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Abstract

This deliverable presents the METIS 5G system concept which was developed to fulfil the requirements of the beyond-2020 connected information society and to extend today's wireless communication systems to include new usage scenarios.

The METIS 5G system concept consists of three generic 5G services and four main enablers. The three generic 5G services are Extreme Mobile BroadBand (xMBB), Massive Machine-Type Communications (mMTC), and Ultra-reliable Machine-Type Communication (uMTC). The four main enablers are Lean System Control Plane (LSCP), Dynamic RAN, Localized Contents and Traffic Flows, and Spectrum Toolbox.

An overview of the METIS 5G architecture is given, as well as spectrum requirements and considerations. System-level evaluation of the METIS 5G system concept has been conducted, and we conclude that the METIS technical objectives are met. A technology roadmap outlining further 5G development, including a timeline and recommended future work is given.

Keywords

5G, 5G System Concept, Extreme Mobile Broadband, Massive Machine-Type Communication, Ultra-reliable Machine-Type Communication, Lean System Control Plane, Dynamic RAN, Localized Contents and Traffic Flows, Spectrum Toolbox, 5G System Architecture, System-Level Evaluations, Technology Components, Technology Roadmap

Executive summary

This deliverable presents the final METIS 5G system concept which was developed to meet the requirements of the beyond-2020 connected information society and to extend today's wireless communication systems to support new usage scenarios. The METIS 5G system concept consists of three generic 5G services and four main enablers. The generic services are:

- Extreme Mobile BroadBand (xMBB) provides both extreme high data rates and low-latency communications, and extreme coverage improving the Quality of Experience by providing reliable moderate rates over the coverage area.
- Massive Machine-Type Communications (mMTC) provides wireless connectivity for tens of billions of network-enabled devices (in the order of 100.000 per access point). Scalable connectivity for an increasing number of devices, wide area coverage and deep indoor penetration are prioritized over peak rates as compared to xMBB.
- Ultra-reliable Machine-Type Communications (uMTC) provides ultra-reliable low-latency and/or resilient communication links for network services with extreme requirements on availability, latency and reliability, e.g. V2X communication and industrial control applications.

The main enablers are:

- Lean System Control Plane (LSCP) provides new lean signalling and control information that is necessary to guarantee latency and reliability, support spectrum flexibility, allow separation of data and control information, support large variety of devices with very different capabilities, and ensure energy efficiency.
- Dynamic RAN provides a new paradigm in Radio Access Networks (RANs). In the Dynamic RAN, the wireless device exhibits a duality, being able to act both as a terminal and as an infrastructure node. Dynamic RAN incorporates ultra-dense networks, nomadic nodes and beam-forming, and supports direct device-to-device communication both for local traffic (off-loading) and backhaul.
- Localized Contents and Traffic Flows allow offloading, aggregation and distribution of real-time and cached content. Localization reduces the load on the backhaul and provides aggregation of e.g. sensor information.
- Spectrum Toolbox contains a set of enablers (tools) to allow 5G systems to operate under different regulatory frameworks and spectrum sharing scenarios. These spectrum sharing enablers are fundamental to design a flexible radio interface that is frequency agile, coexistence/sharing capable, and applicable to the developments in spectrum regulation.

The METIS 5G architecture provides a functional architecture, a logical orchestration and control architecture, and a deployment architecture. An overview is given in this document and the reader is referred to [MET15-D64] for a full exposition.

The METIS 5G system concept is evaluated at a detailed level with respect to the twelve METIS test cases [MET13-D11]. The overall goal assessment is based on the aggregation of these results and we conclude that the METIS technical objectives are met. The details are found in [MET15-D65]. Additionally, two hardware test-beds have been used to complement the system-level evaluations and to show-case parts of the concept [MET15-D13].

A technology roadmap is given, outlining further 5G development, including a timeline and recommended future work.

An annex lists the technology components identified in the development of the METIS 5G system concept and architecture, and the performed system-level simulations.

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List of abbreviations

API	Application Programming Interface
ARIB	Association of Radio Industries and Businesses
BB	Building Block
BS	Base Station
CAPEX	Capital Expenditure
CEN	European Committee for Standardization
CH	Cluster Head
C-ITS	Cooperative ITS
CME	Central Management Entity
cmW	Centimetre Waves
CNE	Core Network Element
CoMP	Coordinated Multi-Point
COQAM	Circular Offset-QAM
C-Plane	Control Plane
C-RAN	Cloud-RAN
CSI	Channel State Information
CSMA	Carrier Sense Multiple Access
CSMA/CA	CSMA with Collision Avoidance
D	Deliverables
D2D	Device-to-Device
DFT	Discrete Fourier Transform
DL	Downlink
DCS	Dynamic Channel Selection
DFS	Dynamic Frequency Selection
DRX	Discontinuous Reception
D-TDD	Dynamic Time Division Duplex
DTX	Discontinuous Transmission
E2E	End-to-End
ECC	Electronic Communications Committee
EIT	European Institute for Innovation and Technology
eNB	Evolved NodeB
ETSI	European Telecommunications Standards Institute
FBMC	Filter-Bank Multi-Carrier
FDD	Frequency Division Duplex
GLDB	Geo-Location Data-Base
GNSS	Global Navigation Satellite Systems
HARQ	Hybrid Automatic Repeat reQuest
HetNets	Heterogeneous Networks
HSM	Horizontal Spectrum Manager
HT	Horizontal Topic
HTD	Horizontal Topic Driver
HW	Hardware
ICT	Information and Communications Technology
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IMT	International Mobile Communications
IPR	Intellectual Property Rights

ISO	International Organization for Standardization
ITS	Intelligent Transport Systems
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union-Radio
KPI	Key Performance Indicator
LAA	License-Assisted Access
LAN	Local Area Network
LSA	Licensed Shared Access
LTE	Long Term Evolution
LTE-A	Long Term Evolution-Advanced
LoS	Line of Sight
LSCP	Lean System Control Plane
M	Milestones
M2M	Machine-to-Machine
MAC	Medium Access Control
MIMO	Multiple-Input Multiple-Output
MISO	Multiple-Input Single-Output
MMC	Massive Machine Communication
MMC-A	MMC via Aggregation node
MMC-D	MMC via Direct network access
MMC-M	MMC via Machine-type D2D
mMTC	Massive MTC
mmW	Millimetre Waves
MN	Moving Networks
MNO	Mobile Network Operator
MTC	Machine-Type Communication
MU-MIMO	Multi-User MIMO
NF	Network Function
NFV	Network Function Virtualization
NGMN	Next Generation Mobile Network
NLoS	Non Line of Sight
NOMA	Non-Orthogonal Multiple Access
NSPS	National Security and Public Safety
OFDM	Orthogonal Frequency Division Multiplexing
ONF	Open Networking Foundation
OPEX	Operational Expenditure
PHY	Physical layer
PLMN	Public Land Mobile Network
QAM	Quadrature Amplitude Modulation
QoE	Quality of Experience
QoS	Quality of Service
RA	Random Access
RAN	Radio Access Network
RAT	Radio Access Technology
RF	Radio Frequency
R&D	Research and Development
RNE	Radio Network Element
RNM	Radio Node Management
RRM	Radio Resource Management
RSC	Reliable Service Composition
SAE	Society of Automotive Engineers
SCM	Spatial Channel Model

SCP	System Control Plane
SDN	Software Defined Networking
SE	Switching Element
SIMO	Single Input Multiple Output
SINR	Signal-to-Interference-and-Noise Ratio
SNR	Signal-to-Noise Ratio
SON	Self-Organizing Networks
SW	Software
T	Task
TC	Test Case
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TeC	Technology Component
TTI	Transmission Time Interval
UDN	Ultra-Dense Network
UE	User Equipment
UF-OFDM	Universally Filtered OFDM
UL	Uplink

uMTC	Ultra-reliable MTC
U-Plane	User Plane
URC	Ultra-Reliable Communication
URL-L	Long-term URC
URC-S	Short-term URC
V2I	Vehicle-to-Infrastructure
V2P	Vehicle-to-Pedestrian
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-anything
VN	Virtual Network
VNF	Virtualized Network Function
WLAN	Wireless Local Area Network
WP	Work Package
WP 5D	Working Party 5D – IMT systems
WRC	World Radiocommunication Conference
xMBB	Extreme Mobile Broadband

1 Introduction

Mobile communication is continuing to change how we work and live as individuals, do businesses and interact within the society. The early voice-centric generations have evolved into the current generation of mobile networks providing mobile broadband services.

This evolution will continue and enable a fully mobile and connected information society that expands from human-centric communications to include both human-centric and machine-centric communications. Mobile communication will increasingly become the primary way for humans and machines to access the Internet. The information society will empower socio-economic transformations not yet imaginable, including productivity, sustainability and well-being.

A fully mobile and connected information society is characterized by highly diverse requirements on e.g. higher data-rates, lower latency, ultra-high reliability, higher connectivity density, and higher mobility range, while at the same time ensuring security, trust, and privacy.

The 5G network will support this development and meet a more advanced and more complex set of performance requirements. Contrary to previous generations, 5G represents a shift in mindset. It encompasses holistic, innovative network design to efficiently support applications with widely varying operational parameters, providing greater flexibility to deploy services. As such, 5G is an important enabler of the information society.

The purpose of METIS – Mobile and wireless Enablers for the Twenty-twenty Information Society – is to lay the foundation for the 5G system. METIS envisions a future where access to information and sharing of data is available anywhere and anytime to anyone and anything.

To realize this vision, METIS has developed a system concept that meets the requirements of the beyond-2020 connected information society, including extending today’s wireless communication systems to support new usage scenarios.

To quantify the challenges, METIS has stated a set of 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.

The key challenge is to meet these goals at similar cost and energy consumption levels as today’s networks. These METIS goals apply for different usage scenarios but do not have to be realized simultaneously. The overall METIS system is therefore designed as highly flexible and configurable in order to adapt to the different use-cases. Twelve Test Cases (TCs) have been defined in the project to emphasize different technical challenges [MET13-D11].

The resulting 5G system concept is

- significantly more efficient in terms of energy, cost and resource utilisation than today’s system, in order to allow for a constant growth in capacity at acceptable overall cost and energy dissipation,
- more versatile and supports a significant diversity of requirements (e.g. availability, mobility, Quality-of-Service) and use cases, and
- providing better scalability while keeping the system efficient in terms of cost, energy and resource, as well as responding to a wider range of requirements regardless of whether a large or low amount of traffic is to be supported.

To meet the objectives and provide a system with the desired properties, METIS has investigated new paradigms and Technology Components (TeCs) in its technical Work Packages (WPs) [MET15-D24, MET15-D33, MET15-D43, MET15-D54].

The most promising TeCs have been integrated into the METIS 5G system concept. First, the TeCs researched and developed in the WPs were integrated into separate concepts meeting the specific requirements of each of the METIS Horizontal Topics (HTs): Direct Device-to-Device Communication (D2D), Massive Machine Communication (MMC), Moving Networks (MN), Ultra-Dense Networks (UDN), and Ultra-Reliable Communication (URC) [MET14-D62]. The final METIS 5G system concept was then developed by integrating the HT-specific concepts taking their commonalities into account [MET14-D63]. This document presents the final version of the METIS 5G system concept.

To support the concept and provide the necessary flexibility, a METIS 5G architecture was developed. An overview of the architecture is given in this deliverable, and the full description is available in D6.4 Final report on architecture [MET15-D64].

System-level evaluations of the concept have been done with respect to the requirements and KPIs set forth in the twelve METIS TCs [MET13-D11]. Using different combinations of the developed TeCs, all METIS technical objectives are reached and the KPIs of all TCs are met. The full detail on the system-level simulation is available [MET15-D65]. In addition to simulations, several TeCs have been implemented on two hardware test-beds to complement the system-level evaluations and to show-case parts of the concept [MET15-D13].

METIS has been a part of the first phase in a long-term 5G development vision consisting of three phases:

1. The exploratory phase which consists of laying the foundation for the future wireless and mobile 2020 system.
2. The optimization and trial phase which consists of system optimisation, contribution to standard and field trial of the system concept.
3. The implementation phase which consists of pre-commercial trials.

The boundaries between the phases are not distinct and each of the phases must adapt to constant developments in technology, international standardisation, regulation and the political environment.

The second phase, predominantly within Horizon 2020 5G PPP projects [EC-H2020], will focus on system refinement, demonstration of key technology components and system concept. Finally, the third step consists of pre-commercial trial conducted by industrial players (operators, vendors and vertical industry, e.g. the automotive industry). A Technology Roadmap outlining the way forward is given in this deliverable.

1.1 Objective of the document

This deliverable presents the final version of the METIS 5G system concept and supporting 5G architecture. It shows that the METIS technical objectives are met, and describes a technology roadmap. A list of enabling technology components is given.

This deliverable is the third and final part of the METIS concept trilogy consisting of D6.4 “Final report on Architecture,” D6.5 “Report on simulation results and evaluations,” and the present D6.6 “Final report on the METIS 5G system concept and technology roadmap”.

1.2 Structure of the document

Section 2 gives an overview of the properties of the forthcoming 5G system from a user perspective and an infrastructure perspective. Section 3 presents the METIS 5G system concept at a high level. The system concept consists of three generic 5G services; extreme

Mobile BroadBand (xMBB), massive Machine-Type Communications (mMTC), and ultra-reliable Machine-Type Communications (uMTC), and four main enablers; Lean System Control Plane (LSCP), Dynamic RAN, Localized Contents and Traffic Flows, and Spectrum Toolbox. The generic 5G services are elaborated in Section 4 and relevant TeCs are described. The spectrum requirements of the generic 5G services are explained in Section 5. Section 6 presents the main enablers and enabling TeCs. A brief expose of the METIS 5G architecture is given in Section 7. The reader is referred to [MET15-D64] for a full exposition. In Section 8 we show how we meet the METIS technical objectives as set forth in [MET13-D11], based on the system-level simulations in [MET15-D65]. A technology roadmap including a 5G timeline and recommended future work is given in Section 9. Finally, Section 10 gives our conclusions on the METIS concept development work.

The annex contains a list of TeCs identified in the development of the METIS 5G system concept and architecture, and the performed system-level simulations. Detailed descriptions of the TeC are found in [MET15-D24; MET15-D33; MET15-D43; MET15-D54].

2 On the development of the METIS 5G system concept

The process of building a new wireless generation can be seen as a synergy among three different levels of abstraction:

Level 1. Objectives and requirements, often very bold, posed to the wireless systems over mid- and long-term;

Level 2. System concepts that are aligned to meet the requirements and at the same time create the context for technical innovation;

Level 3. The detailed technology components of the new wireless system.

The project METIS is among the largest coordinated research efforts worldwide that are aimed towards creating the 5G wireless technology. The starting point of METIS is the following 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 E2E latency.

These objectives belong to Level 1, as described above. METIS provides further input to Level 1 by specifying five 5G scenarios [MET13-D11]:

- Amazingly fast, focusing on high data-rates for future mobile broadband users,
- Great service in a crowd, focusing on mobile broadband access even in very crowded areas and conditions,
- Ubiquitous things communicating, focusing on efficient handling of a very large number of devices with widely varying requirements,
- Best experience follows you, focusing on delivering high levels of user experience to mobile end users, and
- Super real-time and reliable connections, focusing on new applications and use cases with stringent requirements on latency and reliability.

At Level 3, METIS worked on a large number of innovative wireless technologies, covering the physical, MAC/link, and network layers. The technology components cover a wide range, such as frame structure, retransmission protocol, channel estimation, mobility and interference management, etc. that each are optimized to meet their particular requirements.

This deliverable presents the METIS 5G system concept, placed at the second level of abstraction from the three described above. The system concepts are converting the bold numbers of the technical objectives into operational requirements posed to the detailed wireless technology components. For example, one requirement identified at Level 1 is to use the wireless connections to improve traffic safety and efficiency. This belongs to the scenario Super real-time and reliable connections. At Level 2, the system concept identifies and combines TeCs that are instrumental to fulfil this requirement and achieve low latency; here to use reliable device-to-device (D2D) communication in combination with the usual cellular communication. This concept at Level 2 creates a context for positioning and optimizing various Level 3 TeCs in order to achieve Super real-time and reliable connections for traffic safety and efficiency.

2.1 5G features

This section describes a set of *5G features* present in the METIS 5G system concept. In this context a 5G feature is a system property that is different compared to previous generations and allows implementation of novel services and new ways of using communication. The 5G features enable a large variety of applications. The reader may argue that some of the features are already present in 4G or even the earlier generations, such as e.g. Device-to-Device (D2D) connections or Machine-Type Communication (MTC). However, we expect such existing features to mature within 5G and support the ambitious objectives set at Level 1.

2.1.1 Dual role of the mobile wireless devices

Traditionally, mobile wireless networks feature two node types: infrastructure nodes (access points, base stations) and terminal nodes (mobile devices). There has been a clear, predefined hierarchy of master nodes (infrastructure) and slave nodes (terminals) that is underlying any protocol pertaining to the establishment, usage and maintenance of a wireless link. As the processing capability of the wireless devices increases, 5G networks are expected to feature mobile wireless devices that float in the region between pure infrastructure and pure terminal nodes. The key enabler of such operation is the direct D2D communication, where certain radio network control functions are transferred to the device. A device equipped with D2D capability can have a dual role: either act as an infrastructure node or as a terminal. This opens up the possibility to integrate new types of links in the wireless network. Specific examples include:

- Vehicle acting as a terminal, but also as an Access node of a nomadic cell.
- D2D relaying for improved coverage, improved capacity, longer battery life and confinement of the traffic to the local area instead of using resources over a wide area.
- Caching of popular contents in mobile devices, which puts them later on in a position to act as access node for wireless distribution of contents.

The dual role of a mobile wireless device closely parallels the emerging concept of *prosumer* in energy networks and smart grids, where a user can act both as a consumer and producer of energy. The difference between a terminal and a network node will diminish, but not for all device types. The dual role is primarily assigned to devices supporting very large or very reliable moderate rates (in Section 3.1 defined as *xMBB service*). Those devices will be similar in size and complexity to small infrastructure nodes that are deployed in an ultra-dense manner. Contrary to this, simple devices for mMTC will come in massive numbers, and they will be significantly different in terms of complexity and cost compared to the high-rate devices. In other words, in 5G the difference between some infrastructure nodes and some device types will be much smaller than the difference across various device types.

2.1.2 Ultra-reliable links with low latency

The next generation of mobile communication systems will have to satisfy new and yet not supported requirements in terms of reliability and availability in order to enable applications such as road safety, automatic train control systems, industrial automation, and e-health services.

As the first example, some road safety applications require that the information packets are successfully delivered within a certain deadline and with very high probability. The failure to comply with these requirements can have serious implications for the well-being of the users relying on the road safety service. It is important to note however, that a mobile communication system designed to provide the reliability required by this kind of applications at all locations and at every point of time would result in an overdesigned system with a very inefficient air interface in terms of data rate and power consumption. This requires a careful co-design of the application layer and the wireless link, such that the safety of the users is guaranteed.

As the second example, industrial control requires ultra-reliable communication that is capable of handling different kinds of traffic associated with periodic data, sporadic data and configuration messages. Periodic data is associated with inputs and outputs of control algorithms and must be delivered within a certain given time (maximum delay and jitter) and with a high reliability. Sporadic data, e.g. associated with alarms, must be delivered with a bounded latency (may differ depending on criticality of the alarm). Configuration messages are typically non-real-time. In general the typical data packet is short and the bandwidth per node is low.

In order to support such reliable and low-latency (<10 ms[1]) connections within a relatively short range, 5G wireless systems will feature network-controlled D2D communication. The network assistance will enable efficient discovery, link-establishment, as well as optimized management of interference among the proximate interfering links. Due to this, the involvement of the network infrastructure through wide-area connection makes this D2D communication mode fundamentally different from the other modes for short-range connectivity, such as D2D connection in unlicensed bands.

2.1.3 Guaranteed moderate rates and very high peak rates

The feature that is most commonly associated with 5G is the provision of extremely high rates to each user, realistically achievable rates in the order of Gbps in high demand scenarios. However, from the perspective of the end user, reliable provisioning of moderate rates (50-100 Mbps) is at least as important as maximizing the peak rates. This is often expressed as providing a certain minimum data rate “everywhere”. The reliable support for moderate rates is fundamentally different than extrapolating today’s air interfaces to higher data rates, since e.g. 4G can be regarded as a technology optimized for high peak rates. The new transmission technologies, such as Massive Multiple-Input Multiple-Output (MIMO) transmission, and the concept of ultra-dense deployments are instrumental for providing stabilized radio signal and maintain the desired Signal-to-Interference-and-Noise Ratio (SINR). High reliability means that moderate rates should be sustained when the wireless network is challenged, such as in crowded scenarios or under high mobility. For example, in crowded scenarios, the reliable support of moderate rates means that the system is capable to gracefully degrade the performance of each user instead of refusing service to some of the users. This is in line with the concept of Reliable Service Composition (RSC), introduced in METIS in the work on ultra-reliable communication. The RSC implies that the services run by the users, such as cloud connectivity, will decrease their rate requirement when the crowded situation is detected. Another important enabler of reliable moderate rates is the integration of multiple RATs, along with the integrated signalling/control information.

2.1.4 Wireless resilient to the lack of infrastructure support

The lack of infrastructure can occur as a result of mobility, temporary loss of connectivity due to e.g. a weak signal, or damage of the infrastructure. In such a setting, two or more devices should communicate by establishing ad hoc D2D links or, using the dual nature of the wireless devices, establish an ad hoc wireless infrastructure. What is different from the earlier technologies that support ad hoc networking is that the future 5G systems will integrate the complementary use of network-controlled and pure ad-hoc D2D communications in order to satisfy availability and reliability requirements of critical applications. We explain this on the example of road safety. As mentioned above, in relation to the feature of ultra-reliable links with low latency, network-assisted D2D communication contributes to the improved latency and reliability. However, the devices (vehicles) should be capable of detecting the lack of network coverage and set lower service requirements for the ad hoc D2D communication. The reason is that ad hoc D2D links cannot possibly comply with the strict requirements of

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[1] A maximum 10 ms RTT delay is required for METIS TC1 [MET13-D11], and a maximum 5 ms E2E delay is required for industry manufacturing cells [ETSI11-SRD].

reliability or scalability due to the distributed resource allocation and subpar interference management. Also in this example, the RSC can be applied. In order to coordinate the use of network-controlled and ad-hoc D2D communication, 5G networks are expected to feature mode selection schemes that manage the handovers between both D2D modes, and not only between D2D and Infrastructure-based communication.

2.1.5 Increased cooperation among operators

The requirements for reliability, improved coverage and extended coverage require new modes of interaction and cooperation among the operators. Taking the example of Vehicle-to-Anything[2] (V2X) communication, the reliable D2D links among the vehicles, or between a vehicle and a pedestrian, may require network assistance from different operators. In other words, the high reliability and safety for all participants in the V2X communication cannot be guaranteed by a single operator, simply because the actors involved in V2X communication may use different operators. This is an example where 5G will require novel cooperation modes among the operators in order to ensure highly reliable service that involves many actors and different devices. Another venue for increased cooperation among the operators is spectrum sharing and flexible spectrum transfer from one to another operator in order to satisfy the current demand (e.g. crowded scenario).

There are different ways to implement increased cooperation among operators. One possible way is to have one network unit that is running independently and manages inter-operator issues including authentication, inter-operator service authorization etc. Another way in which the operators can coordinate with each other is by exchanging information via devices that have single- or multi-hop connections to all involved operators. For example, one operator can make a decision for handover or obtain reliability indicator from the device measurement report prepared by/for the network of the other operator. Finally, using virtualization, the actors will be able to share parts of the physical infrastructure.

2.1.6 Network follows the crowd

Self-Organizing Networks (SON) have been specified and defined in 3GPP featuring self-configuration, self-optimization, and self-healing functions. However, next-generation networks will show a new level of adaptivity that goes beyond the current notion of SON. The introduction of nomadic nodes will provide a very flexible tool for dynamic network deployment based on capacity, coverage, and energy efficiency demands. In particular, a nomadic node describes a network node that provides relay-like communication capabilities. However, in contrast to a traditional fixed or moving relay (as defined in 3GPP), there is an inherent uncertainty with regards to its temporal and/or spatial availability, i.e. a nomadic node may shut-down its service, change its geographical position and then become available again (hence, the term “nomadic”). For example, the on-board communications infrastructure that will be deployed in future vehicles may serve for such purposes while the vehicle is parked. Although nomadic nodes are stationary in principle, the inherent uncertainty with regards to their availability resembles a network that is “moving” or “movable”. The location of operator-deployed relay nodes is optimized by means of network planning over a certain time-horizon, which may become shorter in the future in order to cover temporary crowded places, such as open-air festivals. On the other hand, nomadic nodes are randomly distributed and operate in a self-organized fashion. Furthermore, nomadic nodes are assumed to be densely populated (e.g. parked vehicles) which allows for activating only those nodes that best serve the current capacity, coverage, load balancing or energy efficiency demands while causing least additional interference. In this sense, future networks will “follow” the crowd (i.e. end users) as well as the demands of novel and revolutionary services.

