3-TeC1 – Coordinated multi-flow transmission for wireless backhaul****:* This TeC uses the ideas of wireless network coding for two-way

communication, but extends it to the case of multiple nodes with two-way communication. Specifically, the TeC is aimed towards flexible deployment of small cells and it demonstrates how the ideas of multi-way relaying can offer performance that is equivalent as if there is a wired backhaul – without increasing the complexity at the end terminal. The wireless backhaul links of nomadic nodes are an exemplary deployment for this TeC, which is therefore considered in dynamic RAN. This TeC has been evaluated in **TC7**, where moving network is the central paradigm of the 5G. [MET15-D33 Section 9.1]

B.3 WP4

- ***T4.1-TeC2 – Unified Solution for Device Discovery:*** A unified framework with the same pre-defined steps to be used for device discovery both under network coverage and out of network coverage. The eNBs or the CH owns the discovery resources and manage their allocation in a totally or a semi centralized or fully decentralized way. Alternatively, the discovery can be performed in a totally autonomous way by a device-centric approach where all devices have the same capabilities and then only best effort type of services are provided. Key enablers for **TC10**, in which fast device discovery is fundamental for the system collapse. [MET15-D43 Section 5.2]
- ***T4.1-TeC3-A1&A2 – D2D mode selection:*** Including distributed CSI-based mode selection and local based mode selection (selection of communication mode: D2D mode or cellular mode). This TeC are useful for the distributed decision needed to establish and reaching the destination with success in the case of D2D communications. These TeC are relevant for **TC1, TC4, TC5, TC7 and TC10**. [MET14-D42 Section 6.1.5 and 6.1.6]
- ***T4.1-TeC4-A1&A2 – D2D resource allocation:*** Including (a) Multi-cell coordinated and flexible mode selection and resource allocation for D2D where A flexible TDD scheme that makes use of different degrees of coordination among cells and different time scales of mode switching based on path loss or SINR and (b) Utilizing users' location information for resource allocation that mitigates interference from D2D overlay. Spectrum efficiency can be improved with possible resource reuse for D2D and cellular. This TeC is relevant for **TC5**. [MET14-D42 Section 6.1.7 and 6.1.8]
- ***T4.1-TeC5-A1&2&3 – D2D power control:*** Including (a) Joint Methods for SINR Target Setting and Power Control for D2D Communications where the key idea of joint SINR target setting and power control is to iteratively set SINR targets and associated transmit power levels both for the cellular and D2D layers. The joint setting of the SINR targets and powers aim at maximizing a system-wise utility function that takes into account both spectral and energy efficiency, and (b) Location-based power control algorithm for D2D.It is relevant for **TC10**. [MET14-D42 Section 6.1.12 and 6.1.13]
- ***T4.1-TeC6-A1 – Coordinated fast uplink downlink resource allocation in UDN:*** This approach investigates resource allocation (user scheduling) to mitigate inter-cell cross-link interference between uplink and downlink generated by dynamic TDD in distributed and fully centralised way of taking the decisions. This TeC is relevant for **TC8**. [MET14-D42 Section 6.1.14]
- ***T4.1-TeC7-A1 – Time-sharing approach to interference mitigation using resource auctioning and regret-matching learning:*** The main idea is to

apply the game theoretic approach to multi-tier interference mitigation using a decentralized algorithm. We assume that BSs learn the regrets of possible actions and aim to minimize their average regret over time. The actions taken by BSs represent the partitioning of resources in time and frequency between BSs and used transmit power. It is relevant for **TC6**. [MET14-D42 Section 6.1.17]

- ***T4.1-TeC15- 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. This TeC enables resource reuse between small cells and D2D links, relevant to **TC6**. [MET14-D42 Section 6.1.23]
- ***T4.2-TeC2 – Context awareness through prediction of next cell:*** This TeC exploits the predictable movement patterns of mobile terminals (e.g., when in a bus, car, etc.) to predict the next cell a terminal would enter. Such information can be useful for load balancing, handover optimization or other RRM-related operations. Hence, this TeC contributes towards the overall optimization of the wireless links and is considered relevant to **TC12**. [MET14-D42 Section 6.1.25]
- ***T4.2-TeC7 – Context aware mobility handover optimization using Fuzzy Q-Learning:*** This TeC optimizes the handover process according to the locally observed network performance. It decreases the number of handover failures, connection dropping, and ping pong handovers. Therefore, this TeC improves the robustness of the communication links and is considered as relevant for **TC12**. [MET14-D42 Section 6.1.29]
- ***T4.2-TeC10 – Signalling for trajectory prediction:*** This TeC is concerned with methods for the signalling of context information use of mobility management optimization. It has been considered in the evaluation of **TC12**. [MET14-D42 Section 6.1.33]
- ***T4.2-TeC9-A2 – Long-term context-aware scheduling for ultra dense networks:*** The proposed method addresses the problem of minimizing end to end packet delay by time-unit-based packet scheduling to meet individual packet deadline exploiting knowledge of deadlines and channel information (CSI) from next *n* upcoming time units. The TeC is relevant for **TC2** indoor scenarios for high reliability of connection in rapidly changing environment. [MET14-D42 Section 6.1.32]
- ***T4.2-TeC12 – Context-based device grouping and signaling:*** The TeC provides uplink random access schemes for M2M signaling in order to reduce the signaling congestion and network overload probability incurred from integrating mMTC into the cellular mobile network. It exploits the bursty nature of the MTC traffic and effectively removes the redundancy in the transmitted messages by either suppressing or compressing the messages with redundant content. Furthermore, event-dependent messages that are not redundant are being scheduled and transmitted in a coordinated manner. This TeC is relevant for **TC9 and TC11** where mMTC traffic takes place. [MET14-D42 Section 6.1.35]
- ***T4.2-TeC13-A1 – Network assisted small cell discovery:*** Finding small cells efficiently is challenging in a dense network deployment. This is especially the case when the small cells are deployed on multiple carriers, as autonomous