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[2] The X in V2X communications refers to vehicles (V2V), pedestrians (V2P) and/or infrastructure (V2I).

2.1.7 Localized traffic offloading

Mobile data offloading from cellular to Wi-Fi has been discussed for several years in order to cope with the exponentially increasing data traffic flow of mobile networks. For this reason, 3GPP is currently specifying mechanisms for seamless Wi-Fi/cellular interworking.

However, D2D communication in 5G will bring a new quality to the localized offloading. Network-controlled direct D2D communication offers the opportunity for local management of short-distance communication links, which allows separating local traffic from the global network (i.e. local traffic offloading). This will not only significantly unburden the load on the backhaul and core network caused by data transfer and signalling, but also reduce the effort necessary for traffic management at the central network nodes, such as Serving Gateway and Packet Data Network Gateway in LTE architecture. Based on direct D2D communication, local data sharing zones can be easily set up, allowing content sharing by a large number of users without putting heavy load on the global network. Direct D2D communication therefore extends the idea of distributed network management by incorporating the end devices themselves into the network management concept.

A further enabler for localized traffic handling is nomadic nodes, which can establish local data sharing hotspots. Moreover, they enable on-demand coverage and capacity provisioning in critical scenarios such as traffic jams or disaster/emergency situations.

Another aspect of localized offloading is related to mMTC. The massive number of devices connected to a wide-area access node or Base Station (BS) may significantly challenge the network, since many requests may enter in a contention for communication resources. By confining the machine-type traffic to local connections, e.g. via a D2D link to a device that acts as an aggregator of machine-type traffic, the spatial reuse, reliability and power consumption are improved. Note that localized offloading may improve the average latency, as localized contention is of smaller size and can be resolved more efficiently than the wide-area contention.

2.1.8 Unprecedented spectrum flexibility

The use of exclusively licensed spectrum builds the basis for mobile network operators to deliver good quality of service for their subscribers. This type of spectrum usage should be prioritized, especially for applications requiring high reliability of data transmissions. However, as we are facing an exponential increase in the volume of wireless data traffic, we need to be prepared for supplementary solutions to serve the mobile users demand. Beside the designation of additional exclusive spectrum for mobile services, also spectrum sharing with other services or between mobile network operators could be considered. Here there could be a significant difference to earlier cellular generations due to the need to provide unprecedented spectrum flexibility. Spectrum aspects are considered more in Section 5.

The required spectrum flexibility can be achieved by generalizing the use of a single chunk of spectrum by using the notion of the Spectrum Toolbox (see Section 6.4), which enables flexible use of all available frequency resources aiming at best serving the user. This is a fundamental enabler of multi-service operations and spectrum-flexible air interfaces. At a regulatory level, the toolbox supports different regulatory frameworks and licensing schemes, and multi-operator operations.

2.1.9 Energy efficiency

One of the key challenges in 5G is to develop a system that implements the described features at a similar cost and improved energy efficiency compared to today’s networks. To meet the requirements on energy efficiency, the system must be energy efficient both when transmitting data and when not transmitting data. The latter may seem trivial, but the network nodes in today’s networks are idle most of the time and the cost of overhead in the form of transmission of control signals even when no data traffic is transmitted is totally dominating the network energy consumption [EAR12-D33]. Improvements in energy efficiency can be achieved by e.g. new, lean signalling procedures, novel air interface designs, and network node activation/deactivation.

Lean signalling only transmits the minimum necessary signals continuously in idle mode, such as paging and random access since users/devices must be able to detect the network, and the network must be able to locate the users/devices.

Energy efficiency also has impact on operational expenditure (OPEX) and capital expenditure (CAPEX). The energy consumption is a significant part of the network OPEX, and hence the OPEX is reduced by improving the energy efficiency. CAPEX is also reduced by improved energy efficiency, since reduced power dissipation allows more cost-efficient solutions in, e.g. battery backup and cooling systems.

The previous mainly discusses the base station functionality and network energy consumption, and traditionally the energy consumption and battery life of the terminals does not pose a problem. In the mMTC service case however, terminals will be deployed long term without the possibility of periodical charging. Therefore power consumption is vital to the mMTC devices in order to fulfil the METIS goal of x10 longer battery life. In general, reduced energy consumption for the terminals is achieved by shorter transmission times and lower output power for a given payload.

3 The METIS 5G system concept

The 5G features defined in Section 2.1 span a wide range of different requirements, such as minimum data rates, latency, battery life, and coverage, data volume, etc. To enable a 5G feature the 5G system must meet the technical requirements of that feature. Using today's systems, one is not able to meet all the requirements, and in particular not able to adapt to the diversity. Figure 3.1 shows how a 5G system is expected to improve over previous generations.

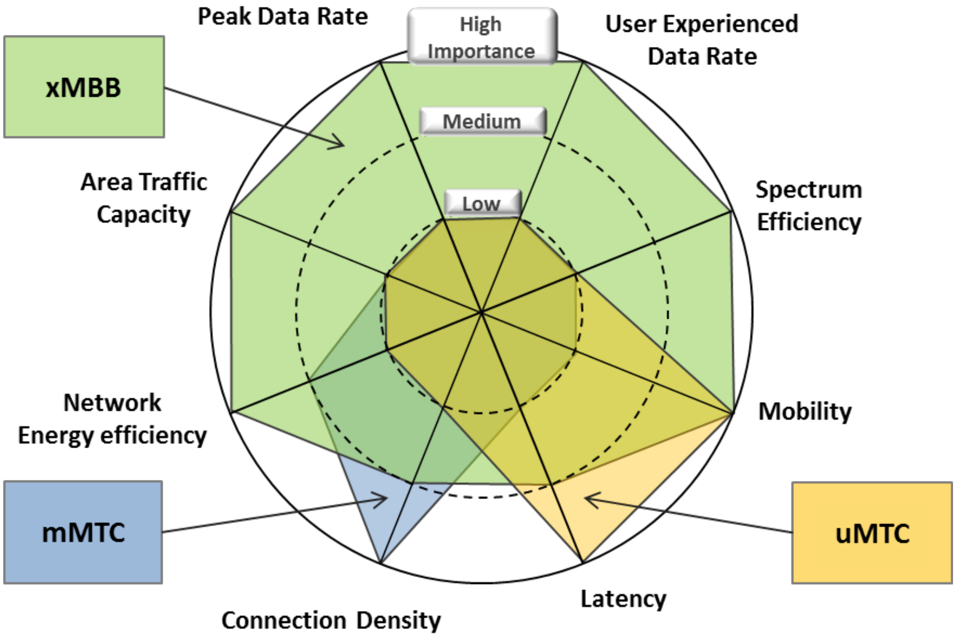

Figure 3.1: The graph shows where improvements over previous generations are needed to meet the 5G requirements. The three generic 5G services need improvements in different subsets of the requirements[3].

Hence the 5G system must be highly flexible and configurable; it must adapt to the different scenarios to provide very different services, dependent on time and location, by utilizing and emphasizing different technical solutions. The METIS 5G system concept that exhibits this flexibility, realizes the 5G features, and provides this 5G system.

We here give a high-level overview and characterize the enabling technology components, and in Sections 4 to 7, we elaborate on the generic 5G services, their spectrum requirements, the main enablers, and METIS 5G system architecture.

3.1 High-level overview

METIS envisions a user-centric multi-RAT 5G system concept that provides improved Quality of Experience (QoE) and reliability to both consumers and devices/machines. The METIS 5G system concept consists of new solutions and evolved versions of existing systems.

The METIS 5G system concept consists of three generic 5G services and four main enablers, as illustrated in Figure 3.2. Each generic 5G service emphasizes a different subset of requirements in Figure 3.1, but all requirements are relevant to some degree to all generic services. The generic 5G services are:

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[3] Adapted from ITU-R [ITU-R15].

- **Extreme Mobile BroadBand (xMBB):** provides both extreme high data rates and low-latency communications, and extreme coverage improving the QoE through a more uniform experience over the coverage area, and graceful degradation of rate and increase of latency as the number of users increases. It is foreseen that xMBB will also be used for reliable communication e.g. for National Security and Public Safety (NSPS).
- **Massive Machine-Type Communications (mMTC)** 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.
- **Ultra-reliable Machine-Type Communications (uMTC)** 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.

The four main enablers are:

- **Lean System Control Plane (LSCP)** providing new lean signalling/control information is necessary to guarantee latency and reliability, support spectrum flexibility, allow separation of data and control information, support large number and variety of devices with very different capabilities and ensure energy efficiency.
- **Dynamic RAN** providing a new paradigm in Radio Access Networks (RANs). In Dynamic RAN, the wireless device exhibits a duality, being able to act both as a regular terminal node and as an infrastructure node. Dynamic RAN incorporates UDN, Nomadic access nodes (mobile relaying does not exist up to now in 3GPP networks), antenna beams and supports D2D communication both for local traffic (off-loading) and backhaul.
- **Localized Contents and Traffic Flows** allow offloading, aggregation and distribution of real-time and cached content. Localization reduces the load on the backhaul and/or provides aggregation of e.g. sensor information.
- **Spectrum Toolbox** contains a set of enablers (tools) to allow 5G systems to operate under different regulatory frameworks and spectrum usage/sharing scenarios. These *Spectrum sharing enablers* are fundamental to design a flexible radio interface that is frequency agile, coexistence/sharing capable, and applicable to the developments in spectrum regulation.

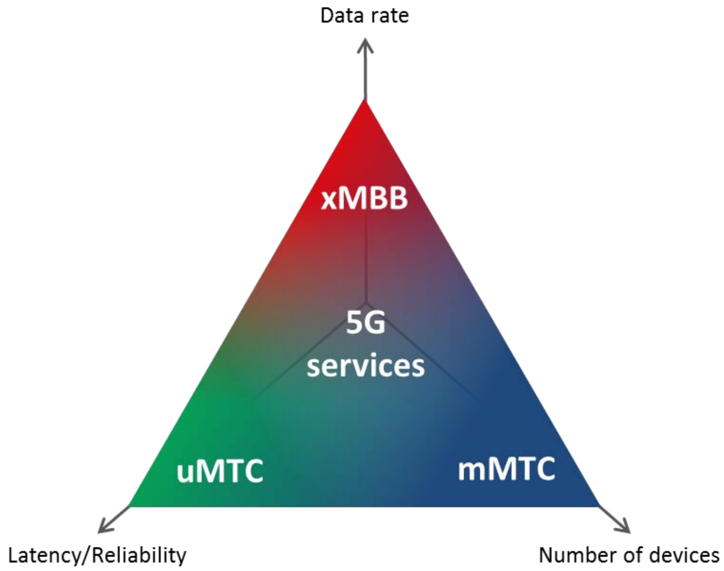


Figure 3.2: An illustration of the METIS 5G system concept consisting of three generic 5G services how they emphasize different 5G requirements.

3.2 Characterization of technology components

Each generic 5G service and main enabler is constructed by combining several TeCs. These TeCs are of three different types:

- Mature system TeCs from previous generations with suitable adaptation, e.g. wide-area coverage, efficient mobility support and energy-efficient terminal operation.
- Emerging system TeCs expected to mature in order to fit the 5G requirements, e.g. Cloud-RAN (C-RAN), and offloading through local connections.
- Novel 5G-specific TeCs, e.g. nomadic nodes, ultra-reliable connections for critical control, enhanced D2D for offloading, relaying, and aggregation of massive-machine-type traffic.

It can be observed that today’s networks integrate different wireless generations and other, unlicensed wireless technologies at the higher layers of the protocol stack. 5G systems will integrate diverse services closer to the terminal and for this purpose the following is required:

- Common control functions that enable integration among different variants of the interface.
- Control functions and metadata that are specifically optimized for xMBB, mMTC, or uMTC.
- Unified radio interface from which the interfaces of xMBB, mMTC, or uMTC appear as instances.

Figure 3.3 shows how the generic services and main enablers are integrated using the METIS 5G architecture.

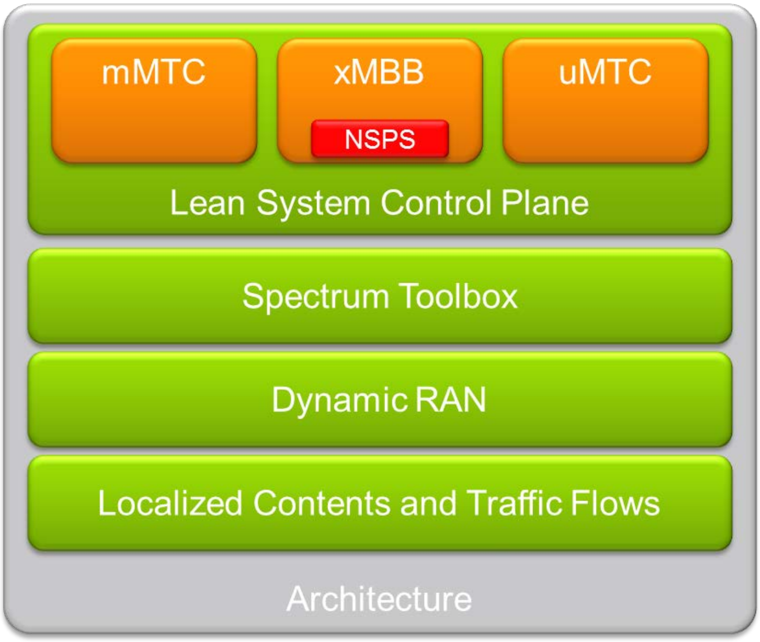


Figure 3.3: Illustration of how generic services and main enablers are integrated and supported by the METIS system architecture.

Meeting the METIS technical objectives requires utilization of additional spectrum, increased spectral efficiency, and higher network node density. The need for additional spectrum is realized through the use of higher frequency bands and new spectrum access schemes, being one main enabler for very high data rates.

Spectral efficiency is improved by Massive MIMO, and multi-node coordination. Time Division Duplex (TDD) is expected to become more widely used in higher frequency bands whereas Frequency Division Duplex (FDD) and TDD are expected to be implemented in traditional IMT bands.

Densification of network nodes into Ultra-Dense Networks (UDNs) meets the demand for increased data volumes and user data rates in densely populated indoor and outdoor environments. The shorter transmission distances allows for use of higher frequencies and hence increased data rates. UDNs require solutions for interference management to facilitate coexistence among each other and with possibly other radio services, and node activation/deactivation to ensure energy efficiency.

4 The three generic 5G services

This section describes a developed version of the three generic services identified in [MET14-63] and some of the enabling TeCs, providing a refinement of the TeC lists in [MET14-D62].

4.1 Extreme Mobile BroadBand (xMBB)

The xMBB service provides both extreme data rates, going to the range of Gbps, and extreme coverage. The extreme coverage is represented by very reliable support of moderate data rates (50-100 Mbps), which offers the user the experience of sustained “true-anywhere-anytime” connectivity. From a network perspective, xMBB will be the chief contributor to the increased traffic volumes foreseen in 5G systems.

xMBB builds on the spectrum-flexible air interface for dense deployment to meet the demands for increased achievable user data rates, which are important for the end-user to support high-demand applications, such as virtual or augmented reality. xMBB will utilize multi-layer and multi-connectivity, the spectrum toolbox, and new signalling procedures to achieve spectrum flexibility.

From the perspective of an end-user experience, the extreme coverage and reliable provisioning of moderate rates are at least as important as maximizing the peak rates. Within the METIS project, the extreme coverage is considered within the METIS project under the name *long-term Ultra-Reliable Communication* (URC-L) [MET14-D62]. The reliable support for moderate rates is fundamentally different than extrapolating today’s air interfaces to higher data rates, since e.g. 4G can be regarded as a technology optimized for high peak rates. Extreme coverage requires the use of new transmission technologies, such as Massive MIMO, and the concept of ultra-dense deployments in order to provide stabilized radio signal and maintain the desired Signal-to-Interference-and-Noise Ratio (SINR). More specifically, the extreme coverage can be challenged by crowded scenarios, high mobility, or emergency situations.

In crowded scenarios, reliable support of moderate rates means that the system is capable to gracefully degrade the performance of each user instead of refusing service to some of the users. This is in line with the concept of Reliable Service Composition, which implies that the services run by the users, such as cloud connectivity, will decrease their rate requirement when the crowded situation is detected.

The xMBB service should also exhibit robustness with respect to mobility in order to ensure that, in the case of users moving at vehicular velocities (e.g. while travelling at more than 100 km/h), high-demand applications can be provided with a QoE comparable to that of stationary users. xMBB applies to both the users travelling inside the vehicle and, therefore affected by significant body propagation losses (30 dB with metalized windows), as well as to the vehicle itself. In this sense, the reliable provisioning of moderate data rates at vehicular velocities can enable the deployment of remote computing services for cars.

xMBB benefits from the Dynamic RAN and localized traffic offloading enablers to allow for dense and flexible network node deployments, which follow the user demand and yield a more uniform user experience over the service area. Moreover, the Dynamic RAN concept makes it possible the establishment of reliable communication in National Security and Public Safety (NSPS) emergency situations and provides minimal connectivity upon damage in the infrastructure. This is for example the case of rescue operations after a natural disaster, for which a large part of the fixed network infrastructure might remain unavailable.

It is hard to predict what kind of service will be a real key driver for xMBB after year 2020, how popular this service might be or what reliability level will be required/tolerated by customers. However from current considerations on future applications like augmented or virtual reality, ultra-high-definition video streaming or tactile Internet combined with cloud computing, we clearly see a need for system that will be able to provide almost no latency in air interface with a gigabit experience when and where it matters. At the same time flexibility of the system should be high enough to provide consistent user experience by guaranteed moderate rates on the level of 50-100 Mbps at anytime and anywhere as a form of the most basic service, similarly to voice coverage almost 20 years ago. Multiple layers of the system, which are built on the well-integrated new designs operating above 6 GHz bands and different existing system like LTE initially improved by the system evolution and later potentially replaced by new designs will provide consistent services in a transparent way. Consequently, for operators the system integration, management or even planning and deployment should be simplified in maximal possible way, with the target to reduce OPEX and CAPEX. Energy consumption per transmitted bit needs to be reduced significantly as overall energy consumption should be kept on current levels (assuming 1000x data volume increase). It might require additional functionality in the system and additional efforts from the network side to save energy in not active nodes.

The key enablers of the extreme high data rates, reduced latency or reliability required in xMBB can be discussed in the context of few aspects: the choice and the management of the spectrum, increased density of nodes and spectral efficiency improvements including solutions for local traffic and higher robustness for user mobility.

4.1.1 Spectrum

Studies in spectrum management area indicate interesting techniques to utilise spectrum in a more flexible and efficient way. In the spectrum range between 6 GHz and 100 GHz METIS identified interesting new spectrum opportunities with large amount of bandwidth [MET14-D53]. First steps have been initiated to make this spectrum available for xMBB, and the work will continue during World Radiocommunication Conference 2015 (WRC-15) with probably first results during WRC-19. Spectrum above 6 GHz can be divided into two parts with respect to wave lengths; centimetre and millimetre waves (cmW, mmW) with relatively different propagation properties, however no sharp boundary exists. Centimetre waves behave rather similarly to classical cellular bands with relatively good penetration through obstacles and properties described by well know models. As shown in [MET14-D53] it is possible to possess significant amount of cmW spectrum, however acquiring contiguous spectrum more than 1 GHz bandwidth might be possible only in limited ranges. Millimetre waves behave in a different way where high diffraction and penetration loss limits successful point to point communication to LoS or single reflection NLoS cases. METIS analysis show huge amount of possible accessible spectrum, even beyond atmospheric absorption phenomena located around 60 GHz. Independently to the effort related with unlocking the new spectrum, both cmW and mmW have their roles to be played in new system design due to the their different properties and use cases in concrete deployment situations. The main challenge will be to achieve high flexibility and accessibility to the resources on distributed wide bandwidths (100-1000 MHz or more) for relatively short periods of time (significantly below 1ms). In this field METIS has developed enablers like the Spectrum Toolbox, see Section 6.4, facilitating operation in widely distributed spectrum.

4.1.2 Densification

Investigations on enablers for further nodes densification have been already started by 3GPP in the recent works as well as considered in IEEE 802.11 standard for some time with certain system complexity. Both systems designs are not feasible to complete METIS requirements properly. LTE initially optimised for wide area coverage is keeping oversized design in PHY layer and suffers significant overhead in signalling and processing during wideband operations. On the other hand Wi-Fi as an example of ‘best effort’ system with low service reliability will have difficulty in fulfilling 5G requirements [SCF13].

Obviously there is a space for new clean slate approach; an optimised system for short distance communication with typical inter site distances equal to tens of meters and maximal cell ranges limited to 100-200 m which would be able to utilise benefits of both legacy systems and combined together with new spectrum opportunities, as discussed above. The system should be optimised not only for cellular use cases, but it should also be ready for extensive use of D2D and access point-to-access point connectivity. Such a system should be able to efficiently provide solution to cover expected increase of data volumes and data rates, far beyond year 2020 use cases. In the context of frequencies above 6 GHz, where higher path attenuation requires sufficient compensation and the LoS communication is preferred, short distance communication is on the top of the list for new spectrum use cases. Additionally decreasing effective average amount of active devices per node in Ultra-Dense Networks (UDN) deployments, leads to the conclusion that this type of networks will be less frequently working in high load scenarios. They will rather try to provide maximal instantaneous capacity for particular user demands. This argument gives motivation to consider a flexible air interface design based on dynamic TDD (D-TDD) resource allocation. T2.1-TeC1.3 is directly investigating this problem and, together with multiple other components such as a frame structure based on Orthogonal Frequency Division Multiplexing (OFDM) with predefined and harmonized numerology for different spectrum. Together with different filtering options e.g. T2.2-TeC8.2 UF-OFDM, these provide a first example of future 5G system design for PHY and MAC layers above 6 GHz.

Beside new air interface for short distance communication in xMBB, METIS is investigating various techniques that help with the emerging problem of new three-dimensional, multi-layer interference environments, which becomes more frequent with continuous network densification. The work is done in different studies on e.g. coordination techniques with use of Multi-User MIMO (MU-MIMO) and Coordinated Multi-Point (CoMP) in T3.2-TeC7, comparison of fully centralized versus distributed interference management techniques in T4.1-TeC6.1 and T4.1-TeC7.1 or studies with extensive use of advanced receivers, coordination and interference alignment like T3.2-TeC4. Another problem of dense deployments is network power efficiency which could be also improved by adaptive coordination of inactive small cells by CoMP techniques as in T3.2-TeC15 or the Phantom Cell Concept (T4.3-TeC5). The mentioned techniques may find use in evolution of current standards, but also in new xMBB operating in cmWs or even mmWs.

METIS also addresses critical issue related with flexibility of small cells deployment. From the network operator point of view, the cost of providing full infrastructure, especially backhaul links, to new locations might be not economically justified. METIS considers solutions for wireless backhauls, such as T3.3-TeC2 considers the impact of the introduction of aggregation nodes on indoor UDN performance with use of mmW. From this perspective, the ability of the new air interface to increase flexibly link capacity combined with shorter PHY layer latency is promising in sense of creating reliable backhaul connectivity. When link latency is not the critical issue from a QoE perspective, different investigated solutions for backhaul such as Massive MIMO below 6GHz (T3.1-TeC1b, T3.1-TeC1.6,T3.1-TeC7, T3.1-TeC8, T3.1-TeC11), Non-Orthogonal Multiple Access (NOMA) (T2.3-TeC11.1.1), and Sparse Code Multiple Access (SCMA), (T2.3-TeC11.1.2,T4.2-TeC17) or two-way relaying (T3.3-TeC1,T3.3-TeC10) may provide sufficient capacity for outdoor and indoor dense small cell deployments. Also for flexible deployments control and signalling can be separated from the user data plane (U-Plane), where the control plane (C-Plane) is controlled by e.g. specialized network nodes operating in wider area, and the U-Plane offloaded locally by new air interface to the closest network gateway like in the Phantom Cell Concept (T4.3-TeC5). This provides new functionalities to the Mobile Network Operator (MNO) that could be used e.g. to increase energy efficiency or control network reliability. Some further aspects are discussed jointly with wireless backhaul for moving users, Lean System Control Plane in Section 6.1, and Dynamic RAN in Section 6.2.

4.1.3 Spectral efficiency

Improving the spectral efficiency of communication systems covers a wide range of improvements studied over decades of research. However, for operation in frequencies below 6GHz it is still expected to see moderate improvements on overall system spectral efficiency like indicated by Massive MIMO e.g. T3.1-TeC2, T3.1-TeC7, T3.1-TeC11 and CoMP studies on advanced receivers T3.2-TeC1b, T3.2-TeC7, T3.2-TeC10, T3.2-TeC12 T3.2-TeC13 or backhaul limitations T3.2-TeC3, T3.2-TeC6 or T3.2-TeC17, which could be either embedded in LTE evolution or may become part of a new system developed over the next years. The use of Massive MIMO below 6 GHz supports both aspects of xMBB: (1) extreme achievable rates in a given area, by improving the spectral efficiency and (2) extreme coverage and reliable moderate rates for all users in crowded scenarios by using very high ranks in combination with multi-user techniques. For the spectrum higher than 6GHz, Massive MIMO will play a key role due to the benefits coming from reduced wave length and correspondingly smaller antenna elements investigated for e.g. in T3.1-TeC7. The Massive MIMO beamforming will be extremely important for mmW in order to compensate higher path attenuation by the creation of pencil beams. This naturally brings the problems of small cell discovery/adaptive pencil beam tracking. These problems are addressed by METIS in T2.3-TeC12.3 and T4.2-TeC13.2, where either by MAC-specific tracking procedures or knowledge about surrounding small cells active on different spectrum ranges is extensively used to overcome these problems. It is extremely important to use well-understood MIMO techniques (based on the OFDM principles) to apply them in various spectrum ranges.

For short distance communication, further system spectral efficiency improvements will be based on the TDD access originated from legacy systems. It was assumed from the beginning of 4G systems that TDD will play a special role for small cells deployments. The TDD access will be further improved by introduction of highly flexible resource allocation for UL, DL, D2D, or for self-backhauling transmission but with maintained very reliable continuous connectivity – the work on spectral efficiency for D-TDD aspects like frame structure or signalling are done in T2.1-TeC1.2 and T3.2-TeC17. Further spectral efficiency improvements can be seen in applying different filtering options like the already mentioned UF-OFDM.

4.1.4 Local traffic

Another example to enhance system performance including latency in short distance communication is direct D2D communication, which consist of various design aspects further described below. The direct D2D, where the data packets are exchanged locally among devices in the proximity area, can provide excellent performance improvement to xMBB in terms of capacity improvement and latency reduction. More specifically traffic offloading via D2D can bring benefits to both operators (e.g. increased capacity and availability, enabling new emerging services and improved spectrum efficiency etc.) and end users (e.g. increased link throughput, reduced latency and power consumption etc.). Direct D2D communication can reduce the unnecessary routing via the core network. Moreover, due to local communication with better propagation conditions, link throughput can be increased as well.

D2D can improve spectrum usage by simply reusing the same spectrum between D2D links and cellular links [MET15-D13]. In order to establish a D2D communication link, the transmitter and the receiver should be aware of whether they are close enough to set up such direct link or not. This is the issue solved by unified D2D device discovery framework where the same pre-defined steps for device discovery both under network coverage and out of network coverage are proposed T4.1-TeC2. Moreover, to support emerging V2X services, multi-operator D2D operation including the discovery procedure, communication mode selection, and how to contribute D2D spectrum, was studied within METIS in WP5-TeC22.

Even for devices found to be close to each other, it may be still uncertain whether the direct communication link is the most suitable communication mode from spectrum reuse and interference management point of view. Mode selection is a mechanism to decide the communication mode, i.e. infrastructure mode or direct D2D communication mode (T4.1-TeC3 and T4.2-TeC14). Mode selection can be handled together with resource allocation as well. Both centralized and distributed mode selection can be integrated into the system concept. Similar to discovery, supporting D2D communication between devices from different operators is of importance (WP5 TeC22). In case of MIMO operation, the D2D transmission can use the same frequency spectrum as cellular communication via physical layer network coding, T3.3-TeC6.

In order to maximize D2D link throughput (i.e. maximizing the offloading gain to xMBB) an appropriate air interface should be selected. The unified air interface design for dense deployment (T2.1-TeC1.1—1.3) provides optimized solution for short distance communication and can be utilized to support D2D communication in a straightforward way. As alternative waveform to OFDM, filter bank based multi-carrier (T2.2-TeC8.1), which enables the network to support more flexible spectrum usage (WP5-TeC04), asynchronous operation and improve spectral efficiency, was investigated for potential future usage as well. Regarding to further contribution to xMBB, D2D communication can be used to extend the network coverage as well T3.3-TeC7. To further increase the spectrum efficiency, the feasibility of full duplex communications in underlay D2D networks was studied in T2.2-TeC10.1.

Interference management is one of the most important issues to be solved in case of D2D communication, and interference can be present both between D2D pairs and between the D2D link and the cellular link. Efficient interference management (via e.g. resource allocation, power control) can lead to much better resource usage and also make it possible to reuse small cell resources in case of Heterogeneous Networks (HetNets) (T4.1-TeC15). In order to obtain the maximal offloading gain, the mobility procedure should be optimized as to maximize the lifetime of D2D link and reduce the unnecessary overhead. Efficient resource allocation is another way to manage the potential interference and in METIS, various aspects for D2D resource allocation have been investigated, T4.1-TeC4. The last aspect that will be an important change in xMBB is the set of enhancements and new approaches for user mobility. With the objective to guarantee a seamless provision of high-demand applications in the case of vehicular terminals, including both the passengers travelling inside a vehicle and the vehicle itself, xMBB provides high robustness and efficiency in highly mobile scenarios (i.e. at velocities higher than 100 km/h), as well as improved handover and mobility management procedures (T4.2-TeC8). In particular, the use of new waveforms (T2.2-TeC8.1—8.2) and advanced Hybrid Automatic Repeat reQuest (HARQ) schemes (T2.3-TeC13.1—13.2) achieves superior robustness against Doppler shift and time diversity, respectively. Moreover, the use of enhanced transceiver implementations that are resilient to multi-path fading and imperfect channel estimation by means of antenna predictor techniques further contribute to the mobility-robustness of xMBB. URC aspects, such as the concept of availability indication and link reliability prediction (T2.1-TeC6.1 and T2.1-TeC6.2 and WP5-TeC20), provide, on the other hand, the dependability required by some high-demand applications such as remote computing. Further aspects are described in Section 6.3.

4.1.5 User mobility

xMBB also features increased network capacity in the case of highly mobile terminals and relays by means of multiple access strategies (NOMA, T2.3-TeC11.1.1, and SCMA, T2.3-TeC11.1.2 and T4.2-TeC17) as well as multi-node/antenna techniques tailored to vehicular reception. In particular, the use of massive Multiple-Input Single-Output (MISO) and CoMP techniques based on predictor antenna arrays, T3.1-TeC6, can boost the network capacity and provide higher data rates for vehicular terminals and mobile relays. In the uplink direction, the inclusion of D2D communication between the terminals inside a vehicle improves the network capacity in the presence of high penetration losses (i.e. as with metalized windows), T3.3-TeC9b. Moreover, radio resource management schemes particularized for highly mobile scenarios and handover optimization mechanisms enhance the network capacity and QoE of vehicular users by exploiting synergies between the Radio Resource Management (RRM) and handover mechanisms, as well as with components responsible for the interference identification and context awareness, e.g. T4.1-TeC8 and T4.2-TeC9.1. Regarding context awareness, information on the trajectory of a vehicle and on its expected consumer behaviour (e.g. regular access of audio/video streaming applications at certain times of the day) can be used to improve the QoE. Moreover, the prediction of the next cell a vehicle is about to enter helps prepare for the handover procedure in advance and contributes towards a faster and more reliable handover, e.g. T4.2-TeC10 and T4.2-TeC11.

4.2 Massive Machine-Type Communication (mMTC)

Massive MTC (mMTC) provides efficient connectivity for a large number of cost and energy-constrained devices. mMTC includes a very wide range of use cases, ranging from the wide-area use case with sensor and actuator deployments for surveillance and area-covering measurements, to more local cases connecting electronic devices in the smart home restricted to indoor environments in populated areas, or co-located with human users as in the case of body-area networks. Common for all these cases is that traffic is of small size and typically sporadic in comparison to the xMBB case. More importantly, mMTC should be generic enough to cover new unpredicted use cases in the time frame 2020 and not restricted to what can be currently imagined.

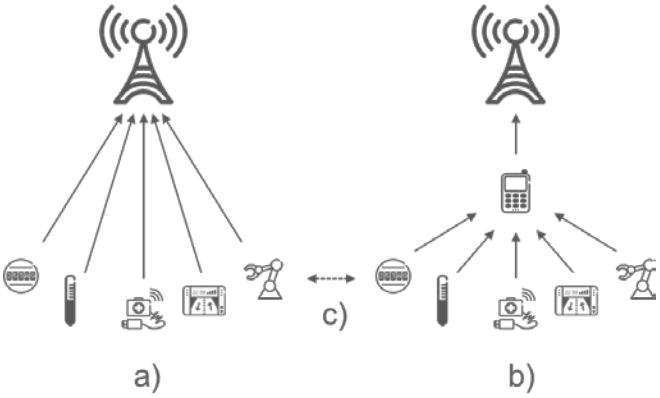


Figure 4.1: Illustration of the three access types: a) MMC-D, b) MMC-A, and c) MMC-M.

Three access types are envisioned for the mMTC service: direct network access (MMC-D), access via an aggregation node (MMC-A), and short-range D2D access in the case the traffic is end-to-end between nearby devices (MMC-M), as illustrated in Figure 4.1. Preferably, the mMTC air interface solution should be the same for all three access types to minimize costs on the terminal side. In the MMC-A case, solutions should allow for even a simple battery operated device to act as an aggregation node, i.e. to have a dual-role as described in Section 2.1.1. This device, and also the devices in MMC-D, would need somewhat higher capabilities, e.g. for the FDD case they must be able to receive transmissions in the uplink band. The cost of such capability addition should still be within the cost restriction for the devices. It may be advisable that all terminal devices have these additional capabilities such that they are all equal and always able to access the network with any of the three access types. This would allow for an ad-hoc setup of the network with a minimum of effort in planning and deployment.

The aggregation node access, MMC-A, and the D2D access, MMC-M, are enabled by mMTC specific solutions for D2D communication. For the devices that scale with the number of people, UDN solutions can be used for mMTC, i.e. piggy-back and benefit from UDN deployment [MET14-D62], but most solutions come from mMTC-specific work.

The key features for mMTC are very high protocol efficiency (i.e. very low signalling overhead), enhanced coverage, high capacity in terms of number of devices and the requirement for long device battery life, cf. Section 2.1.9. For the majority of machine devices, such as sensors and actuators, the access method will be MMC-D. Coverage improvements for low complexity devices are critical, and Massive MIMO on the access node side is one enabler of enhanced coverage. For really challenging coverage cases, MMC-A access can offer machine-to-machine (M2M) relaying operation and provide increased coverage as well as improved device battery life. This case may further be combined with Massive MIMO as described above to obtain beamforming gains between the access node and the accumulation/relay node.

MMC-A and MMC-M address capacity and long battery life by providing short-range transmissions when possible and macro access node offloading, cf. Section 2.1.7. This is enabled by D2D-M and differs from regular D2D in that the user traffic is usually of lower data rates and volume and comparably delay-tolerant. In the case of mMTC, the D2D setup procedure (discovery and mode selection) needs to be lightweight for the sake of low signalling overhead and long battery life. However, the devices are also typically stationary and could rely on long-term and delay-tolerant setup procedures.

Deploying devices with x10 battery life only makes sense if the service can be guaranteed to work more than 10 years. Overall the bandwidth requirements for the mMTC service is relatively small, ≈1-2 MHz is enough for the traffic stated in TC11. However, since it is unknown exactly which applications will mMTC include in the future, it is important to be able to dynamically increase the system bandwidth for the service and not be tied to a fixed bandwidth allocation. Therefore, mMTC needs to share the spectrum flexibly with xMBB and uMTC.

Both connectionless and always-connected approaches should be supported. The former is optimal for mobile devices, e.g. parcel tracking, whereas the latter is optimal and minimizes the bits over the air for stationary devices. This poses requirements on the dynamic RAN, since in the connectionless approach, there is no user context stored on the network side and all required control plane data must be appended, whereas in the always-connected approach user context is stored on the network side.

To offer Internet access for machine-type devices, from the network architecture point of view, one option is to have an aggregation node, which can act as relay station or local gateway device. In either case, the communication between the machine-type device and the aggregation node can be based on direct D2D communication. Hence, direct D2D communication can be used to extend the communication range of mMTC. In addition, due to the short communication distance, the power consumption of the MTC devices can be reduced as well.

An important issue for mMTC is the capacity in terms of number of devices. Typically the uplink capacity is more problematic because of the more limited output power of the terminal devices. A way to increase the uplink capacity is to excessively multiplex or overload of devices and rely on advanced receivers to still be able to distinguish the signals from different devices (schematically illustrated in Figure 4.2). This has been covered by diverse technical solutions in METIS (T2.1-TeC2.1-2.3, T2.3-TeC11.1.2, T2.3-TeC12.1.3, and T2.3-TeC12.1.1).

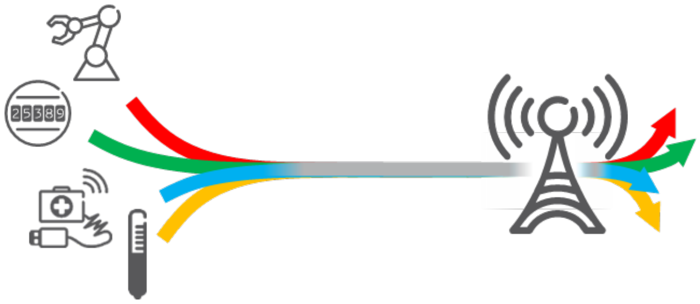


Figure 4.2: Illustration of solutions overloading user transmissions by use of advanced receivers.

Compressive Sensing Multi-User Detection (T2.3-TeC12.1.3) spreads the users signals with pseudo-random codes and relies on the sparsity of the joint signal of all users in order to be able to distinguish separate users on the receiver side. The sparsity comes from the fact that many of the users are not active. In Coded Random Access with Successive Interference Cancellation (T2.3-TeC12.1.1) users transmit their data with individual repetition patterns over time slots and over a certain evaluation period consisting of a number of time slots. At the end of the period an individual user transmission can (most often) be decoded in one slot and cancelled from transmissions in other slots. With successive application of this cancellation all users' signals can eventually be decoded. Basically, a higher capacity is obtained at the expense of increased redundancy as well as increased complexity of the receiver. For SCMA (T2.3-TeC11.1.2, T4.2-TeC16) the coded bits are not modulated and transmitted in the traditional sense, but codewords are directly mapped to sparse code words, e.g. in the frequency domain in an OFDM grid. Each user has its own code book with an individual sparsity pattern to simplify reception. Further, the SCMA codebook parameters such as spreading factor and the sparsity (number of non-zero elements) can be adjusted to address either coverage or higher user multiplexing and a more simple receiver. (Codebooks with larger spreading factor and more non-zero elements would provide coverage enhancement).

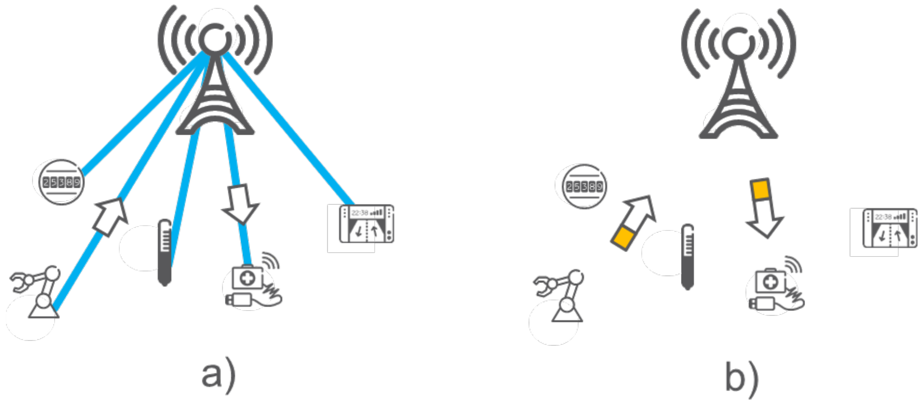


Figure 4.3: Illustration of a) always-connected approach and b) connectionless approach.

All the above technical solutions assume the use of contention-based transmission of data. That is, the uplink payload is transmitted directly at the risk of collision with other users without first reserving some resources for the transmission. For larger payloads it makes sense to first reserve resources for the transmission, but for the relatively small payloads in the case of mMTC, contention-based transmission of data could bring gains in reduced control signalling overhead and reduced terminal energy consumption. The alternative is that the devices request a transmission grant by using a Random Access (RA) procedure. In this case there will be contention in the RA and risk of collision between users. In Coded Access Reservation (T2.3-TeC12.1.2) the contention space is increased by coding over time or frequency resources. That is, the contention frame is extended over several slots and the coding comes from which of these slots the user is transmitting in. Thereby a larger contention space is achieved and the RA capacity is increased at the expense of increased latency, higher receiver requirements and somewhat higher battery consumption.

Another approach is to reduce the risk for collisions by reroute traffic that must not necessarily use contention based access. This is implemented in the solution Hybrid Access Scheme for Reduced Signalling Overhead (T2.1-TeC2.3) where periodical and predictable traffic is rerouted to use semi-persistent scheduling instead.

Contention-based transmission of data is often considered in a connectionless approach, i.e. a message-based transmission scheme where the payload and control signalling is combined and transmitted at one instance as opposed to the traditional scheme where a connection is setup prior to transmission of the payload. This is illustrated in Figure 4.3b. Note that for a fair comparison, most control signalling that is included in the connection setup procedure, such as security keys, addressing etc., would have to be added to the payload (indicated by the orange addition in Figure 4.3b). The contention-based approach is closer to Wi-Fi technologies such as IEEE 802.11ah and 802.15.4 using Carrier Sense Multiple Access (CSMA) with Collision Avoidance CSMA/CA, with the difference being the carrier sensing part. Since no user context has to be stored in base station and no connections need to be maintained, this solution is good for mobile devices, such as parcel tracking. For stationary devices, control signalling can instead be minimized by setting up a connection once and for all and not having to resend control signalling such as security keys, addressing etc. upon every payload transmission. This “always-connected” approach is schematically illustrated in Figure 4.3a and optimal for stationary terminal devices that remain in the same cell for long period but puts higher requirements on memory in the access node. Although the contention-based access is often associated with the connectionless approach, it is not limited to that but would work equally well in an always-connected approach. Vice versa, access reservation by the use of RA would work perfectly fine also in a connectionless approach, and would make sense if the combination of payload and required control signalling, as described above, becomes larger than a certain limit.

If the number of transmission occasions also is to be kept to a minimum, contention-based transmission should be combined with a waveform which does not require uplink synchronization. In LTE, the RA procedure is not only used to get an uplink grant for contention-free transmission of the payload, but also gives a “timing advance” offset which is applied to uplink transmissions in order to be received in sync at the base station. FBMC (T2.2-TeC8.1) is a waveform which does not require any such synchronization; if users are assigned to different carriers in uplink, they will not cause any intra-cell interference to each other even if they are largely not synchronized. The drawback with FBMC is the tail problem of the wave form which makes it less efficient for small payloads, and therefore for mMTC. However, this tail problem has been solved by introducing a circular convolution which folds the tail back into the transmission block. This is called Circular Offset-QAM (COQAM) or circularly convolved FBMC, respectively, and makes small payload sizes feasible at the price of slightly worsened interference isolation. However, if moderate interference suppression levels are required only, unsynchronized uplink transmissions will still be possible. Also UF-OFDM (T2.2-TeC8.2) supports relaxed uplink synchronization by applying sub-band filtering with tail length limited to the length of the cyclic-prefix of OFDM. In this way these solutions are enablers of contention-based transmission of data.

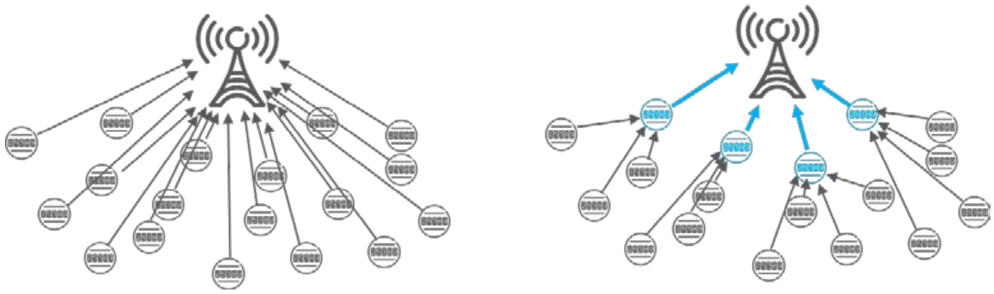


Figure 4.4: Illustration of MMC-A access enabled by D2D-M.

Coverage is one of the KPIs for mMTC which is very crucial, but addressed by very few approaches. At long range it is a matter of accumulating energy and no waveform can provide a remedy to the very long transmission times, which are in turn devastating for another KPI for mMTC - the terminal energy consumption. M2M relaying, in which devices act as relays for the proximate nodes in poor coverage, can provide gains in coverage, terminal energy consumption, and also capacity at the same time (illustrated in Figure 4.4), but potentially at the expense of increased end-to-end latency. The latter since if long transmission times are avoided, less system resources are used and a higher number of devices can be served. The M2M relaying is enabled by D2D-M, allowing devices to discover and set up a communication link between them (T4.1-TeC2, T4.1-TeC3.1, T4.1-TeC4.1, T4.1-TeC5.1, and T4.1-TeC5.2). A key difference from regular D2D is the terminal energy consumption constraint. Because of this, the discovery procedure and the mode selection must be performed with a minimum of transmission and reception time for the device. Therefore it is not feasible to do this setup for each data transmission, but a long-term setup of relay links is suitable for M2M relaying.

Further, due to the difference in received power, the rate of the transmission from a base station to the relay device can be adjusted such that the relay device can at the same time receive a transmission from an end-device by the use of successive interference cancellation. This is the idea of the technical solution Relay-assisted underlay MMC links (T2.1-TeC2.1). Radio resources are in this way reused within the cell, which translates to gains in capacity.

Yet another solution addressing the coverage is Constrained Envelope Coded Modulation (T2.2-TeC9.1), where the signal is transmitted with constant amplitude. This would lead to a higher efficiency of the power amplifier and would bring either coverage gains, since the output energy is higher, or battery life gains, since the energy consumption is lower for a given output power. With this solution the requirements on cooling and linearity of the power amplifiers would be lower, this enabling the production of cheaper mMTC devices.

A cheaper device is subject to a higher inaccuracy, and the carrier frequency offset could potentially become a problem. However, with repetition of the symbol sequence prior to Discrete Fourier Transform (DFT) operation, as done in Support of Low-cost MMC Devices Under Poor Coverage and High Frequency Offset Conditions (T4.1-TeC16), a waveform similar to the one in T2.2-TeC9.1 is created. That is, the waveform is spread in frequency in a comb-like pattern. This gives frequency diversity and at the same time a power spectral density boost yielding coverage gains.

For many mMTC applications the transmissions can contain redundant information. For example for periodical transmissions where only a sensor reading differs from time to time, or transmissions from a group of devices in which only the device identity differs. Context Based Device Grouping and Scheduling (T4.2-TeC1 and T4.2-TeC12) makes use of this by storing a reference copy of a transmission to reduce the number of bits transmitted over the air. Furthermore, among a group of similar devices, some messages may only need to be transmitted by one device, as other devices hear this broadcast transmission they can omit their own transmission. This will bring gains both in increased protocol efficiency and increased capacity since a higher number of devices can be supported.

With the emerging of new mMTC applications New Management Interface Between the Operator and the Service Provider (T4.3-TeC1.1) can further introduce the possibility to tune network parameters for only a certain time, location or service type.

As stated in the previous section, a large group of devices will scale with the number of people and also be collocated with people in urban areas. In this it may be beneficial to piggy-back an existing UDN deployment to provide service and gains for mMTC (T2.1-TeC1.2 and T2.1-TeC1.3). One benefit is better battery life due the shorter transmission times which stems from the reduced frame lengths. Another benefit is that the capacity requirements of mMTC are easily addressed by the large bandwidth available at these frequencies. The drawbacks is the propagation properties and also that a uniform device fleet, supporting only one air interface, could most likely not be used since lower bands would be preferable for wide area coverage.

As mentioned Massive MIMO with many antennas on base station side can bring gains in coverage. Further the multi-user aspect of the tighter beams should also be able to give gains in capacity. However, no work has been pursued in this line for mMTC and it will, although it is promising, remain a topic for future research.