searching by the UE would mean frequent measurements on multiple carriers. This TeC is important especially for dynamic networks in dense indoor and outdoor deployments for **TC1, TC2** and **TC3**. [MET14-D42 Section 6.1.36]

- ***T4.2-TeC16 – Scalable solution for MMC with SCMA:*** This TeC focuses on the integration of machine communications into a cellular system using SCMA codebooks. Hence, it contributes towards the more efficient resource utilization and user multiplexing in code/power domains and helps boost the network throughput, coverage, energy efficiency and scalability with minimum channel state information. This TeC is relevant for **TC5, TC9, and TC11**. [MET14-D42 Section 6.1.39]
- ***T4.2-TeC17 – Open-Loop MU-SCMA CoMP for MN:*** This TeC delivers a resource overloading method based on SCMA codebooks. Hence, it contributes towards the more efficient resource utilization and user multiplexing in code/power domains and helps boost the network throughput, coverage and scalability with minimum channel state information. It delivers high network throughput for both pedestrian and vehicular users. Though multiple SCMA layer connectivity across multiple transmit points, this TeC enables UE-centric open-loop CoMP for UDN in which interference management and frequent handover is challenging. Therefore, this TeC addresses some of the issues in **TC2, 6, and 8**. [MET14-D42 Section 6.1.40]
- ***T4.3-TeC1-A1 – New management interface between the operator and the service provider:*** Using this TeC, service providers have access to SON based functionalities of the network and can tailor specific network setting towards better scalability and availability of the resources for nomadic nodes. This TeC has been evaluated in **TC12**. [MET14-D42 Section 6.1.42]
- ***T4.3-TeC3 – Dynamic Nomadic Node Selection for Backhaul Optimization**:* This TeC enables identification of the optimum nomadic cell based on the backhaul link quality. The backhaul link quality is essential in achieving the performance enhancements promised by nomadic nodes since the channel conditions can be severe on the backhaul link due to low alleviation as user equipments. The TeC improves the end-to-end performance in nomadic node deployments in terms of backhaul link SINR, link rate, and end-to-end rate while considering co-channel Interference. Therefore, this TeC is relevant for **TC7** and could be also of interest for **TC2**. [MET14-D42 Section 6.1.45]
- ***T4.3-TeC4-A1 – Activation and deactivation of nomadic cell:*** This TeC proposes an intelligent activation and deactivation scheme for nomadic nodes by solving an optimization problem that uses energy consumption of the whole network, user battery life or network load as an objective. Certain relaxation techniques are proposed to efficiently solve the optimization problem where both objectives and constraints are non-convex. This TeC is considered for **TC7** and could be also of interest for **TC2**. [MET14-D42 Section 6.1.46]
- ***T4.3-TeC5 – Self-management enabled by central database for energy savings in the Phantom Cell Concept:*** This TeC provides dual connectivity between terminal, macro and small cells. The feature offers the possibility to flexibly put unused small cells to a sleep mode in which they consume a reduced amount of energy but cannot serve any user and to wake up on demand by macro base station to offload user data locally it is relevant in

outdoor and indoor heterogeneous deployments represented by **TC2**. [MET14-D42 Section 6.1.48]

B.4 WP5

- **WP5-TeC04 – *Coordinated multi-carrier waveform based sharing technique*:** In this TeC a common subcarrier grid is defined for all operators for a shared band, and each operator activates parts of subcarriers in this grid according to the partition decision of the spectrum manager. Additionally concept assumes freedom to adapt actual subcarrier spacing, pulse shape and signal frame structure. Concept might be relevant in xMBB especially below 6 GHz or in the cmWave bands. This spectrum sharing technique can be a promising enhancement for the main base station in **TC1** or **TC2**, increasing the available spectrum from 60 to 400 MHz. [MET14-D53 Section 3.1.2]
- ***WP5-TeC14 – Spectrum sharing & mode selection for overlay D2D communication:*** A potential D2D user measures the activity in D2D spectrum and uses a threshold-based test (e.g. energy detection) to decide whether it transmits in D2D mode or in infrastructure mode. When the measured energy is below the threshold there is indication there are not many ongoing D2D communication and D2D mode is selected. Otherwise, the D2D users select infrastructure-based mode. Essentially, D2D users employ a CSMA type of contention control to transmit in D2D mode. This TeC has been evaluated in **TC6**, where D2D activation is based on sensing and SINR thresholds. [MET14-D53 Section 3.1.2]