4.3 Ultra-reliable Machine-Type Communication (uMTC)

uMTC addresses the needs of ultra-reliable and time-critical services based on machine type communications. A representative example of uMTC is the case of road safety and traffic efficiency applications, which are based on the exchange of information between nearby traffic participants, including vehicles and vulnerable road users such as cyclists or pedestrians, with low end-to-end latency and very high reliability. This is usually referred to as V2X communications, in which the X refers to vehicles (V2V), pedestrians (V2P) and road infrastructure (V2I). Another example is the industry automation/control, which is seen as one of the new applications for future 5G systems where the requirements on latency and reliability are really challenging.

Taking V2X applications as one example, the use of D2D communication is considered as a key solution within the context of uMTC. On the one hand, a direct link between traffic participants avoids the necessity of using both uplink and downlink resources for the dissemination of a single message, whereas the localized nature of the transmissions enables the spatial reuse of resources and improves the spectral efficiency in the entire network. On the other hand, the use of non-assisted D2D communication enables the exchange of information between traffic participants even in locations with insufficient network coverage. It is important to note that the ability to exchange information between traffic participants under strict latency and reliability constraints, regardless of which Public Land Mobile Network (PLMN) they are connected to, is essential for the effectiveness and usefulness of V2X communications. As a result, multi-operator D2D operation is seen as a fundamental enabler for the provision of V2X services within uMTC.

Similar to xMBB, the uMTC service in the case of V2X communications must cope with the impairments of highly mobile propagation channels, namely inter-carrier interference caused by the Doppler shift, multi-path fading, and inaccurate channel state information. In this sense, the use of filtered and filter-bank based multi-carrier (T2.1-TeC8.1 and T2.1-TeC8.2) could improve the transmission robustness against Doppler in high mobility scenarios by adapting the waveform to the UE characteristics and the propagation scenario. Furthermore, it is also possible to enable the concurrent support of multiple speed classes without the need for compromising between the different device and mobility classes. This might prove critical to satisfy the requirements of V2X services in an efficient manner when multiplexed with other service categories. Combined with non-coherent communication, T3.2-TeC16, this reduces the need for synchronization. In addition, enhanced transceiver implementations with improved resilience against multi-path fading by means of advanced channel estimation and predictor antenna techniques (T2.1-TeC6.3 and T2.1-TeC6.4) contribute to further improve the mobility-robustness of V2X communications. On one hand, the particularities of the V2X propagation channel (certain structure found in the delay-Doppler domain) can be exploited in order to reduce the channel estimation error and achieve important gains in terms of the Signal-to-Noise Ratio (SNR) at the cost of computational complexity. On the other hand, predictor antenna systems have the capability to exploit the presence of multiple antennas in vehicles, placed in a line along the longitudinal axis, to improve the accuracy of the channel estimation. In particular, the first antenna is used to predict the transmission channel of the other antennas behind it. The improved channel information has the potential to enable the use of Massive MIMO beamforming and CoMP at high velocities, and thus, to contribute to the provision of reliability in vehicular communication. It must be noted though, that the placement of multiple antennas along the longitudinal axis of the vehicle might be limited by implementation and design aspects.

Furthermore, the concept of availability indication for reliability together with link reliability prediction provides the dependability required by V2X services and applications. Future 5G networks cannot possibly satisfy the strict requirements of V2X communications at all times and in every reception scenario, as this would results in an overdesigned system with a very inefficient air interface in terms of data rate and power consumption. In this context, dependable applications such as highly autonomous driving should be informed about the presence or absence of reliability according to their QoS requirements. A framework for URC based on a novel metric referred to as *Availability*, which indicates the absence or presence of link reliability, as well as a concept for modelling and predicting the reliability of a link have been developed for this purpose (T2.1-TeC6.1 and T2.1-TeC6.2).

To enable V2X communications, uMTC also incorporates the use of both network-assisted and pure ad-hoc D2D communication in a complementary manner. Thanks to the nature of local communication, the use of direct communication between traffic participants (i.e. without being relayed by the network infrastructure) can reduce the E2E latency significantly. Furthermore, comparing to the regular cellular communication, the propagation condition can be much better which gives the potential to achieve improved reliability. Network-assisted D2D communication is enabled by means of resource allocation and power control schemes tailored to V2X applications, which take into account the QoS requirements of the direct communication links, and minimize the amount of signalling overhead that needs to be exchanged between the devices and the network infrastructure. Both inband (underlay with uplink resource sharing) and outband D2D communication are considered for the provision of V2X applications. One approach to limit the amount of signalling that is exchange between devices and with the infrastructure is to exploit the properties of the V2X communication such as the short range communication or the periodical transmission of messages. For instance, each traffic participant might need to broadcast a beacon with information regarding its position, velocity and trajectory, among others, periodically (i.e. every 10 ms) and reliably (i.e. reliability 99.999%) within a certain range (i.e. 100 m). In this sense, it is possible to rely on cell partitioning and spatial resource reuse in order to enable simple RRM and efficient signalling in a D2D underlay (T4.1-TeC4.3). Hereby, scheduling decisions can be made based on crude location information instead of unreliable/infeasible channel measurements. Another approach in the case of D2D underlay is to employ radio resource allocation and power control schemes that aim at maximizing the cellular user´s sum rate under the constraint of satisfying the strict QoS requirements in terms of latency and reliability of V2X communications (T4.1-TeC4.5). The use of Cluster Heads (CHs) is on the other hand considered for enabling outband V2X communication (T4.1-TeC4.4). In particular, the proposed concept relies on network assistance to assign separate resources (time and/or frequency) to different clusters located in the vicinity of each other. The network assistance can also enable efficient spatial reuse of resources when the density of nodes exceeds the available resources based on location information collected from different CHs. The role of the CH is to control the vehicles within its cluster, to handle the cluster joining and leaving requests, and to manage the radio resources on the basis of resource assignment received from the cellular node. The two-level assignment of resources (network and cluster level) allows maintaining a reasonable signalling overhead even for a large number of vehicles.

While the coordination of transmissions performed by a central entity (i.e. a base station or a cluster head) in the case of network-assisted D2D communication allows for a better resource allocation and interference management, non-assisted D2D communication is fundamental in order to enable the exchange of V2X data even in locations with insufficient network deployment (i.e. out of coverage). In particular, non-assisted D2D communication is provided by a combination of Coded Slotted Aloha, particularized to broadcast transmissions with latency constraints (T2.1-TeC6.5), and distributed network synchronization (T2.3-TeC12.2). The former improves the reliability compared to the current state of the art based on CSMA, such as in the case of the 802.11p standard. The latter provides the synchronization across communicating partners that is required by slotted Aloha protocols if the user is outside network coverage.

Interference identification schemes are also considered as part of the uMTC, as they provide valuable input to the RRM mechanisms regarding the interference environment. The improved interference knowledge might prove fundamental for the efficient provision of reliability as a result of superior interference management in the case of V2X communications. Among the different techniques for interference identification investigated within METIS, the Adaptive Projected Sub-gradient Method (T4.1-TeC1.1) has shown to provide good results when estimating and tracking the time-varying long term channel gain between all of the transmitters and receivers in the network.

Together with improved interference knowledge, context information might play an important role for providing reliability in V2X communications. Particularly, the context information regarding the trajectory of a moving vehicle (T4.2-TeC10) allows for the timely preparation of an imminent handover and, hence, contributes towards the fulfilment of the posed QoS requirements. Moreover, optimized distribution schemes might contribute to improve the availability and timeliness of context information by reducing the cost of the increased signalling overhead (T4.2-TeC1). Similarly to context information, database information can be used to anticipate the use of ultra-reliable links and configure them in advanced (WP5-TeC20). For example, the right amount of spectrum can be allocated in the right band. Furthermore, spectrum can be also temporarily and locally leased to increase the reliability.

Within the context of V2X communication, multi-operator D2D operation is seen as a fundamental enabler. The ability to exchange information between all neighbouring vehicles (regardless of which PLMN they are connected to) is key for the effectiveness and usefulness of V2X safety applications. In addition to multi-operator communication, solutions for enabling multi-operator discovery and for joint spectrum allocation schemes are incorporated into the service (WP5-TeC22).

In industrial control applications, the discovery and communication establishment requirements may be less stringent but the reliability must still be high. In the industrial automation setting we consider three main categories;

- Stationary equipment, including rotating and moving parts, deployed indoors. Sensors and actuators attached to the equipment are assumed to be part of the manufacturing process control loop.
- Autonomous transport robots, both indoors and outdoors. This category is similar to V2X applications but the expected speeds are lower, and the environment is not public.

- Sensors deployed on equipment and/or parts for monitoring purpose. The output of these sensors is not a part of the manufacturing process control loops.

TeCs identified as relevant for automatic control relate to high-reliability and low latency, e.g. T2.3-TeC13.1 and T2.3-TeC13.2, both on Deadline driven HARQ. The sensor category is considered to be communication-wise identical to mMTC, and relevant TeCs are not listed here. In addition to the listed TeCs, all D2D-related TeCs may be relevant for autonomous transport robots. Industrial automation is further described in [MET15-D15].

5 Spectrum requirements and considerations

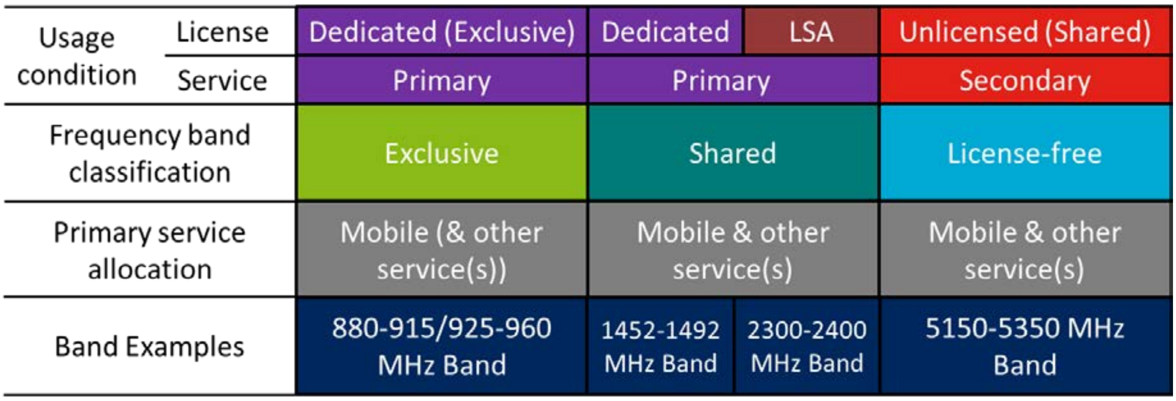
5G systems will serve a wide variety of use cases with different technical requirements. Thus, the required characteristics of the employed spectrum, i.e. suitable frequency bands, available contiguous bandwidth, and authorisation schemes will be different. Therefore, a high flexibility in spectrum usage is necessary, as already noted in section 2.1.8. In this section spectrum requirements are analysed from the perspective of the three generic 5G services xMBB, mMTC and uMTC. Furthermore, spectrum usage scenarios for satisfying the increasing need for spectrum within the future spectrum landscape are considered.

5.1 Spectrum usage within the future spectrum landscape

Currently, four frequency band classifications - Exclusive bands, Shared bands, Licence-free bands, Receive-only bands (not relevant for mobile communications) - and two service categories - Primary service, Secondary service - are defined and commonly used in national allocation tables [UK-FAT13].

Future regulation and technology development will create a complex landscape of spectrum availability and authorization modes. Multiple frequency bands, subject to different regulation including various forms of shared spectrum as illustrated in Table 5.1, are expected to be available for mobile communication systems.

Table 5.1: The future spectrum landscape for mobile communication systems consists of different bands made available under different authorization modes.



Usage condition	License	Dedicated (Exclusive)	Dedicated	LSA	Unlicensed (Shared)
	Service	Primary	Primary		Secondary
Frequency band classification		Exclusive	Shared		License-free
Primary service allocation		Mobile (& other service(s))	Mobile & other service(s)		Mobile & other service(s)
Band Examples		880-915/925-960 MHz Band	1452-1492 MHz Band	2300-2400 MHz Band	5150-5350 MHz Band

In order to exploit these opportunities, 5G system design requires a high degree of flexibility to be capable of operating under different regulatory models and usage scenarios. Authorization modes recognized as relevant for wireless communications are Primary user mode, Licensed Shared Access (LSA) mode and Unlicensed mode. The Spectrum Toolbox (see Section 6.4 developed by METIS offers technical enablers to facilitate a flexible application of these different authorization modes within various spectrum usage/sharing scenarios.

5.2 Generic 5G service specific requirements on spectrum

xMBB addresses the expected 1000 times increase in mobile traffic capacity beyond 2020. Despite advances in spectral efficiency and network densification, additional spectrum is necessary to meet this requirement. As sufficient spectrum currently not seems to be available below 6 GHz, there is a need to utilize frequencies in higher bands. Higher frequencies allow for using wider contiguous bandwidths reducing transceiver requirements. However, compared to lower frequencies, the usage of higher frequencies generally leads to reduced coverage and larger penetration and atmospheric losses. Thus, for the extreme coverage aspect of xMBB usage of lower frequency bands is essential. Also new spectrum access methods may need to be used to meet the xMBB requirements.

A mixture of frequency spectrum comprising lower bands for coverage purposes and higher bands with large contiguous bandwidth to cope with the traffic capacity, including wireless backhaul solutions, is required for xMBB. Exclusive licensed spectrum is essential to guarantee the coverage obligation and QoS, supplemented by other licensing regimes, e.g. LSA or unlicensed access (e.g. Wi-Fi offload) or new enhanced unlicensed access schemes, e.g. License-Assisted Access (LAA) to increase overall spectrum availability.

The possibility to use higher frequency bands with large contiguous bandwidths for wireless communication depends in particular on the existing usages within the respective bands. METIS has performed an analysis of spectrum above 6 GHz [MET13-D51] [MET14-D53].

mMTC requires good coverage and penetration conditions and comparable small bandwidths which motivate the use of lower frequency bands. Sensors will be simple devices with no or very limited possibility for upgrades after deployment, and with a long expected life-time. Therefore, a stable regulatory framework is needed.

For mMTC applications, frequency spectrum below 6 GHz is most suitable and spectrum below 1 GHz is needed to provide large coverage and good propagation. Exclusive licensed spectrum is the preferred option, however, other licensing regimes might be considered depending on specific application requirements and on economical, confined area, and global harmonization merits.

uMTC requires high reliability. Therefore, exclusive or very high priority in spectrum access is essential. uMTC may also require low latency, which could be realized by spreading the signal over a larger bandwidth (e.g. at higher carrier frequencies).

Licensed spectrum is considered most appropriate for uMTC. For safety V2V and V2X communication the frequency band 5875-5925 MHz harmonized for Intelligent Transport Systems (ITS) is an option [ECC-DEC].

A simplified overview on the suitability of frequency bands for the three generic 5G services, which would finally also depend on the specific application, the desired range and the propagation characteristics, is provided in Table 5.2.

Table 5.2: Simplified overview on suitability of frequency bands for generic 5G services.

	Bands < 6 GHz	Bands > 6 GHz	Exclusive Bands	Shared Bands	License-free Bands
xMBB	☺	☺	☺	☺	☺
mMTC	☺	😐	☺	😐	😐
uMTC	☺	☹	☺	😐	☹

5.3 Conclusions on spectrum availability for 5G

Sufficient amount of spectrum needs to be available in low spectrum bands in order to satisfy the requirement for seamless coverage of the 5G services xMBB and mMTC. Spectrum below 6 GHz is essential to cope with the mobile traffic in urban and suburban areas, and in medium dense hotspots. Spectrum above 6 GHz is necessary for enabling wireless access in high-dense usage scenarios, i.e. to fulfil the high contiguous bandwidth demand for xMBB, and also for wireless backhaul solutions for high capacity ultra-dense small cell networks.

Exclusive licensed spectrum is essential for the success of 5G to provide the expected QoS and to secure investments. Shared spectrum can be considered in addition, provided that predictable QoS conditions are maintained, e.g. by LSA regime. License-exempt spectrum might be suitable as a supplementary option for certain applications.

6 The four main enablers

This section describes a developed version of the four main enablers identified in [MET14-D63] and some of the enabling TeCs, providing a refinement of the TeC lists in [MET14-D62].

6.1 Lean System Control Plane (LSCP)

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

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

mMTC, on the other hand, benefits from a closer coupling between the control and data plane, even integration of the control and data planes. mMTC also requires optimized sleep mode solutions for battery operated devices, and mobility procedures with a minimum of signalling and measurements. The increasing number of network nodes requires lean signalling for energy performance boost.

uMTC requires guaranteed latency and reliability. Here it should be noted that the successful reception of control information is a prerequisite for communication of the data part. For very reliable, low-latency V2X connection the device discovery can be assisted by the wide-area network. The term “lean signalling“ in the context of uMTC has a different meaning, as signalling should be lean in terms of how much does it affect the total latency budget for a given packet transmission. Furthermore, for delay-tolerant uMTC connections that should be critically available, signalling should be designed in a way that ensures connection resilience under practically all conditions.

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

The METIS 5G system concept is an integrated multi-RAT system concept. It is possible that the generic 5G services will not all have the same air interface (a flexible OFDM-based air interface is the most suitable for xMBB, whereas new air interfaces as FBMC and UF-OFDM are promising for new applications such as V2X or MTC where synchronization is an issue). Additionally, evolved LTE is a part of the METIS concept to provide wide-area coverage. METIS has developed Massive MIMO and similar techniques to be used for coverage enhancements, and Massive MIMO will most likely be a part of the LTE evolution.

Given this, the purpose of the LSCP is to:

- Integrate the three generic 5G services and provide a common system access
- Integrate different spectrum and inter-site distance ranges, in particular for xMBB (should be considered as one RAT, not separate)
- Ensure energy performance
- Ensure scalability

The generic 5G services are integrated in the LSCP to provide a single access to the 5G system. The services share a common broadcast where the first signalling is common to all services and thereafter the signalling is service-specific. The common system access should also allow selected legacy technologies to be accessed through the LSCP. Finally, the LSCP must provide flexibility enough to accommodate for not yet foreseen services.

Concerning signals over the air, there should be one minimal system detection signal always transmitted (always may not be continuously but with short enough silent periods so that the detection delay is not too large). Additional system information should be transmitted only when a user/device signals that it desires to transmit data. When a device requests access to the network, the device indicates what service it wants and service-specific reference signals would then be transmitted (turned on). So if a user enters an empty cell and want to use LTE, then LTE reference signals are turned on. If it is a uMTC user, then appropriate reference signals would be turned on. It is not energy and resource-efficient to guarantee the latency requirements of e.g. uMTC on the initial network contact, but only after a connection has been established.

Separation of the control and data planes minimizes the “always on” signalling, and support discontinuous transmission and reception in the data plane. A 5G system will integrate nodes with large and small coverage areas operating in different frequencies, e.g. macro cells below 6 GHz and fixed and/or nomadic nodes in mmWs. This leads to a different split of the control and user planes. For xMBB it makes sense to separate the C- and U-Planes, to have control at a lower frequency and user traffic at higher frequencies for higher data rates. For mMTC it may be advantageous to tightly combine them. The current solution in LTE is not sufficiently good for mMTC concerning signalling overhead, energy performance and coverage. The EU FP7 project 5GNow is advocating integrating the C- and U-Planes [5GNow]. For a sensor where the payload is a byte or two, the signalling associated with setting up a session, transmitting the very small payload, and then tear down the connection constitutes an unmotivated overhead, and integration of the C- and U-Planes can be considered. Obviously, it will be a challenge to reach the goal of having xMBB and MTC on the same carrier (and hardware).

METIS has investigated methods to integrate macro-cellular base stations with small cells operating in the mmW band, addressing the need for ubiquitous control information, preferably carried over a lower frequency for reliability, and provisioning of capacity by having a user plane at mmWs. T4.3-TeC6 Framework for control/user plane design provides a solution focusing on the control- and user-planes in heterogeneous networks. Two over-the-air signalling variants are proposed where macro cell provide instruction to small cell how it should use the available resources. Such approach enables reliable signalling connection between macro and small cells which is crucial, e.g. for tight RRM.

METIS has been the carrier project for the EIT-ICT project 5GrEEn, which has developed a concept for energy efficient signalling [FOE14, OCF+13]. The 5GrEEn clean slate system concept is designed around two fundamental challenges:

- Be efficient when transmitting data.
- Be efficient when not transmitting data.

This may seem trivial, but there is significant room for improvements, in particular when not transmitting data, since today’s systems are continuously transmitting reference signals and system information even when no user is present. In fact, in today’s networks, the network nodes are idle most of the time and the cost of transmitting overhead signals when no data traffic is transmitted is totally dominating the network energy consumption.

When active, the data transmission should be packet-oriented since packet data inherently supports discontinuous reception and transmission (DRX and DTX). Furthermore, protocols should be designed such that the amount of additional transmissions outside of the packet bursts is minimized. Also, by making use of advanced antenna systems the transmitted energy can be concentrated to the intended receiver, and thereby reduce the transmission burst time and/or increase the active user bitrate.

A basic design rule for an energy efficient system has been developed from the two challenges above, namely to separate solutions for providing coverage and capacity. The coverage must be omni-present, ubiquitous and static, i.e. if it is possible to access the 5G system at a certain time and location, it must always be possible to access the system from that location. The capacity solutions, on the other hand, must be more adaptive than today's solutions, as traffic hot-spots move around. This calls for a logical decoupling of system information and data plane functionality, which is done in the METIS concept by decoupling the LSCP from the localized traffic and data flows.

The LSCP also addresses scalability. As networks densification continues to meet the capacity demands, it becomes increasingly important to be able to activate and deactivate network nodes depending on the traffic load, or alternatively, to switch off some of the node functionality in low-load modes. As described in Section 6.2 on Dynamic RAN, the METIS 5G system concept includes UDN nodes and nomadic nodes to meet the demand on traffic volume and data rate. Network nodes not serving any users should be deactivated to improved energy performance. T4.3-TeC4.1, T4.3-TeC4.2 and T4.3-TeC5 concerns the activation and deactivation of nomadic nodes and UDN nodes. If the signalling and reference signals are properly designed, network densification and maximum capillarity will also reduce the power requirements by reducing the necessary transmit power.

6.2 Dynamic RAN

To meet the requirements on data rate, the average SINR need to increase in the covered area. Several solutions are possible to achieve this since a terminal does not care whether the radio signal comes from e.g. a macro BS, micro BS, UDN node, nomadic node, or Massive MIMO beam, as long as the received signal strength is sufficiently high.

Dynamic Radio Access Network (Dynamic RAN) is a new paradigm of wireless networking which integrates Ultra-Dense Networks (UDNs), nomadic nodes, moving relays, beamforming, D2D communication and device duality in a dynamic manner for multi-RAT environments.

Network densification offers a fast way to increase the network capacity. Networks have been densified from traditional macro-cellular networks to small cells, and the densification will continue to UDNs for both outdoors and indoors deployments. In some deployments the inter-site distance will be as small as tens of meters. The large number of UDN nodes prohibits cell planning in the traditional sense, furthermore, to avoid unnecessary interference and power consumption, UDN nodes not serving any users will be turned off. Hence, although stationary in a physical sense, a UDN network will hence exhibit a dynamic behaviour in a communication sense.

With the rise of connected cars in the current decade, the cars will not be only communicating with each other and the network, they can also serve as flexible means of wireless access points for both in-car and out-car users, e.g. nomadic nodes and moving relays. Such access points on the move can be utilized to enable temporal network densification to tackle the varying traffic demand over time and space on-demand. Nomadic nodes resembles UDN, but nomadic nodes offer their services as temporary access nodes at non-predictable locations and at non-predictable times, and solutions must deal with the dynamic behaviour as well as the inherent uncertain availability of nomadic nodes.

Beamforming, e.g. Massive MIMO or CoMP, can be used to increase the SINR in a local area. The illuminated area can be considered as a small cell, which is movable not by moving the physical access node as in case of nomadic nodes, but rather by re-pointing the beam in another direction, in effect creating a virtual cell.

The number of smart user devices such as smartphones, tablets and wearables is increasing at an astonishingly rapid pace. The smartness comes in part from the increased processing capabilities, e.g. processing power, memory, and storage, and in part from the radio capabilities, e.g. the supported wireless communications generations along with supported frequency bands, and more advanced antennas. Furthermore, not only do the user devices connect to the network but also a wide range of other devices, such as, sensors, robots and drones, will co-exist, and the mobile network operator may also have further degrees of freedom to coordinate the functionalities of these devices.

Flexible D2D operation is one of the key elements of the Dynamic RAN. After devices discovers each other, the most suitable communication mode will be selected based on various criteria for example interference level. When D2D mode is selected, it is possible that one of the devices will take certain network management role for example resource allocation between D2D pairs and relay certain control information from network to other devices within the same group. D2D communications allows a user device to temporarily take over the role of access nodes for other users, e.g. to guarantee the ubiquity of high quality services[4].

The METIS 5G system concept considers the network as a whole which takes into account any connected or connectable network element. Within the framework of Dynamic RAN, the network deployment becomes flexible to cover the inhomogeneous distribution of traffic demand over time and space in an agile way. The network needs to react quickly and dynamically to fulfil the service requirements, which may unpredictably change in a certain region during a relatively short time period. An example of a Dynamic RAN is given in Figure 6.1.

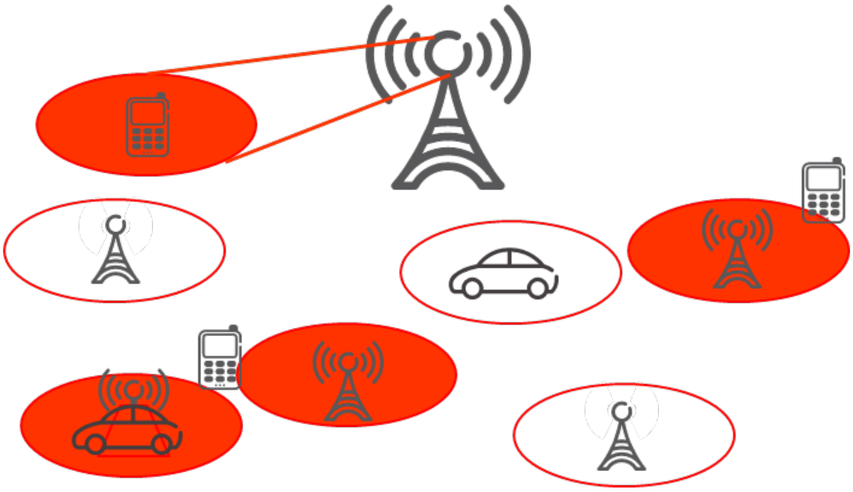


Figure 6.1: Illustration of a Dynamic RAN including UDN nodes, nomadic nodes, and beamforming lobes. Solid red indicates activated, empty indicates deactivated.

These similarities between the elements constituting the Dynamic RAN and some enabling TeCs are described below.

To minimize the total energy consumption of the network and controlling the interference environment, the Dynamic RAN utilizing activation/deactivation mechanisms to select which nodes/beams should be activated at which times and locations.

UDN nodes are densely deployed at fixed locations, whereas the availability of the nomadic nodes depends on battery constraints and parking behaviour of the drivers, which in turn depends on, e.g. day time and region. Activation/deactivation mechanisms for UDN and nomadic nodes are treated in e.g. T4.3-TeC4.1 and T4.3-TeC4.2.

A moving relay is a wireless access node that can provide service to the in-vehicle users especially for high-mobility scenarios. During low-mobility or stationary operation, moving relays may be configured as nomadic nodes. Antennas implemented in the interior of the vehicles can eliminate the penetration loss due to the metalized windows, T3.3-TeC9b.

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[4] Admitting user devices into the RAN as temporary access nodes leads to security issues. These should be addressed with the support of the network infrastructure. This is however outside the scope of METIS.

A user device exhibits a duality, being able to act both as a terminal and as an infrastructure node by temporarily taking over the role of access nodes for other users. Activation/deactivation mechanisms are used to determine when it is suitable to use the device as a temporary part of the infrastructure, e.g. T4.1-TeC5.1, T4.1-TeC5.2, and T4.1-TeC5.3.

Beams can be activated and steered to provide coverage and capacity as needed if no physical access nodes are present, e.g. T3.2-TeC1b.

However, the activation and de-activation of nodes/beams have to be done carefully since it will affect the interference environment - interference will occur not only from users but also from time-varying access nodes/beams. Therefore, dynamic interference and radio resource management algorithms are instrumental in the Dynamic RAN. Smart scheduling of user resources minimizes the interference, e.g. T4.1-TeC6.1, and T4.1-TeC7.1 for UDNs and T4.1-TeC13 for nomadic nodes. T3.1-TeC2 reduces inter-cell interference in beam-based solutions and T3.1-TeC8 addresses local interference reduction for mixed usage of Massive MIMO and UDN. Interference management for D2D is treated in e.g. T4.1-TeC5.1, T4.1-TeC5.2, and T4.1-TeC5.3. Coordinated resource usage in virtual cells, including all access types in Dynamic RAN, is treated in T4.1-TeC12.

Clustering of nodes in a Dynamic RAN allows for simpler interference management. Different clustering mechanisms can be performed based on the use case and the current status of the network [MET15-D64]. Algorithms for creation of UDN and nomadic node clusters for improved interference management are given in e.g. T4.1-TeC9 and T4.1-TeC7.2.

Timely action of activation/deactivation schemes and interference management requires the prediction of node and user behaviour. I.e. a nomadic node may become unavailable and a user could encounter handover decision even if the user itself is fully stationary. Hence, smart mobility management techniques are required that ensure seamless connectivity in the Dynamic RAN. They must react fast upon arrival and departure of nomadic cells, while avoiding to be connected to a nomadic cell which would soon be unavailable. Moreover, UE discovery and node activation mechanisms are essential to steer the activation and deactivation of nomadic nodes and embed them seamlessly in the existing network. The prediction of the trajectory of the users as well as their traffic profile helps identifying upcoming capacity and coverage demands, e.g. T4.2-TeC2, T4.2-TeC6, T4.2-TeC7, and T4.2-TeC8.

This is an important input to the nomadic node activation and deactivation schemes. New management interfaces are an important enabler to share the predicted data efficiently among the various network entities as well as among operators and service providers. This makes possible the practical implementation of centralized and decentralized data distribution schemes. Spectrum management requires the detection and selection of available spectrum for nomadic nodes. This is essential to enable smart spectrum coordination in order to decrease inter-cell interference. It is also important to note that a sufficient amount of spectrum needs to be available to allow for high-data rate backhaul links, and that the full potential of nomadic networks can only be leveraged by enabling multi-operator support.

Since nodes constituting the Dynamic RAN may not always be connected to a wired backhaul, enhancement techniques for wireless backhaul links are essential to leverage the gains of Dynamic RAN. Such schemes significantly improve the capacity and reliability of the whole network as the backhaul link is often the bottleneck in the end-to-end communications. Interference alignment and cancellation schemes, CoMP (T3.2-TeC1b) and Massive MIMO techniques (T3.1-TeC8, T3.1-TeC9b, T3.1-TeC10) as well as dynamic resource allocation and nomadic node selection schemes increase the robustness and throughput of wireless backhaul links of nomadic nodes, e.g. via reducing the impact of shadowing [MET15-D43]. Similarly, advanced backhauling and relaying schemes – such as and two-way relaying (T3.3-TeC1, T3.3-TeC5) and interference-aware routing (T3.3-TeC2) – can be applied to nomadic nodes, which increase the user throughput and reliability of communication links in such a dynamic network. Additionally, D2D communication can provide local traffic offloading utilizing localized traffic flows, cf. Section 6.3.

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

One example of the device duality is the context-aware cluster head operation. Cluster head functionality, e.g. T4.3-TeC2, can be utilized to coordinate the transmissions of a large number of MTC devices, which can reduce signalling congestion in mMTC. Another example is D2D where the traditional network management functionalities are extended to user device in a dynamic way in order to maximize the offloading gain and support new use cases including local caching and sharing.

The Dynamic RAN implies a flat architecture from service point of view resulting in low latency, supporting also the requirements of *short-term URC* (URC-S) [MET14-D62]. It is also accompanied by an agile infrastructure support since ad-hoc and smart coordinated setup of networks is expected under this service/user-centric model. Dynamic RAN also entails a different distribution of functions over network nodes depending on the service at hand and the hardware and software capabilities of the network nodes.

6.3 Localized Contents and Traffic Flow

One of the main goals of METIS is to reduce current latency by a factor of five. However, the delay budget analysis of legacy technologies reveals that most of the delay comes from the Internet and the core network parts of the E2E link. Therefore, localized contents and traffic flows, including data traffic offloading, aggregation, caching and local routing contribute to meeting this target [San12]. With the help of unified air interface (T2.1-TeC1.1—1.3), communication among local units (for example via UDN or D2D) can reduce communication latency significantly.

In the context of D2D traffic offloading, the control and data planes can be separated. The control plane is managed by the network and the data plane is transmitted over the direct D2D link. The network operator improves the user experience by providing e.g. authentication and security features while reducing the load on the data transport. In this framework context information and network assistance for D2D discovery are of paramount importance to enable such direct communication. Different ways to discover each other between content owner and content consumer have been studied in T4.1-TeC2 for device to discovery each in case with and without network coverage. While it should be pointed out that there could be scenarios for example V2X communication where the message is just broadcasted without the discovery in order to further improve the latency. After devices discovered each other, the most suitable communication mode between direct D2D communication and regular cellular communication can be selected based on different algorithms studied in e.g. T4.1-TeC3 and T4.2-TeC14. Local content sharing can be easily supported with direct communication model. To facilitate local communication, efficient resource allocation and interference management are necessary which have been well studied (e.g. T4.1-TeC4, T4.1-TeC15) within METIS. Moreover, to maximize the benefits owing to content sharing with local traffic flow, multi-operator operation should be supported as well as investigated in WP5-TeC22.

In mMTC, the use of concentrators acting as local gateways could allow direct communication among sensors located in a local area without the need to reach the core network gateway as discussed for example in T2.1-TeC2.1. For mMTC the localized traffic flows allow low-power access to the network. The network edge nodes can provide aggregation and information fusion of sensor data reducing the transport load and provide local added information value. Here, semantic aggregation provides greater reduction of the transport load than simple data aggregation. Further, the necessary context information for mMTC operations can be stored locally.

For delay-sensitive services, e.g. V2X, it is necessary to turn-around the traffic flow and perform critical computations close to the user to meet the latency constraints.

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

6.4 Spectrum Toolbox

5G services have differing requirements concerning spectrum band, signal bandwidth and access scheme. Hence, a 5G system has to be capable of operating under different authorization modes in various frequency bands. Additionally, the mix of different services in a 5G system may be changed and it is therefore necessary to reassign spectrum on a timescale of hours. To meet these requirements, a spectrum toolbox has been developed which is applicable to all foreseen 5G use-cases and services [MET14-D53]. The spectrum toolbox utilizes the spectrum-related TeC listed in Section A.4.

The spectrum toolbox enables flexible use of available spectrum resources aiming at increasing the efficiency in the use of spectrum. Thus, it is a fundamental enabler for multi-service operations and spectrum-flexible air interfaces. The toolbox provides tools to:

- Enable operation in widely distributed spectrum bands, both at high and low frequencies, by considering the suitability of different spectrum bands dependent on applications.
- Facilitate different sharing scenarios by applying respective mechanisms either solely or in combination.
- Facilitate operation by using small as well as large bandwidths, which enables spectrum-flexible air interfaces supporting higher data rates.
- Adopt different rules for different services, e.g. certain spectrum may only be used for specific services.

An overview of the application of the Spectrum Toolbox is show in Figure 6.2.

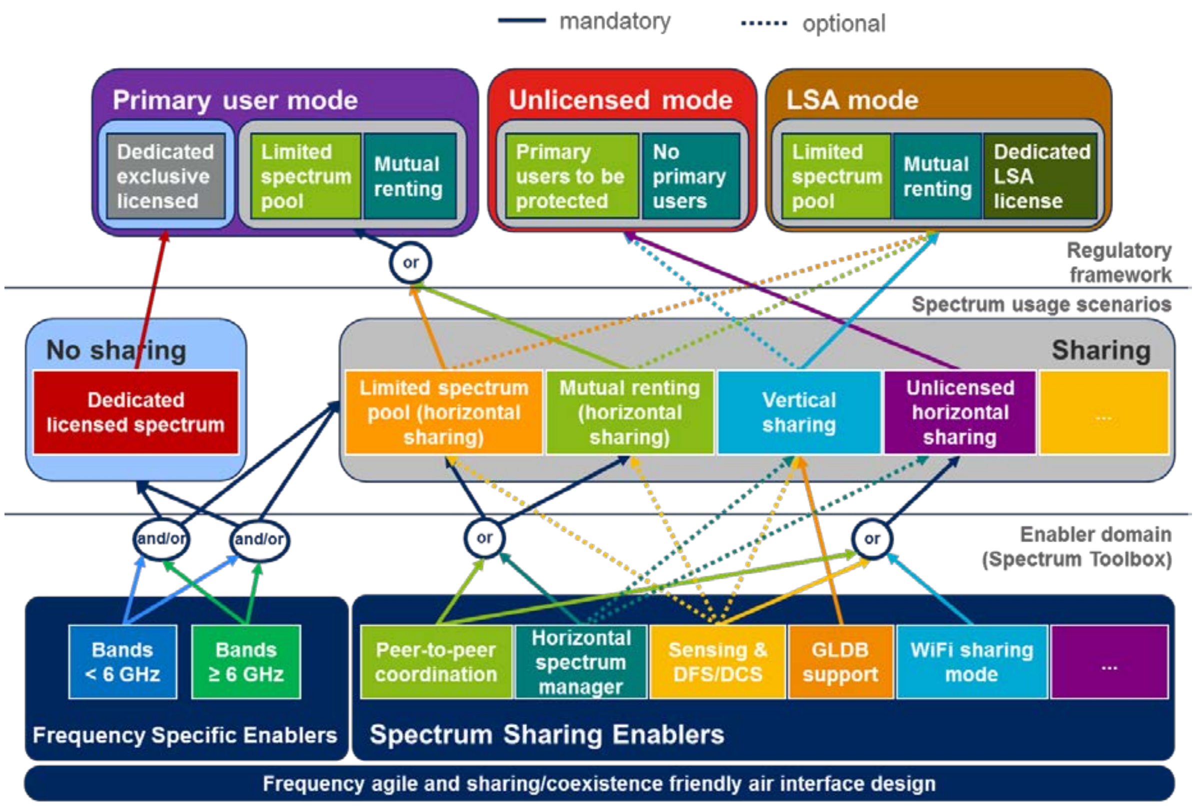

Figure 6.2: The METIS Spectrum Toolbox.

In order to illustrate the functionality of the spectrum toolbox, three domains are considered; Regulatory framework domain, Spectrum usage scenario domain, and Enabler domain. Relations between parts of the domains are either necessary (mandatory: continuous lines) or supplementary (optional: dotted lines).

The *regulatory framework domain* concerns the authorization of radio spectrum usage. In principle spectrum can be authorized in two ways; Individual Authorization (Licensed) and General Authorization (Licence Exempt / Unlicensed). The individual authorization includes “Primary user mode” and “Licensed Shared Access (LSA) mode” [MET14-D53].

The *spectrum usage scenario domain* represent five distinct spectrum usage scenarios that 5G system should support, one exclusive usage scenario; dedicated licensed spectrum; and four spectrum sharing scenarios, namely; Limited spectrum pool (horizontal sharing), Mutual renting (horizontal sharing), Vertical sharing and, Unlicensed horizontal sharing. Note that the sharing scenarios are not mutually exclusive and that in some cases multiple of these scenarios may occur simultaneously.

The *enabler domain* (Spectrum Toolbox) consists of a set of technical enablers needed for spectrum sharing in a specific frequency range, or more generally providing a frequency agile and coexistence/sharing friendly radio interface design. Depending on the network operators’ usage strategy, only a subset of the enablers might need to be implemented. Due to the different physical characteristics, enablers may vary for frequency bands below or above 6 GHz. The spectrum sharing enablers are:

- **Peer-to-peer Coordination Enablers** that enable spectrum utilization negotiations between operators for spectrum sharing between resource-compatible networks using the same coordination protocol. This logical connection can have different physical realizations (e.g. over-the-air, via the core network, etc.).

- **Horizontal Spectrum Manager (HSM) Enablers** that enable spectrum sharing through the use of a centralized HSM, which is responsible for resource assignments to networks with equal priority. The HSM assigns a particular resource exclusively, i.e. to one spectrum user only.
- **Sensing and Dynamic Frequency/Channel Selection (DFS/DCS) Enablers** that enable a distributed way of sharing spectrum, each individual device detects the presence of others (e.g. through measurements of received signal strength), and avoids using the same radio resource by either waiting until the medium is vacated or by jumping to another frequency channel.
- **Geo-Location Data-Base (GLDB) Support Enablers** that provide a centralized solution for vertical sharing between networks with different regulatory priority, i.e. use of spectrum resources is facilitated while ensuring that higher regulatory priority usages remain unaffected.
- **Wi-Fi Sharing Mode Enablers** that provide procedures for mobile operators using bands with general authorisation status, i.e. in particular to enable the use of the same frequencies as used by Wi-Fi systems, while maintaining appropriate spectrum access opportunity for Wi-Fi as well.

A detailed description of the enablers and examples for the applicability of the spectrum toolbox in different usage scenarios can be found in [MET14-D53] and [MET15-D54].

7 Architecture

The diversity of 5G use cases necessarily requires a 5G architecture which is more flexible and less expensive to deploy and operate than the current 4G architecture. Novel paradigms, such as Software Defined Networking (SDN) [KRV+14; BDS+14] and Network Function Virtualization (NFV) [ETSI-NFV; 4GA14b], coupled with advances in computing and storage provide an opportunity for a radical rethinking of 5G architecture design [EBZ+14; AIS+14].

Most significant 5G architecture key elements are:

- Focus on Network Functions (NFs), rather than network entities/nodes – define functions, which can be implemented and applied where needed.
- Separation of C- and U-Plane; separation of SW and HW, where feasible.
- Adaptation to use cases – not all NFs need to be used for different use cases. Functions can have variants, tailored for different use cases.
- Interfaces between NFs, rather than between network entities, aiming to achieve flexibility and avoiding further complexity. In this context interfaces not necessarily have to be protocols, but rather Application Programming Interfaces (APIs), which reduce the associated specification work.

The METIS 5G architecture development approach, also envisioned in a comparable way by other organisations like the NGMN Alliance [NGMN15] and ARIB [ARIB14], is driven by three key aspects: flexibility, scalability, and service-oriented management. The logical orchestration and control architecture [MET15-D6.4] (see Figure 7.1 for a high-level view) will provide the necessary flexibility for realizing efficient integration and cooperation of NFs according to the individual service needs as well as future evolution of existing cellular and wireless networks [NGMN15; ARIB14; 4GA14a].

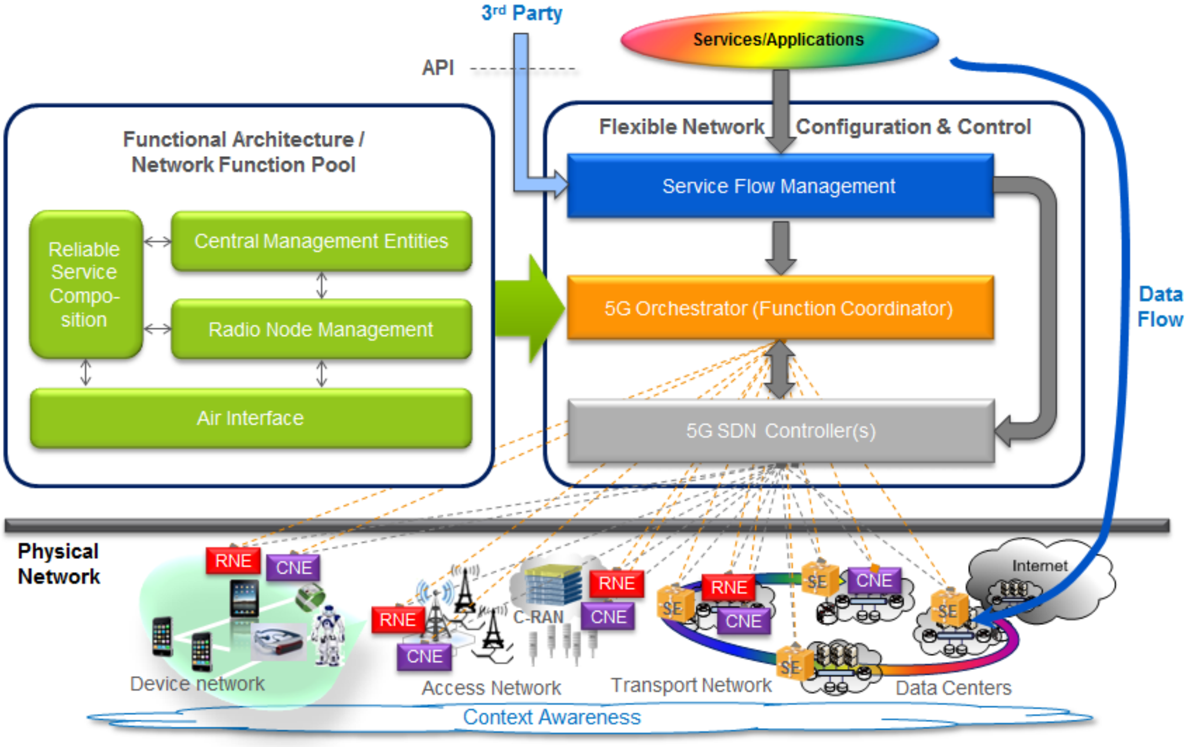

Figure 7.1: Logical orchestration and control architecture with included network function pool related to main building blocks of the functional architecture.

NFs derived by functional decomposition of most relevant METIS TeCs [MET15-D64] can be mapped to 4 main building blocks (BBs) identified from functional architecture point of view as illustrated in Figure 7.1 as part of the logical orchestration and control architecture:

- Central Management Entities (CMEs), covering overarching NFs which are not specific for certain use cases/scenarios. Typical examples are Context Management and Spectrum Management. The corresponding NFs are usually more centrally arranged. However, depending on the use case, a partially distributed realization might be possible, as well.
- Radio Node Management (RNM), providing radio NFs that usually affect more than one radio node. Exemplary functions are Long-/Short-Term Radio Resource and Interference Management, Mobility Management, Radio Node Clustering and (De-) Activation, and D2D Device Discovery and Mode Selection. In principle those NFs will be deployed at medium network layers (e.g. at dedicated C-RAN nodes [RBD+14]).
- Air Interface, including air interface related functionalities of radio nodes and devices. It comprises common NFs as well as NFs that are 5G service-specific. Examples are air interface enablers for xMBB (e.g. for UDN deployment) or for different types of mMTC applications.
- Reliable Service Composition (RSC), representing a central C-Plane functionality with interfaces to all other main BBs. It is used for availability evaluation and/or provisioning of ultra-reliable radio links which can be applied for novel service types requiring extremely high reliabilities in message data transfer and/or extreme low latencies (e.g. industrial environments, eHealth, or V2X communication).

A detailed description of the BBs as well as of derived NFs can be found in [MET15-D6.4]. It has to be noted that METIS is primarily focusing on the RAN part of the 5G network, so not all components required to finally build and operate a 5G system are covered with those BBs.

The NFs are flexibly deployed and instantiated by the 5G Orchestrator (Function Coordinator) which covers the ETSI NFV-MANO (Management and Orchestration) framework [ETSI14-MO] as well as extensions by service-oriented function processing and topology managers (for details see [MET15-D64]). The 5G Orchestrator is responsible for managing all NFs (virtualized as well as non-virtualized) of the 5G network including radio, core and service layer by mapping logical topologies of C-/U-Planes to physical resources in the network infrastructure dependent on corresponding logical topologies for each service.

The Service Flow Management is analysing the customer-demanded services and outlining their requirements for data flows through the network infrastructure. These requirements are communicated to 5G Orchestrator and 5G SDN Controller. Application/service requirements (e.g. from a 3rd party service provider), like maximum delay and/or minimum bandwidth on data flow path, can be taken into account through dedicated APIs. The architecture enables on-demand set-up of customized Virtual Networks (VNs) using shared resource pools and allowing effective service-adaptive decoupling of C- and U-Plane in order to optimize routing and mobility management across the whole service transport chain.

Radio Network Elements (RNEs) and Core Network Elements (CNEs) in the orchestration and control architecture are logical nodes that are specified having in mind the possibility to be implemented on different SW/HW platforms (both virtualized and non-virtualized). The 5G Orchestrator is interfacing with RNEs and CNEs to perform their configurations according to service requirements, also known as service orchestration. In terms of the communication between different RNEs (including wireless devices), flexible protocol functionalities and properly configured air interface variants will co-exist by applying varying radio-related NFs customized within VN slices according to requirements of target services and associated 5G use cases.

It is expected that, increasingly, the HW platforms designed to run RNEs are capable of supporting NFV to a certain extent, but especially low-cost equipment – such as small cell nodes for UDN – will probably be realized without or with still limited NFV capabilities due to cost reasons. In contrast, CNE-related computing platforms allow fully flexible deployment of NFs based on virtualization concepts, which is already happening today in 4G systems [4GA14b]. Thanks to the anticipated 5G flexibility, certain core-related functionalities can also be moved to same physical nodes, where RNEs are implemented (e.g. deploying Authentication, Authorization and Accounting, and mobility management functions in a C-RAN environment to reduce the service latency).

The 5G SDN Controller is finally setting up the service chain on the physical network infrastructure taking into account the configurations orchestrated by the 5G Orchestrator. The 5G SDN Controller (implementation as Virtualized Network Functions (VNFs) is also possible) then constructs the U-Plane processing for the data flow, i.e. it builds up the connections for the service chain of CNEs and RNEs in the physical network. Accordingly, it configures the Switching Elements (SEs) (e.g. utilizing OpenFlow [ONF12]) taking furthermore care of more radio-related functionalities, e.g. of the mobility management and steering of data flows in case of multi-connectivity.

The flexibility is restricted by limitations of physical network elements, but also by pre-coded accelerators implemented in certain nodes, e.g. hard-coded physical layer procedures in order to minimize processing delay and energy consumption. Those node capabilities are reported by RNEs and CNEs and are taken into account by the 5G Orchestrator.

With the flexible architecture in principle NFs can be deployed at arbitrary nodes, but finally, it strongly depends on the underlying service/use case requirements. Important requirements include latency and throughput on the input and output interfaces, time synchronicity (e.g. on radio time slot level) and scaling of processing (e.g. relation to U-Plane throughput). The exact deployments will depend on varying 5G service requirements and scenarios to be considered as well as on distance ranges between nodes and respective latencies which again are also dependent on transport network transmission technology applied (e.g. fibre, wireless back-/front-haul).

Results of detailed investigations of different architecture options including related functional deployment combinations based on a reference network can be found in [MET15-D64].

8 Assessment of METIS goal fulfilment

In this section we assess the fulfilment of the METIS technical goals based on the simulation results of the evaluation of the twelve METIS test cases [MET15-D65].

8.1 5G system evaluation performed in METIS

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

[MET13-D61] provided simulation guidelines to align assumptions, methodology and simulation reference cases in order to allow for a direct comparison of different technology components. This was to address the need of guaranteeing valid simulation results for the evaluation of the METIS concept at the last phase of the project. In order to ensure consistency of results, a procedure for calibration, guidelines for simulation and a mechanism to support and control the validity for the simulations performed in the technical work within the project was set up.

Partners involved in the technical research used these guidelines in their performance evaluations, resulting in already-valid results ready for the benchmarking process. This allowed for the initial design of the system and the identification of promising techniques. Note that most of results provided in METIS final deliverables (see [MET15-D24; MET15-D33; MET15-D43; MET15-D54]) follow the assumptions and guidelines defined in METIS, which at the end resulted in great collaboration between partners.

In a second phase, METIS performed full-system simulations necessary to support the 5G system design. These system evaluations were split into two different parts, focusing first on the Horizontal Topic (HT) impact and afterwards on the METIS 5G system performance in the set of twelve test cases defined in METIS [MET13-D11]. By specifically focusing on HTs at the beginning, it was possible to stimulate and identify novel 5G-specific concepts and techniques that complement and extend the performance of mature elements of existing systems, as well as emerging system concepts expected to mature in the 5G timeframe.

Evaluation assumptions and results are summarized in [MET14-D63]. Following the guidelines described in [MET13-D61], an analysis was made to assess the impact of the different HTs on the METIS goals. Results permitted drawing very interesting conclusions, as for instance that the efficiency in the air interface must improve by a factor of 4-5 as compared with LTE Release 8 in Single-Input Multiple-Output (SIMO) mode, to keep the needs of bandwidth within the margin of 10 times the available spectrum. Moreover, D2D communications are a key pillar to reduce latency in the evolution towards 5G. Furthermore, in D6.3 we demonstrated that it is not feasible to reach the objectives of latency without a significant change in the system architecture.

These intermediate simulation results, together with the self-evaluation performed by technical WPs 2–5, provided the basis for the selection of TeCs in METIS to achieve the best system performance. These TeCs mostly contribute to the third category of 5G features defined in Section 2.2, namely novel-5G specific concepts. After this selection, and using the metrics defined by WP1, full system evaluations were carried out to quantify the impact of the selected technology components on all the twelve test cases. Deliverable D6.5 [MET15-D65] studied the extent to which the METIS 5G system concept was able to achieve the METIS technical objectives. To this end, the novel 5G-specific features of the METIS 5G system concept were evaluated putting together more than forty TeCs. The main findings of this huge simulation effort have allowed us to identify and quantify, under certain assumptions, the potential impact of some fundamental technology enablers of the 5G mobile and wireless communication system.

8.2 Potential impact on the METIS technical objectives

This section highlights the potential impact of relevant technology enablers identified in the METIS system concept that contribute to the fulfilment of the METIS technical goals. The observations and initial conclusions highlighted are based on the specific setup and simulation assumptions used in evaluating the twelve test cases, as detailed in [MET15-D65], and the baseline technology assumptions. In particular, the baseline assumed in evaluating test cases where a cellular-based technology is applicable is a 3GPP LTE Release 8 system with 20 MHz of available bandwidth in 2.6 GHz, 4x2 MIMO, and conventional macro/micro deployment assumptions. LTE Release 8 was the technology baseline in mind when the METIS goals were specified. Specific applicable baseline systems, as detailed in [MET15-D65], are employed in evaluating test cases where a cellular-based technology is neither applicable nor appropriate. Thus, changes in the specific evaluation setup as well as the baseline systems may lead to different conclusions, especially with regards to the quantitative numbers provided here. Nevertheless, these initial observations provide important hints about the potential impact of different technology enablers on the future 5G system.

In general, more spectrum, higher spectral efficiency and reduced communication distance (e.g. network densification, local offload) are all important enablers to achieve METIS technical objectives such as 1000x throughput, 10 to 100x typical user data rates, 10 to 100x higher number of connected devices and 5x reduction in E2E latency. The rest of this section summarizes the potential impact of specific instances of the above enablers studied specifically within the scope of the METIS project.

8.2.1 Use of spectrum

By using the simulation setup described in [MET15-D65], spectrum bandwidths of at least 1500 MHz for indoor and 650 MHz for outdoor METIS 5G test cases described in [MET13-D11] are required to meet the respective demands. These figures assume best case scenario, i.e. maximum trunking efficiency (i.e. a single block of spectrum is available to all operators), no cost constraints on the level of possible densification and the presence and utilization of additional technology components that improve spectral efficiency. Thus, much higher bandwidths will be needed when these assumptions are relaxed.

Due to the favourable propagation conditions at lower frequency bands, it is expected that such frequencies will be used for providing ubiquitous coverage in outdoor environments. Given the limited contiguous bandwidths of spectrum in the lower frequency bands, it is expected that additional frequency bands in higher frequencies will be needed and used to provide additional capacity where required. Higher frequency bands face challenging propagation conditions, but could be suitable for use in outdoor hotspots (e.g. squares, campus, stadium, business districts, etc.), indoors (e.g. airports, fairs, malls, enterprise, home, etc.), or fixed wireless links between buildings and backhaul.

8.2.2 System densification

Densification is needed to fulfil the METIS 5G requirements. In the evaluation setup used, between 1 and 2.5 nodes per 100 square meters are needed indoors, depending on the available bandwidth and carrier frequency, whereas a single node for each 400 square meters suffices for outdoors under the conditions studied in [MET15-D65].

Concerning the impact of higher dense networks, it is worth noting that capacity is directly proportional to the number of nodes, provided centralized interference coordination. For indoor cases, the coefficient of proportionality could be as high as 0.73 with 1 node per 100 square meters [MET15-D65]. For outdoor, as compared with LTE Release 8, increasing the available bandwidth with additional 100 MHz and using three times more nodes, capacity could be boosted by a factor of 10 [MET15-D65]. As compared with the baseline deployment assumed, the levels of densification that we foresee in METIS are from 3 to 5 times. With such a level of densification, new paradigms and tools for network deployment will therefore be needed in order to cost-effectively deploy and manage such dense networks. For instance, nomadic nodes in vehicles could be one means to temporally increase the level of network densification.

8.2.3 Cell coordination

The relevance of cell coordination increases with densification. In particular, the evaluations demonstrate that the use of joint transmission techniques among adjacent nodes can realize significant performance gains.

If system is interference limited, the performance mostly in the cell border changes drastically with the use of joint transmission techniques. Proper clustering must be used, being it dynamic and sensitive of the level of isolation between transmitters. Within each cluster, one cell could work as controller, since centralized coordination outperforms full-distributed coordination.

Finally, results show that coordination without a reduction in the transmission time interval could damage average performance. In this sense, transmission intervals must be reduced down to a quarter of millisecond to make the most of such coordination.

8.2.4 D2D and V2X communications

Direct communications among nodes is one of the main drivers contributing to increased capacity, reduction in latency, and support for a massive number of devices. The evaluations performed in METIS show that when coupled with localized traffic offloading, D2D and V2X communications could increase the system capacity by a factor of two assuming an opportunistically shared spectrum [MET15-D13; MET15-D65].

Without any doubt, the introduction of this new paradigm of communication requires the network control to avoid some important issues, like interference management (hidden node problem), security and service announcement overhead.

One of the main impacts of this new direct communication channel is the reduction of the average latency, since it allows for latencies in the order of 1 to 2 ms. Network infrastructure is not involved in the data plane, which obviously improves the final transmission latency.

In any case, direct mode operation in critical situations requires optimal cluster head selections and energy saving techniques, as the ones proposed in METIS.

8.2.5 New waveforms and multiple-access schemes

5G will comprise a flexible set of radio waveforms (likely separated in different carriers). Three waveform candidates have been investigated in the evaluations performed, namely OFDM, FBMC, and UF-OFDM. For xMBB all waveform candidates achieve similar performance. Nevertheless, OFDM-based ones have a strong case due to its already wide-spread usage in current cellular networks [MET15-D24].

Moreover, new signalling procedures are to be implemented for mMTC, including the possibility of narrowband transmissions (much less than current 180 kHz) and the use of FBMC and SCMA as potential solutions to be explored in the future.

With FBMC, 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. On the other hand, SCMA allows for the implementation of more efficient open loop MU transmission, which can increase the efficiency by more than 50%. Moreover, the number of users multiplexed in the uplink can increase up to 10 times, which is very relevant for mMTC. The higher multi-user detection reliability of SCMA receiver reduces the time a device spends in active mode, thus helping to conserve energy.

Finally, with FBMC, uplink synchronization needs can be relaxed, thus reducing access time and removing timing advance procedures [MET15-D13].

8.2.6 Massive Machine Communications

According to the results in METIS (see [MET15-D65] for more details), narrowband transmission enabled with FBMC increases coverage by a factor up to 3, as compared with LTE Release 8, while increasing capacity by a factor up to 12. Moreover, the battery optimization techniques proposed in METIS can increase battery life by a factor of 20. On the other hand, the use of machine concentrators can increase capacity up to 200 times while increasing battery life twice. In this direction, clustering and cluster head identification affects a lot the performance of the system, which motivates the interest for further study.

8.2.7 Moving and nomadic 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 by 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, as detailed in [MET15-D65]. This results in better coverage or higher user throughput, mostly at the cell edge. Nomadic cells can also be used for out-of-band relaying so as to increase capacity in hotspots.

Moreover, battery is not a big issue for vehicles (switched on) as compared with smartphones, which opens the door for more active collaboration between cars and end-users. Note also that 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. In this sense, cmW and mmW bands can be used in the relay and access links. For the V2X communication in the case of nomadic nodes, the use of very directive two-dimensional antenna patches pointing towards several directions (doors, locker, and rooftop) is an important means to improve the link budget.

8.2.8 Massive MIMO

Massive MIMO must reach the 256x256 scheme to satisfy METIS 5G requirements. Spectral efficiency can be increased by a factor of 20 with this setup as compared with 4x4 antenna systems. Of course, we do not foresee 256 antenna elements in the handheld terminal. However, an equivalent 256 antenna receiver can be configured multiplexing with MU-MIMO 8 users, 32 antennas each. For the same spatial multiplexing capability as legacy systems (8 streams), beamforming gain reaches 15 dB [MET15-D33].

Form factor makes the use of Massive MIMO more attractive for cmW and mmW bands. This statement fits quite well together with our proposal of using higher frequencies above 6 GHz due to the reduced antenna size. Therefore, Massive MIMO use is mainly expected for wireless backhaul, indoor scenarios and hotspots (stadiums, concerts, malls) provided the LoS condition.

The C-RAN concept is also highly related with the flexible definition of Massive MIMO transmission schemes. If an optical fibre distribution system connecting several infrastructure nodes is available, this could form a virtual distributed array with massive antenna availability.

8.2.9 Wireless backhaul

According to our evaluations, the benefits of wireless backhaul depend on the environment and the traffic profile of the intended use case. In indoor environments, wireless backhaul always provides capacity benefits in the uplink direction of the access link, but on the contrary reduces the downlink capacity [MET15-D65]. However, this is a good solution for outdoor environments in which LoS conditions apply by using frequency bands above 6 GHz. Moreover, solutions for wireless backhauling are needed to support moving/nomadic nodes. In any case, further research is necessary to explore TDD multi-flow coordination schemes to avoid bottlenecks in the downlink backhaul.

8.2.10 Localized traffic flows

According to METIS results, with a dedicated bandwidth of 80 MHz used for D2D link, the end-to-end latency is reduced to 60 %, as compared with current LTE Release 8 system and using the same Transmission Time Interval (TTI) and assumptions detailed in [MET15-D65]. Moreover, half of the traffic can be offloaded from the cellular system.

The use of localized traffic flows is simple to implement and can be easily integrated into current networks. We foresee a very relevant application of such techniques in small cells, moving networks and D2D scenarios. This will be also of paramount relevance in MMC concentrators to reduce potentially duplicated information from sensors.

8.2.11 Summary of the study on the impact

Figure 8.1 summarizes the main enablers of the METIS 5G system concept, where the specific evaluation setup and assumptions are described in [MET15-D65]. Table 8.1 quantifies the foreseen improvement realized through the use of each of these techniques under the METIS evaluation framework and assumptions discussed in [MET13-D61; MET14-D63; MET15-D65].

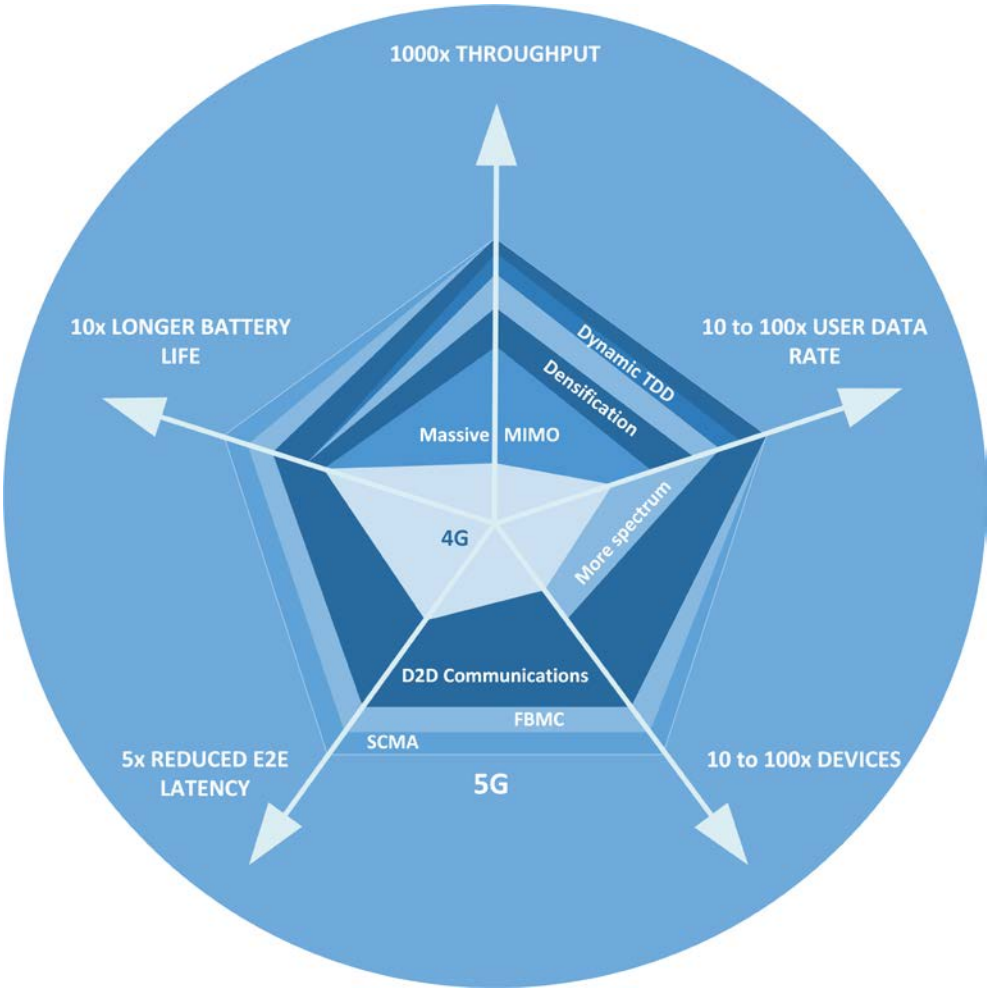

Figure 8.1: Main enablers to fulfil METIS goals represented by the pentagon. 4G refers to LTE Release 8 system with 20MHz bandwidth operating at 2.6 GHz, using 4x2 MIMO setup and 3 sectors per macro site.

Table 8.1: Summary of the impact of the most promising techniques contributing to the fulfilment of the METIS goals. The baseline system is an LTE Release 8 system with 20 MHz bandwidth operating at 2.6 GHz, 4x2 MIMO, 3 sectors per macro site.

METIS Goal	Most promising techniques	Impact
1000x throughput	Sufficient spectrum, including additional bandwidth from new spectrum bands. This spectrum needs range from 2350 MHz, assuming no cost constraints on the level of densification, up to 8600 MHz, assuming the same level of densification as today.	x 3.40 (assuming 693 MHz of spectrum availability today)
	Densification of the system and use of distributed radio heads. Number of nodes 3-5 times the number of nodes we have today.	x 3.65
	More prominent use of TDD mode in a dynamic manner	x 1.67
	Coordination among cells with reduced TTI	x 1.21
	Massive MIMO with 256x256 antenna elements	x 20
	D2D and localized traffic flows	x 2
	≈ 1000 times achieved	
10 to 100x end typical user data rate	Sufficient spectrum, including additional bandwidth from new spectrum bands. This spectrum needs are higher than 2150 MHz	x 3.10 (assuming 693 MHz of spectrum availability today)
	Shorter transmission distances with D2D and denser deployments, reducing the transmission distance down to 10 m	x 4
	More prominent use of TDD mode in a dynamic manner	x 1.67
	Massive MIMO, with 32 antenna elements in each UE	x 2.50
	≈ 50 times achieved	
10 to 100x higher number of connected devices	Flexible use of different radio interfaces. Implementation of specific transmission schemes in dedicated carriers for MTC	Enabler
	FBMC or similar with narrowband transmission	x 12 (DL)
	SCMA multiple access scheme	x 10 (UL)
	Traffic concentration	x 200
	Sufficient spectrum, including additional bandwidth from new spectrum bands. At least 200 MHz required.	Enabler
	Efficient signalling to reduce the overhead of MMC	Enabler
	≈ 2000 times achieved	
10x longer battery life for low power MMC devices	Efficient signalling	x 20
	FBMC	x 1.20
	SCMA	x 1.50
	Shorter transmission distance with traffic concentrators	x 2
	≈ 70 times achieved	
5x reduced E2E latency	D2D communication with localized traffic flows	x 3
	Reduced TTI and retransmission processes	x 1.80
	Better QoS differentiation	Enabler
	Optimized architecture	Enabler
	New waveforms, e.g. FBMC and/or SCMA	Enabler
	≈ 5 times achieved	

9 Technology roadmap for 5G

The purpose of this section is to describe a Technology Roadmap for the continued evolution of mobile and wireless systems towards a deployed 5G system beyond 2020. The roadmap reflects the final outcome of the METIS project and addresses the next steps to be taken. We first describe the overall 5G timeline, then address the maturity of different METIS TeCs, and finally identify topics for further research.

This Technology Roadmap is aligned with relevant time plans of regulation and standardisation organisations as known so far as well as with further R&D activities on 5G.

9.1 Overall 5G timeline

The overall 5G timeline should consider the development of requirements, regulatory processes, standardisation approaches, and intended deployment objectives for 5G. Different sources were taken into account and aligned to establish an overall 5G timeline in METIS. The results from these investigations are summarized in Figure 9.1, and explained in detail in the following. This timeline serves as base for the elaboration of the METIS technology roadmap explained in detail in Section 9.2.

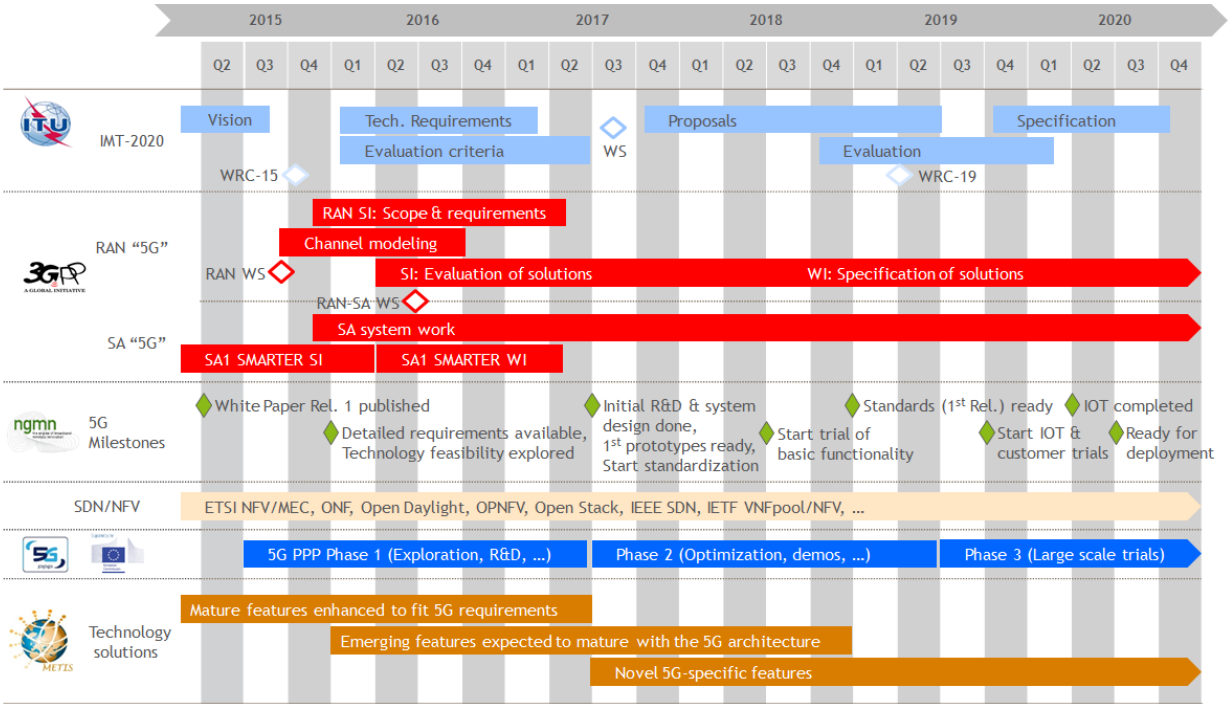

Figure 9.1: Overall 5G timeline including METIS technology roadmap.

A 5G roadmap was issued by the NGMN Alliance, the worldwide operators' community, in their recent White Paper [NGMN15]. It includes a set of relevant milestones beginning with the finalization of 5G requirement analysis end of 2015 until system readiness for commercial deployment mid of 2020. This roadmap is considered in the 5G timeline in Figure 9.1.

In the regulatory domain, ITU-R is currently working on an IMT Vision document to be finalized in June 2015 [ITU-R]. Based on this vision and identified technology trends [ITU-R14], it is planned that ITU-R WP 5D will formalize the requirements in a set of key capabilities for an IMT-2020 system until the beginning of 2017. These are then the requirements a system proposal should meet to be called 5G. The ITU-R timeline including also the proposal evaluation process is included in Figure 9.1.

3GPP is foreseen to be the main 5G standardisation body, in particular for mMTC and xMBB and services tightly coupled to xMBB. For mMTC the first steps have already been taken for LTE in 3GPP Rel-12 and Rel-13, and work is also ongoing in GERAN. xMBB extends the capabilities of today's MBB in terms of supported data rates and frequency ranges, and adds new features including increased reliability. The first standardisation task should be to develop the 3GPP design targets and requirements based on the ITU-R vision document as well as the NGMN White Paper as guidance. The 3GPP RAN and SA plans addressing regulation recommendations from the ITU-R WP 5D [ITU-R15] are given in [3GPP15] and summarized in Figure 9.1.

As 5G system features go beyond those addressed so far by 3GPP, additional standardisation development organisations and industry forums will be involved in the final process, especially addressing SDN and NFV (ETSI, IETF, ONF, IEEE, ITU-T, etc.) [MET15-D64]. Furthermore, the general 5G timeline is also impacted by future R&D activities of 5G PPP funded by the EU as described in [5GPPP15]. These activities are also indicated in Figure 9.1.

5G systems will be introduced gradually. There will be a need for more capacity and shorter latency below 6 GHz. LTE will continue to evolve in a backwards-compatible way and will be an important part of overall the 5G wireless access for frequency bands below 6 GHz. Around 2020, there will be massive deployments of LTE providing services to an enormous number of users and devices in these bands. Additionally, evolved versions of LTE are expected to play a vital role in the wide-area coverage, e.g. reliable moderate rates for xMBB and mMTC (MMC-D). In parallel, there will be new 5G RAT without backwards-compatibility constraints targeting spectrum above 6 GHz as well as new spectrum below 6 GHz for new use cases, e.g. mMTC and uMTC (V2X).

There is a common understanding that the solutions need to support many different types of deployments and services, e.g. through the introduction of SDN and NFV [MET15-D64]. For that reason, 5G systems will be built to enable logical network slices, which will enable operators to provide networks on an as-a-service basis and meet the wide range of use cases that the 2020 timeframe will demand. The flexibility of the 5G radio architecture, the flexibility to link functional building blocks and technology components depending on the service requirements may introduce new logical and physical interfaces. Therefore, standardisation actions ensuring technology interoperability will continue to play an important role even for 5G systems. From vendor perspective interoperability testing procedures needs to be standardised and implemented in a very efficient way in order to keep the cost at a reasonable level.

Since 5G will include verticals and new application areas as considered by the METIS use cases [MET15-D15] and the METIS system concept described in the previous sections, some 5G components may be standardised by other organizations than 3GPP, e.g. ISO, CEN, and ETSI [TDF+14].

One example is the concept of the connected car, which enables new services and functionalities for the automotive industry based on wireless communications, in particular cellular systems since they provide the wide area coverage and performance demanded by automotive applications. However, to gain widespread acceptance, 5G systems must comply with the stringent requirements on latency, reliability, and high mobility even in non-urban areas with its sparse deployment of infrastructure.

Another example is given by the Cooperative Intelligent Transport Systems (C-ITS) where ETSI, CEN and ISO are developing specifications together as e.g. the joint work between ISO TC204 WG18 and CEN TC278 WG16 [ISO]. There is also a global cooperation with IEEE and SAE International standardisation. In addition to radio interfaces, information models and some architecture for C-ITS need to be standardised as well.

9.2 METIS technology roadmap

Section 3 of this document indicates the classification used in the project for 5G features in wireless systems in "Mature features enhanced to fit 5G requirements", "Emerging features expected to mature with the 5G architecture," and "Novel 5G-specific features", which indicates a timeframe for introduction of these technology components in the overall 5G timeline established in Section 9.1.

These 5G features are built on the TeCs developed by the project and included in the system concept. A comprehensive analysis has been conducted from the architecture point of view as documented in Annex 8 of [MET15-D64] showing their complementarities and dependencies as well as their decomposition into functional elements and network functions, respectively. Furthermore the TeCs selected for specific novel 5G-specific features in the METIS system concept have been evaluated towards the METIS goals (see Section 8) and are further described in Annex B of [MET15-D65]. The outcome of these investigations together with the final evaluation results of the TeCs in the relevant WPs of the project [MET15-D24; MET15-D33; MET15-D43; MET15-D54] give the opportunity for a more detailed classification introduced above as shown in the following. Table 9.1 lists the TeCs that have been studied in METIS and classifies them into evolutionary or novel 5G-specific. To avoid a breakdown to the greatest detail in Table 9.1, the TeCs are partly collected together in higher-level solutions where feasible. Detailed information if a single TeC is seen as evolutionary from LTE-A perspective (Rel. 11 as reference) or if it requires a revolutionary approach to be implemented can be found in the deliverables listed above.

Table 9.1: METIS technologies and solutions.

Technologies and solutions	Evolution of LTE-A	Novel 5G-specific
Air interface for dense cell deployments		For higher frequency bands based on new numerology and design principles for flexibility in the OFDM scheme and the transmission framing.
Air Interface for moving networks		Attempting to achieve ultra-reliable data transmission between vehicles.
Optimized signalling for low-cost MMC devices	Some hybrid access schemes can be seen as emerging, evolutionary approach for LTE-A.	Complex schemes require changes in the system design to add e.g. MMC-D2D functionalities.
Multiple air interface management		Allowing increased flexibility for the choice of a dedicated air interface or for multi-flow transmissions via different air interfaces based on SW-configurable PHY layers and protocol stacks.
Filtered multi-carrier schemes (FBMC, UF-OFDM, etc.)		FBMC requires redesign of air interface and corresponding signalling procedures. UF-OFDM can be efficiently combined with new MMC schemes.
New modulation and coding concepts	Derived enablers are primarily seen as evolutionary w.r.t. LTE-A.	
Advanced transceiver designs (Full duplex, etc.)		Schemes like full duplex transmission / reception are novel features.
Non- and quasi-orthogonal multiple access (NOMA, SCMA, etc.)	Both access schemes can be applied in principle on top of LTE-A, so they are definitely evolutionary ones, but can also be applied in a revolutionary way with other air interface schemes/waveforms.	
New MAC schemes (contention based massive access, etc.)	Proposed schemes can be evolutionary extensions with LTE PRACH resource usage, but require changes in higher layer connection and message handling. Therefore, also revolutionary approaches are possible.	
Enhanced Hybrid Automatic Repeat Request (HARQ) schemes	Proposed schemes follow evolutionary approaches by extension of procedures applied in LTE-A, but addressing also novel 5G-specific handling by addition of feedback mechanism with backtrack decoding.	
Multi-antenna / Massive MIMO		Approaches considered require major changes in LTE-A. In addition Massive MIMO is especially foreseen for frequency bands above 6 GHz.
Advanced inter-node coordination / CoMP	The schemes addressed are primarily evolutionary as compared to LTE-A only minor extensions are required.	
Improved receivers for interference handling		Requiring new functionalities on the radio node side as well as in the UE.
Coordinated wireless backhaul		In UDNs in combination with joint usage of mmW bands for access requires new approaches (e.g. interference aware routing and resource allocation).

Technologies and solutions	Evolution of LTE-A	Novel 5G-specific
Relaying (mobile relaying, network coding, etc.)	Both evolutionary and revolutionary approaches for relaying have been derived within METIS, considering also incorporation of devices as relays and applying D2D features.	
Interference management and resource allocation schemes		Schemes proposed are e.g. online learning algorithm estimating path-loss characteristics, resource partitioning between BSs using resource auctioning and regret-matching learning, and scheduling approaches for more than one cell.
D2D and V2X mechanisms	Enablers for D2D mode selection and D2D power control are re-using or extending mechanisms.	Corresponding enablers are for example a unified solution for device discovery with new cluster based or device-centric approaches, and D2D resource allocation schemes supporting V2X.
Mobility management and context awareness approaches	Enhancements of existing schemes are e.g. context aware handover optimisation, D2D handover reducing signalling overhead, and context aware scheduling.	Optimised distribution scheme for context information requiring new interfaces/channels for the exchange of context information or context information building using data mining techniques for which new network entities/functions are necessary.
Dynamic reconfiguration enablers	New management interface between the operator and the service provider or the clustering toolbox.	Enablers for dynamic management of nomadic nodes/cells requiring new equipment and entities.
	UDN enablers cover evolutionary (de-)activation of small cells as well as revolutionary control/user plane design.	
Flexible spectrum usage		Proposed enablers require new entities (e.g. a spectrum controller) within the operator's network.

9.3 Future work

The work conducted in the METIS project is part of a long-term vision consisting of three phases: the exploratory phase, the optimization and trial phase, and the implementation phase. METIS has been a part of the exploratory phase, and developed a basic 5G system concept build on the TeCs developed by the WPs, including the architecture (see previous chapters). The optimization and trial phase will focus on system refinement, demonstration of key technology components and system concept. The third implementation phase covers pre-commercial trial conducted by vendors and operators.

Though METIS has taken a comprehensive approach, there are some necessary areas that have not been possible to address in the scope of METIS. Therefore, the optimization and trial phase should address both system refinement, and topics not covered in METIS, e.g. security, positioning, and lawful interception related to D2D.

As wireless systems become an integral part of society, the security issue becomes more central. The generic services have different security aspects that must be addressed. As xMBB will be increasingly used for e.g. cloud service, the vulnerability to attacks and the cost damage caused by e.g. denial-of-service attacks [YW12] will increase. mMTC will transport large amounts of data in the IoT, which by themselves may not be very sensitive, but the data- and/or information-fusion may extract sensitive knowledge. For uMTC services, it is important to guarantee the integrity and authenticity of the transmitted information. As a nomadic node offers it services as a temporary access node in a Dynamic RAN, a trust must be established between the anchor node (base station) and the nomadic node to avoid man-in-the-middle attacks [FSK10].

Accurate positioning is either necessary or improves the QoE in several applications, e.g. C-ITS, D2D services and proximity-based services. For outdoors applications, positioning based on Global Navigation Satellite Systems (GNSS) can be used. For indoors applications, GNSS-based positioning does not work in general, and the position must be established by other means. For C-ITS application wireless communication positioning can assist and/or replace GNSS-based positioning. Positioning is outside the scope of METIS but should be considered as additional services are enabled and value created by adding positioning.

In addition to topics not covered by METIS, there are topics that need refinement before they are mature enough to take to standardisation, such as the 5G system architecture and the LSCP. Additionally, integration of 5G with existing RATs to ensure seamless and reliable interworking between them has to be elaborated more. Adding functions for security and lawful interception implies an update to the architecture and protocols. Currently, there are alternative TeC candidates to implement certain functions and the set of air interfaces has not been determined. The air interface(s) affect both the architecture and the design of the LSCP. Therefore it is expected that further refinements of the LSCP will happen in future research.

Based on this, a number of research areas have been identified:

- Wireless system design to design a 5G wireless system that efficiently meets the large variety of use cases and application requirements beyond 2020, and builds upon a smooth migration from current technology.
- Air interface design for multi-service and multi-bands to address flexible and adaptable air interfaces able to efficiently support a multitude of service classes, device types, and spectrum bands for access, backhaul and front-haul.
- Access, front-haul and backhaul integration for convergence of technologies and management methods of heterogeneous technologies.
- 5G architecture providing a highly flexible support of a multitude of diverse services, including broadcast and multicast services, considering different fixed-mobile-convergence scenarios and SDN and NFV principles.
- Efficient Hardware/Software and Platforms for 5G network elements and devices with respect to e.g. hardware/software complexity, energy consumption, latency, radio technology, and multi-RAT implementations for different kinds of platforms.
- 5G Network Security and Integrity to identify 5G network-specific vulnerabilities, and development of solutions to overcome the security and vulnerability threats.

In Europe, the necessary research work will be done in the framework of the ICT-Leadership in Enabling and Industrial Technologies Work Programme under H2020 [EC-H2020].

The research projects under H2020 will be smaller in scope than previous framework programmes (METIS is conducted under Framework Programme 7, FP7). To meet the 5G-infrastructure-PPP impact and objectives, a coordinated set of projects working together will be necessary [5GPPP14b]. Coordination between projects will be paramount for success.

To this end, a pre-structuring model has been developed to cover the full breadth of the call and to ensure that no critical elements of the 5G system are overlooked, while not excluding other topics that still may be suggested in the future [5GPPP14a].

The pre-structuring model contains four strands:

- Strand 1: Radio network architecture & technologies
- Strand 2: Convergence beyond last mile
- Strand 3: Network management
- Strand 4: Network Visualization and Software Networks

Strand 1 “Radio network architecture & technologies” is the most relevant for continuing the METIS work, but projects in other strands may also develop certain TeCs. Strand 1 consists of seven project areas, addressing the topics described above[5] [5GPPP14a].

The exact mapping of the METIS results into the different projects will be further developed can be done in collaboration with the project coordinators when the set of approved projects is known.

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[5] Note that the submitted project proposals must not necessarily have the same objectives or address all objectives of a project area.

10 Conclusion and outlook

METIS started by defining five scenarios that captures the challenges for mobile networks beyond 2020, also known as 5G networks. These five scenarios were concretized in twelve different test cases that provide a sample of an uncountable number of possible uses of mobile communication in the future. A techno-economical trade-off analysis on what to include in the future 5G system is still to be made. For each of the twelve test cases, a number of performance requirements that a system needs to meet was extracted. The first conclusion is that the 5G system must be flexible enough to address highly diverse requirements and also provide a platform to address hitherto unforeseen uses of mobile communication.

Based on the scenarios, the technical work packages conducted research into a large number of technology components. The research results were sifted through five horizontal topics into the overall METIS 5G system concept described in this deliverable. The system concept consists of three generic 5G services, four main enablers, and a supporting system architecture providing the necessary flexibility. Simulations of the twelve test cases and aggregation of the results lead us to the second conclusion that it is indeed possible to design a 5G system concept that meets the requirements of each test case as well as the technical objectives.

The foundation and framework of the 5G system was laid by METIS but the detailed design of the 5G system still remains. Though the direction is clear, significant work remains before 5G systems can be deployed. There are a number of areas that need attention, for instance; refinement of the system concept and technology component selection, adaptation to developments in specification, regulations and standardisation activities, system-level simulation and evaluation of the complete, refined system concept, and demonstration and validation in trials.

Finally we conclude that METIS has indeed laid the foundation for 5G systems. It is now up to new follow-up projects to complete the cathedral. We hope you will enjoy the journey as much as we have.

11 References

[3GPP15] 3GPP TDoc RP-150483 “Getting ready for 5G,” 3GPP TSG RAN #67 Shanghai (China), March 2015.

[4GA14a] 4G Americas, “Recommendations on 5G Requirements and Solutions,” White Paper, October 2014.

[4GA14b] 4G Americas, “Bringing Network Function Virtualization to LTE,” White Paper, November 2014.

[5GPPP14a] 5G-PPP “EC H2020 5G Infrastructure PPP Pre-structuring Model RTD & INNO Strands,” Version 2.0, March 2014. http://5g-ppp.eu/wp-content/uploads/2014/03/5G-Infra-PPP_Pre-structuring-Model_v2.0.pdf

[5GPPP14b] 5G-PPP, “A Pre-structuring proposal based on the H2020 Work Programme.” http://5g-ppp.eu/coverage-plans/

[5GPPP15] 5G-PPP “5G Vision,” Version 1.0, March 2015.

[AIS+14] P. Agyapong, M. Iwamura, D. Staehle, W. Kiess, and A. Benjebbour, “Design considerations for a 5G network architecture,” IEEE Commun. Mag., November 2014.

[ARIB14] ARIB 2020 and Beyond Ad Hoc Group, “Mobile Communications Systems for 2020 and beyond,” White Paper, V1.0.0, October 2014.

[5GNow] http://www.5gnow.eu/

[BDS+14] C. J. Bernados, A. De La Oliva, P. Serrano, A. Banchs, L. M. Contreras, H. Jin, and J. C. Zúñiga, “An architecture for software defined wireless networking,” IEEE Wireless Commun. Mag., June 2014.

[EAR12-D33] EARTH D3.3 “Final Report on Green Network Technologies,” *INFSO-ICT-247733 EARTH Deliverable 3.3, Version 1*, July 2012.

[EBZ+14] J. Eichinger, Ö. Bulakci, G. Zimmermann, P. Marsch, and H. Tullberg, “Building a New Multi-Facial Architecture of 5G,” IEEE MMTC E-Letter, September 2014.

[EC-H2020] Information and Communication Technologies, http://ec.europa.eu/programmes/horizon2020/en/h2020-section/information-and-communication-technologies

[ECC-DEC] ECC Decision of 14 March 2008 on the harmonised use of the 5875-5925 MHz frequency band for Intelligent Transport Systems (ITS), (ECC/DEC/(08)01), 2008.

[ETSI-NFV] ETSI Industry Network Functions Virtualisation Industry Specification Group (NFV ISG), Webpage with White Papers, Specifications, etc. http://www.etsi.org/technologies-clusters/technologies/nfv

[ETSI11-SRD] ETSI, “Technical characteristics for SRD equipment for wireless industrial applications using technologies different from Ultra-Wide Band (UWB),” TR 102 889-2 V1.1.1, Part 2, August 2011.

[ETSI14-MO] ETSI ISG NFV, “Network Functions Virtualisation (NFV); Management and Orchestration,” v1.1.1, December 2014.

[FOE14] P. Frenger, M. Olsson, and E. Eriksson, “A Clean Slate Radio Network Designed for Maximum Energy Performance,” Proc IEEE Annual International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC 2014), Washington DC, USA, September 2014.

[FSK10] N. Ferguson, B. Schneier, and T. Kohno, *Cryptography Engineering – Design Principles and Practical Applications*, Wiley, 2010.

[ISO] http://its-standards.info/

[ITU-R] ITU-R, “Recommendation Vision of IMT beyond 2020,” ITU-R WP 5D. http://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2020/

[ITU-R14] ITU-R, “Future technology trends of terrestrial IMT systems,” Report ITU-R M.2320-0, November 2014.

[ITU-R15] ITU-R WP 5D Chairman Report 21st meeting Auckland, Attachment 2.12, February 2015.

[KRV+14] D. Kreutz, F. Ramos, P. Verissimo, C. E. Rothenberg, S. Azodolmolky, and S. Uhlig, “Software-Defined Networking: A Comprehensive Survey,” Version 2.01, October 2014. http://arxiv.org/pdf/1406.0440.pdf

[MET13-D11] METIS D1.1 “Scenarios, requirements and KPIs for 5G mobile and wireless system,” *ICT-317669 METIS Deliverable 1.1, Version 1*, April 2013.

[MET15-D13] METIS D1.3 “Test-bed/demonstration results,” *ICT-317669 METIS Deliverable 1.3, Version 1*, April 2015.

[MET15-D15] METIS D1.5 “Updated scenarios, requirements and KPIs for 5G mobile and wireless system with recommendations for future investigations,” *ICT-317669 METIS Deliverable 1.5, Version 1*, April 2015.

[MET15-D24] METIS D2.4 “Proposed solutions for new radio access,” *ICT-317669 METIS Deliverable 2.4, Version 1*, February 2015.

[MET15-D33] METIS D3.3 “Final performance results and consolidated view on the most promising multi-node/multi-antenna transmission technologies,” *ICT-317669 METIS Deliverable 3.3, Version 1*, February 2015.

[MET15-D43] METIS D4.3 “Final report on network-level solutions,” *ICT-317669 METIS, Deliverable 4.3, Version 1*, February 2015.

[MET13-D51] METIS D5.1 “Intermediate description of the spectrum needs and usage principles,” *ICT-317669 METIS Deliverable 5.1, Version 1*, August 2013.

[MET14-D53] METIS D5.3 “Description of the spectrum needs and usage principles,” *ICT-317669 METIS Deliverable 5.3, Version 1*, August 2014.

[MET15-D54] METIS D5.4 “Future spectrum system concept,” *ICT-317669 METIS Deliverable 5.4, Version 1*, April 2015.

[MET13-D61] METIS D6.1 “Simulation guidelines,” *ICT-317669 METIS Deliverable 6.1, Version 1*, October 2013.

[MET14-D62] METIS D6.2 “Initial report on horizontal topics, first results and 5G system concept,*” ICT-317669 METIS Deliverable D6.2, Version 1*, April 2014.

[MET14-D63] METIS D6.3 “Intermediate system evaluation results,” *ICT-317669 METIS Deliverable D6.3, Version 1*, July 2014.

[MET15-D64] METIS D6.4 “Final report on Architecture,” *ICT-317669 METIS Deliverable 6.4, Version 2*, January 2015.

[MET15-D65] METIS D6.5 “Report on simulation results and evaluations,” *ICT-317669 METIS, Deliverable 6.5, Version 1*, February 2015.

[NGMN15] NGMN Alliance, “5G White Paper – Final Version,” White Paper, February 2015.

[RBD+14] P. Rost, C. J. Bernardos, A. De Domenico, M. Di Girolamo, M. Lalam, A. Maeder, D. Sabella, and D. Wübben, “Cloud Technologies for Flexible 5G Radio Access Networks,” IEEE Commun. Mag., May 2014.

[OCF+13] M. Olsson, C. Cavdar, P. Frenger, S. Tombaz, and R. Jantti, “5GrEEn: Towards Green 5G Mobile Networks,” Proc. IEEE Int. Conf. Wireless and Mobile Computing, Networking and Communications (WiMob 2013), October 2013.

[ONF12] “Software-Defined Networking: The New Norm for Networks,” Open Networking Foundation (ONF) White Papers, April 2012. https://www.opennetworking.org/index.php

[San12] C. B. Sankaran, "Data offloading techniques in 3GPP Rel-10 networks: A tutorial," IEEE Communications Magazine, vol.50, no.6, pp.46 – 53, June 2012.

[SCF13] Small Cell Forum, “Wireless in the Home and Office The need for both 3G femtocells and Wi-Fi access points,” Report 007.05.02, December 2013.

[TDF+14] H. Tullberg, H. Droste, M. Fallgren, P. Fertl, D. Gozalves-Serrano, E. Mohyeldin, O. Queseth, and Y. Selén, “METIS Research and Standardization – A path towards a 5G system,” Proc. IEEE Globecom, December 2014.

[UK-FAT13] UK Frequency Allocation Table 2013, Issue No. 17, 2013. http://stakeholders.ofcom.org.uk/binaries/spectrum/spectrum-information/UKFAT_2013.pdf

[YW12] D. Yu and W. Wen, “Non-access-stratum request attack in E-UTRAN,” in Computing, Communications and Applications Conference (ComComAp), pp. 48 – 53, January 2012.

Annex A

A. List of Technology Components

This annex contains a list of TeCs identified by the Horizontal Topic Drivers. Each TeCs listed here has been identified as a promising TeCs to contribute to meet one or more of the METIS technical objectives. The selections have been discussed with and feedback received from the WPs in an iterative process. Detailed descriptions of the TeC are found in [MET15-D24; MET15-D33; MET15-D43; MET15-D54] for WP2, WP3, WP4 and WP5, respectively.

A.1 WP2: Radio link concepts

- **T2.1-TeC1.1—1.3 – Air interface in dense deployments:** The TeC cluster provides a flexible air interface for ultra-dense network targeting gigabit mobile broadband communication for distances up to 200 m. The TeC provides the numerology for a unified frame structure with dynamic TDD and harmonised OFDM from 3GHz to 90GHz, cmW and mmW bands optimised with respect to spectral efficiency in the UDN context. The solution supports robust and fast control plane, fast network synchronization, and user plane latency is analysed showing ≈5 times reduction w.r.t. LTE-A. Multi-antenna techniques for spatial multiplexing and high-gain beamforming and high channel capacity can be achieved in the mmW band with a simple MRC receiver and very low transmission power, and a concept for initial beam-finding and beam tracking is included. The TeC cluster also includes mechanisms for switching on/off UDN nodes on demand and providing seamless mobility, and support for in-band wireless backhauling. Relevant for **xMBB**, **Dynamic RAN** and **Localized Contents and Traffic Flows**.
- **T2.1-TeC2.1 – MMC type D2D links**: This TeC controls the macro base station output power such that simultaneous transmission from both the base station and machine devices with low output power is possible, hence reusing radio resources. Relevant for **mMTC** and **Localized Contents and Traffic Flows**.
- **T2.1-TeC2.3 – Hybrid access scheme for reduced signalling overhead:** Steering of traffic with different characteristics (periodicity, predictability, etc.) between RA and pre-allocated resources to obtain gains in reduced overhead and capacity. Relevant for **mMTC**.
- **T2.1-TeC4.2 – Software Configurable Air Interface:** Software Configurable Air Interface is a framework concept that allows the adaptation of different air interface components to provide the flexibility in adapting the diverse characteristics of future applications. Relevant for **xMBB, mMTC** and **uMTC.**
- **T2.1-TeC6.1 – Framework for URC**: This TeC introduces a novel metric referred to as “Availability” that indicates the presence or absence of link reliability according to the application requirements. This availability indication plays an important role for the provision of URC communications, since it allows the system and even the applications to react properly and timely to the presence or absence of reliability in the communication link. Relevant for **xMBB** and **uMTC**.
- **T2.1-TeC6.2 – Modelling and predicting the reliability of a link**: This TeC aims at predicting the reliability of the communication link according the application requirements and based on the statistics of the propagation channel. The modelling and prediction of reliability is essential in order to determine the presence or absence of availability as defined in-TeC6.1. Relevant for **xMBB** and **uMTC**.
- **T2.1-TeC6.3 – Channel estimation for V2V links**: The TeC exploits the particularities of the V2V propagation channel in order to improve the channel estimation in V2V scenarios and achieve significant gains in terms of SNR compared to the state of the art. Because of the focus on V2V communication, the TeC is relevant to **uMTC**.

- **T2.1-TeC6.4 – Channel prediction**: This TeC exploits the presence of multiple antennas in vehicles, which are placed in a line along the longitudinal axis of the vehicle. In this manner, the first antenna can be used in order to predict the transmission channel of the other antennas behind it. This TeC has the potential to enable the use of Massive MIMO beamforming and CoMP techniques at vehicular velocities and is therefore relevant for **xMBB**.
- **T2.1-TeC6.5 – Ad-Hoc MAC for V2V**: This TeC investigates the use of Coded Slotted Aloha, particularized to broadcast transmissions with latency constraints, in order to enable ad-hoc D2D communication with better performance than CSMA schemes. As a result, the TeC is relevant to **uMTC**.
- **T2.2-TeC8.1 – FBMC**: FBMC has 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. 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 requirements posed by device and mobility classes. The adaptation between different speed classes is possible on a per sub-band level (e.g. a single Physical Resource Block in LTE terminology), enabling the system to be highly scalable. As a result of the improved robustness against signal distortions in high mobility scenarios including Doppler shift, the TeC is relevant for **xMBB** and **uMTC**. Furthermore, the waveform is also relevant for **Dynamic RAN**, since it provides additional flexibility and spectral efficiency in fragmented spectrum scenarios as well as for spectrum sharing including inter-operator sharing. The TeC is especially relevant for **mMTC** as they enable flexible scaling of the data rate and facilitate coexistence of multiple low-rate devices with high-rate devices.
- **T2.2-TeC8.2 – UF-OFDM**: This TeC addresses the same targets as FBMC as described above (T2.2-TeC8.1), but instead of filtering each single subcarrier, it applies a filter on sub-band level. Thus, it can maintain full compatibility with OFDM, enabling the reuse of almost all OFDM-based solutions. FBMC, on the contrary, introduces some changes in the signal structure and thus requires redesign of some signal processing procedures, but offers on the other hand maximum degrees of freedom for the system design. Key features of UF-OFDM are similar to those of FBMC in most of the cases, and hence its relevance similarly covers **xMBB**, **uMTC** and **mMTC**.
- **T2.2-TeC9.1 – Constrained envelope coded modulation**: Constrained envelope coded modulation is beneficial to support energy efficient, robust, and low cost transceivers. This TeC provides a precoded Single Carrier Frequency Division Multiple Access (SC-FDMA) scheme. This scheme is compatible with OFDM transceivers, and still controls the envelope variations, which is beneficial for efficient and low cost non-linear amplifiers. It is also robust to frequency selective fading and interference. Relevant to **mMTC**.
- **T2.2-TeC9.2.1 – Adaptive complexity flexible base band**: Iterative MIMO detection offers significant improvement in error-rate performance for a reduced SNR ratio at the cost of additional baseband complexity. This TeC investigates a flexible detector allows for the optimum selection between the executed algorithm and choice of the main parameters based on channel conditions and targeted performance. The TeC can improve the link performance by overcoming the influence of fast fading and improve robustness. Relevant for **xMBB** and **uMTC**.
- **T2.2-TeC9.2.2 – Practical lattice codes**: Lattice codes achieve the capacity of the AWGN channel, and this TeC investigated whether lattice codes are promising in

practice. In LTE, error correction and modulation are implemented separately through the popular BICM scheme. However, for short frame lengths, lattice codes can outperform BICM from the perspective of error rate and spectral efficiency. Relevant for **uMTC** and **mMTC**, where high spectral efficiency for short frame lengths are desired.

- **T2.2-TeC10.1 – Full Duplex communications**: This TeC investigates the feasibility of full duplex communications in underlay D2D networks. Using full duplex for transmission and reception at the same time on the same frequency band has the potential to double the spectrum efficiency, if sufficient self-interference cancellation be employed. Full duplex is mature enough for small transmit power systems such as small cells, D2D, and Wi-Fi. Relevant for **xMBB** and **Localized Contents and Traffic Flows**.
- **T2.3-TeC11.1.1 – Non-orthogonal multiple access (NOMA)**: This TeC investigates the multiplexing of users in the power domain on the base station side, with multi-user signal separation at the UE side by means of successive interference cancellation. The multi-user power allocation and MCS selection is conducted based on the SNR feedback information from users, and does not rely on accurate channel state information. As a result, the TeC is well suited for increasing the network capacity not only for pedestrian, but also for vehicular users, and thus relates to **xMBB**.
- **T2.3-TeC11.1.2 – Sparse code multiple-access (SCMA)**: This TeC investigates the multiplexing of users in the code/power domains by means of multi-dimensional sparse codewords. Similarly to T2.3-TeC11.1.1, no accurate channel information is required in order to multiplex the 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 **xMBB.** In addition, by means of blind detection techniques, SCMA can enable uplink contention-based access with low latency and signalling overhead, which is relevant for **mMTC**.
- **T2.3-TeC12.1.1 – Coded Random Access with Successive Interference Cancellation:** This TeC uses random repetition over slots combined with successive interference cancellation to sort out the individual signals of the users in order to enable random, contention-based access. Relevant for **mMTC** and **uMTC**.

  T2.3-TeC12.1.2 – Coded Access Reservation: Coding of user transmissions in time combined with an increased contention frame extending over several frames increases the contention space and lowers collision rate and increases the capacity at the expense of increased latency. Relevant for **mMTC** and **uMTC**.
- **T2.3-TeC12.1.3 – Advanced PHY processing for enhanced MAC:** Spreads users' transmissions using pseudo-random codes, and the sparsity of the joint signal, which is created due to inactivity of users, is used to obtain gains in capacity. Relevant for **mMTC** and **uMTC**.
- **T2.3-TeC12.2 – Distributed Network Synchronization:** This TeC investigates the distributed provision of network synchronization across communication nodes, i.e. without the presence of a central controller, based on the random broadcast mechanism of message transmission. This effectively enables the use of TDMA mechanisms in the case ad-hoc D2D communication. Relevant for **uMTC**.
- **T2.3-TeC12.3 – MAC for UDN and mmW:** High gain beamforming 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 **xMBB.**

- **T2.3-TeC13.1 – Backtrack retransmission with ternary feedback**: This TeC proposed a new HARQ concept in which posteriori channel state information is used in order to configure future retransmissions. The concept enables to trade-off between data rate and delay and promises important gains compared to traditional HARQ mechanisms in delay-constrained scenarios, such as those relevant for **xMBB** and **uMTC**.
- **T2.3-TeC13.2 – Multi-level ACK/NACK transmission scheme for reliability-based HARQ**: This TeC investigates the use of reliability-based HARQ in which the reliability feedback information is transmitted by means of an asymmetric Quadrature Phase-Shift Keying (QPSK) modulation. The proposed approach can improve the link performance in static and in particular in mobile scenarios, as a result of better time diversity. This TeC is relevant for **xMBB** and **uMTC**.

A.2 WP3: Multi-node/Multi-antenna transmissions

- **T3.1-TeC1b – Discrete Fourier Transform (DFT) based Spatial Multiplexing (SM) and Maximum Ratio Transmission (MRT) for mm-wave large MIMO**: This TeC enables the transmission of a high number of independent streams using mmW large scale MIMO, relevant in the context of **xMBB**.
- **T3.1-TeC2 – Coordinated resource and power allocation for pilot and data signals in multicell massive SIMO/MIMO systems:** Coordination of resources used for pilot and data transmission in a multi-cell massive Single Input Multiple Output (SIMO) system. Goal of the coordination is to mitigate pilot contamination and reduce inter-cell interference. Relevant for **xMBB** and **mMTC**.
- **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 T2.1-TeC6.4 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 **xMBB**.
- **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 **xMBB**.
- **T3.1-TeC8 – Massive MIMO and ultra-dense networks**: This TeC is Massive MIMO in ultra-dense networks with a TDD-based network architecture, where interference is tackled locally. Relevant for **Dynamic RAN** and **xMBB**.
- **T3.1-TeC9b – Uplink power control with MMSE receiver in multi-cell MU-Massive-MIMO**: Uplink per-user pilot and data transmit power control satisfying per-user power and SINR constraints. The power control provides solution to one of the basic problem in the realization of Massive MIMO. Relevant for **xMBB**
- **T3.1-TeC10 – Decentralized coordinated transceiver design with large antenna arrays**: Decouples the precoder optimization subproblems at different BSs for a minimum power beamforming by utilizing a large dimension approximation for inter-cell interference terms as the coupling variables. Relevant for **xMBB**

- **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 **xMBB.**
- **T3.2-TeC1b – Non-coherent joint processing CoMP for energy-efficient small cell networks**: Jointly optimize the precoding, load balancing, and BS operation mode (active or sleep) for improving the energy efficiency of heterogeneous networks. Multiple BSs can serve the users by joint non-coherent multiflow beamforming. Relevant for **Dynamic RAN**.
- **T3.2-TeC3 – Distributed Precoding in Multi-cell Multi-antenna Systems with Data Sharing**: Precoding strategies that utilize local CSI and exploit some form of data sharing among the BSs (e.g. the presence of caching mechanism in the BSs that stores frequently downloaded content) in order to mitigate the interference, relaxing backhauling requirements. Since no exchange of CSI is required between the cooperating APs, it can also be used in the cases that require low latency. Relevant for **xMBB**.
- **T3.2-TeC4 – Alignment of Intra Cell Multi User and Inter Cell Interference in a MU-MIMO Cellular Network**: This TeC proposes a transmission technique along with user selection algorithms in order to increase the system spectral efficiency by dealing with multi user and inter cell interference on the basis of interference alignment in a MIMO system. This scheme improves the spectral efficiency of nomadic node backhaul links and therefore is relevant for **Dynamic RAN**.
- **T3.2-TeC6 – Distributed Low-Overhead Schemes for MIMO Interfering Networks**: Algorithms relying on the use of UL / DL pilots and forward-backward iterations to gradually refine both transmit and receive filters, in a fully distributed manner, to maximize the sum-rate. The proposed schemes only require a handful of such F-B iterations, to deliver high spectral-efficiency. Can be used to improve the power of the desired signal and combat interference. Relevant for **xMBB**.
- **T3.2-TeC7 – Dynamic Clustering with multiple receive antennas in downlink CoMP systems**: This TeC develops a dynamic clustering algorithm for downlink CoMP systems by assuming that the UEs are equipped with multiple antennas. The TeC can be adapted to improve the performance of wireless backhaul links for nomadic nodes and is therefore relevant for **Dynamic RAN** and **xMBB**.
- **T3.2-TeC8 – Non-Orthogonal Multiple Access (NOMA) with multi-antenna transmission schemes:** 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 **Dynamic RAN**, and **xMBB**.]
- **T3.2-TeC10 – Joint linear downlink CoMP with enhanced signal processing at the UEs and bounds for Clustered Joint Transmission**: Dynamic user centric Clustering of BSs for joint transmission CoMP offers a large gain in data rate for static receivers and therefore is beneficial for the backhaul link of nomadic nodes. Relevant for **Dynamic RAN**.
- **T3.2-TeC11 – Decentralized Interference Aware Scheduling**: This TeC provides a decentralized interference aware scheduling mechanism based on beacon signals sent from the UE. The TeC is applicable to extremely dense deployments, D2D communications and similar, to solve outages arising from harsh interference. Relevant for **Dynamic RAN**.

- **T3.2-TeC12 - Network-assisted interference suppressing/cancelling receivers and ultra-dense networks:** This TeC uses network assistance to enhance the interference estimation accuracy of the UE leading to an improved interference suppression and cancellation performance. The TeC is relevant to **xMBB**.
- **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. Relevant for **xMBB**.
- **T3.2-TeC15 – Adaptive and energy efficient dense small cells coordination**: The design of CoMP based algorithm that allows reducing power consumption in a dense network, where the traffic is below the peak by turning off BSs. It thus makes the network inherently resilient to damages and hence contributes to **Dynamic RAN.**
- **T3.2-TeC16 – Non-coherent transmission schemes for practical inter-node coordination systems:** This TeC focuses on the use of non-coherent communication, which performs data detection without a prior knowledge of the channel coefficients. On one hand, this has the potential to enable the use of multi-user MIMO techniques for vehicular scenarios in an efficient manner as a result of reduced pilot pollution and immunity against outdated channel estimates. On the other hand, non-coherent communication is well suited for broadcasting transmissions as described in TC12, for which no feedback information is available at the transmitter. Relevant for **xMBB** and **uMTC**.
- **T3.2-TeC17 – Bidirectional signalling for dynamic TDD:** The aim is to at jointly optimizing the allocation of resources (space, frequency and time, including the allocation to UL and DL) and coordinated precoder/beamformer (CB CoMP) design across the entire network to maximize various system performance measures with use of bidirectional signalling. Relevant for **xMBB**.
- **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. This Tec can be applied in the wireless backhaul links of nomadic nodes and UDN, and it is therefore relevant for **xMBB** and **Dynamic RAN**.
- **T3.3-TeC2 Interference aware routing and resource allocation in a millimetre-wave ultra-dense network** This TeC is based on the idea to provide high data rate coverage in mmW indoor environments, a denser network than fixed backhaul can provide is required. In order to enhance spectrum efficiency, wireless backhaul and access share spectrum and nodes. The purpose is to develop and evaluate sub-optimal low-complexity routing and resource allocation schemes that take interference into account for several multi-hop flows in the mesh of access nodes, to one or several fibre connected access nodes servings as aggregation nodes. This TeC is enabler for mmW system in **xMBB**.
- **T3.3-TeC3 – Virtual Full-Duplex Buffer-aided Relaying:** Enable virtual full-duplex relays, by having buffers at the relays and inter-relay interference cancellation. One relay receives the information from the source while the other forwards the information to the destination. The idea is to find the best relay-pair selection for Source-Relay and Relay-Destination links with an efficient beamforming design at both transmitting and

receiving relays. Improves coverage and can contribute to the **Dynamic RAN** and **xMBB**.

- **T3.3-TeC5 – Bi-directional relaying with non-orthogonal multiple access:** This TeC focuses on bidirectional relaying with multiple data flows and multiple communication pairs employing Interleave Division Multiple Access (IDMA) as non-orthogonal multiple access. The application of IDMA offers a high degree of flexibility and allows for the combination with known approaches, such as network coding, in order to create efficient combinations of the MAC and broadcast phases. The impact of IDMA is analysed in combination with network coding to identify efficient strategies regarding MAC/broadcast structuring, resource allocation and channel coding for bi-directional communication. Improves coverage and can contribute to the **Dynamic RAN** and **xMBB**.
- **T3.3-TeC6 – MIMO physical layer network coding based underlay D2D communication**: This TeC provides multi-antenna techniques to be used at the transmitting or receiving nodes to ensure coexistence of D2D and cellular communications in the same spectrum. The relay node uses physical layer network coding to deliver high spectrum efficiency. Relevant for **xMBB** and **Dynamic RAN**.
- **T3.3-TeC7 – Cooperative D2D Communications:** This TeC loos at the cooperation between cellular links and direct device-to-device communication links to increase spectral efficiency, cell throughput, number of connected devices within the cell, and cell coverage. Can be extended to cover the scenarios for UE-to-network relay to extend network coverage in **xMBB**.
- **T3.3-TeC9b – Uplink enhancement of vehicular users by using D2D communications**: The TeC investigates the cooperation between users inside a vehicle by means of D2D communication in order to improve the link performance in the uplink direction. By doing this, important gains in terms of energy efficiency are expected for vehicular scenarios with high penetration losses. Relevant for **xMBB** and **Dynamic RAN**.
- **T3.3-TeC10 – Combining physical layer network coding and MIMO for TDD wireless systems with relaying**: This TeC considers the joint application of network coding and MIMO transmission with the aim at improving throughput or reliability and robustness in two-way relaying scenarios. Two-phase transmission reduces delay by half. The proposed solution causes additional interference to directly connected users. Therefore, interference management schemes should complement this solution especially in dense deployment. This TeC improves the performance of nomadic nodes and is therefore relevant for **Dynamic RAN**.

A.3 WP4: Multi-RAT/Multi-layer networks

- **T4.1-TeC1.1 – Adaptive Projected Sub-gradient Method**: This TeC builds upon set-theoretic techniques for the estimation and tracking of the time-varying long term channel gain between all of the transmitters and receivers in the network. As such it provides valuable input to the RRM mechanisms in place by allowing for the estimation of the interference environment. Therefore, this TeC can help improve the spectral efficiency of the wireless transmissions and addresses challenges rising from the **xMBB, uMTC,** and **Dynamic RAN**.
- **T4.1-TeC1.3 – Interference Identification using multi-layer inputs**: This TeC provides a mechanism to identify sources of interference in environments where topology information is available. A centralized interference identification entity exploits available knowledge of network components, e.g. UEs and eNBs. The added value of interference identification entity is that it examines uplink and downlink, cellular and

D2D communication distinctively, in order to indicate aggressor nodes in a fine grained manner. Relevant for **xMBB** and **Dynamic RAN**.

- **T4.1-TeC2 – Unified Solution for Device Discovery:** A unified discovery framework for both UE-based and network-based schemes. A common dedicated resources allocation procedure consisting of pre-defined is 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 enabler for **xMBB** and **Dynamic RAN**.
- **T4.1-TeC3.1—3.2 – D2D mode selection:** Including distributed CSI-based mode selection and local based mode selection (selection of communication mode: D2D mode or cellular mode). Key enablers for **xMBB**.
- **T4.1-TeC4.1—4.2 – 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. Key enablers for **xMBB** and **Localized Contents and Traffic Flows**.
- **T4.1-TeC4.3 – Context-aware resource allocation scheme for enabling D2D in moving networks:** This TeC exploits the properties of automotive applications to enable their adoption in a D2D underlay. Hereby, scheduling decisions are based on crude location information instead of unreliable/infeasible channel measurements. The TeC reduces the involved management overhead and improves the overall efficiency of vehicle-to-device broadcast transmissions. Relevant for **uMTC** and **Localized Contents and Traffic Flows**.
- **T4.1-TeC4.4 – Network assisted resource allocation for direct V2V communication:** This TeC delivers a clustering concept for vehicular safety applications where the cellular network nodes assist few vehicles (operating as CHs) in the coordination and reuse of out-band radio resources. Moreover, it enables a feasible signalling strategy where the CHs assume the management role for their assigned resources within the respective cluster. Hence, this TeC improves the reliability of vehicular communications and is relevant for **uMTC**.
- **T4.1-TeC4.5 – Allocation and power control scheme for D2D-based V2V communication:** This TeC aims at maximizing the sum throughput in the cellular network under the condition that the strict QoS requirements of automotive applications are satisfied in a D2D underlay. Hence, this TeC is relevant for **uMTC**.
- **T4.1-TeC5.1—5.3 – 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.Relevant for **Dynamic RAN** and **xMBB**.
- **T4.1-TeC6.1 – 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 Relevant for **xMBB**.

- **T4.1-TeC7.1 – 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 **xMBB**.
- **T4.1-TeC7.2 – X2-based distributed interference management in femto-cells (DIM-X2):** This groups nomadic nodes into small Clusters and coordinates dynamically the resource allocation taking into account the interference received from neighbouring nomadic nodes and small cells. Therefore, this TeC is relevant for **Dynamic RAN**.
- **T4.1-TeC8 – Handover optimization for moving relay nodes:** This TeC aims to optimize the handover trigger parameters (handover hysteresis margin and the time to trigger) for in-vehicle UEs that are served by a moving relay node. As such, this TeC helps lower the power outage probability which is affected by the penetration loss due to the vehicle's body and improves the overall user experience. Relevant for **xMBB** and **Dynamic RAN.**
- **T4.1-TeC9 – Dynamic clustering:** This TeC enables the efficient creation of clusters of network nodes targeting collaboration. Such clusters can be useful, for instance, in interference coordination. The TeC can improve the overall transmission efficiency of wireless links and is relevant for **xMBB** and **Dynamic RAN**.
- **T4.1-TeC10 – Overlapping super cells for dynamic effective user scheduling across bands:** Different carriers can be allocated to different clusters. By intertwining the connectivity, one can form these supercells in such a way that every cell edge user finds itself near the centre of a supercell with favourable situation for enhanced Inter-Cell Interference Coordination (eICIC). This improves the coverage reliability and is therefore relevant for **xMBB.**
- **T4.1-TeC12 – Coordinated resource usage in virtual cells and nomadic relays:** This TeC uses rateless coding to reduce the need for interference coordination among nomadic cells and stationary small cells in a heterogeneous network deployment. Therefore, this TeC is relevant for **Dynamic RAN**.
- **T4.1-TeC13 – Interference management for MNs in ultra-dense urban scenarios:** This TeC investigates interference management schemes for the mitigation of inter-cell interference in a MN setup. It helps improve the QoE of in-vehicle UEs served by a MN node whilst limiting the impact this communication has on outdoor UEs. Relevant to **xMBB** and **Dynamic RAN**.
- **T4.1-TeC15- Further enhanced ICIC in D2D enabled HetNets:** This TeC addressed Inter-Cell Interference Coordination (ICIC). The 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, and is relevant to **xMBB** and **Localized Contents and Traffic Flows**.
- **T4.1-TeC16 – Support of low-cost MMC devices under poor coverage and high frequency offset conditions:** This is TeC with two parts, first a Multimedia Broadcast Multicast Services scheme for efficient mMTC transmission, and secondly a wave form alteration to cope with carrier frequency errors and improve the coverage. Relevant for **uMTC**.

- **T4.2-TeC1 – Optimized distribution scheme for context information:** This TeC constitutes an efficient mechanism for the dissemination of context information. Such information can be exploited at various network nodes and layers for the overall optimization of the network performance. Relevant for **xMBB**, **uMTC**, and **Dynamic RAN**.
- **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 relevant to **xMBB**.
- **T4.2-TeC5.1 – User-oriented context-aware vertical handover**: This TeC selects the optimal RAT to connect to in an ultra-dense radio environment. It triggers handover decision based on context-related information built on parameters such as the mobility (velocity) of the UE, the traffic load of the macro/femto LTE eNBs (or Wi-Fi Access Point), as well as the backhaul load of the network and session-related context information. Relevant to **xMBB** and **Dynamic RAN**.
- **T4.2-TeC6 – Handover optimization using street-specific context information:** This TeC aims at reducing the handover failures for mobile users by exploiting information on their trajectories and travelling speeds. In this manner, this TeC contributes towards the improvement of the link robustness. Relevant for **xMBB**.
- **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 in scenarios covered by **xMBB**.
- **T4.2-TeC8 – D2D handover schemes for mobility management:** This TeC delivers additional handover conditions related to D2D communication. As such, this TeC reduces the signalling overhead and reduces the control latency. Therefore, it contributes towards a solution to the challenges posed by **uMTC**.
- **T4.2-TeC9.1 – Smart mobility and resource allocation using context information:** This TeC investigates resource allocation based on context information. It explicitly targets mobile users travelling at high speeds on a fixed road topology and improves the network performance for delay-tolerant applications (such as video streaming). Relevant for **xMBB**.
- **T4.2-TeC9.2 – Long-term context-aware scheduling for ultra-dense networks:** The proposed component addresses the problem of large user packet delay due to outage or coverage holes in indoor ultra-dense wireless networks. More precisely, the method prioritizes scheduling of the users that are approaching the outage zones**.** Relevant for **xMBB.**
- **T4.2-TeC10 – Signalling for trajectory prediction:** This TeC is concerned with methods for the signalling of context information. Hence, it provides input to TeCs that exploit such information and contributes to **xMBB, uMTC,** and **Dynamic RAN**.
- **T4.2-TeC11 – Context information building using data mining techniques:** This TeC classifies users and services based on historic observations. Such context information is useful for the RRM and can help optimize the user throughput in specific situations. Relevant for **xMBB**.

- **T4.2-TeC12 – Context-based device grouping and signalling:** The TeC provides uplink random access schemes for M2M signalling in order to reduce the signalling 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. Relevant for **mMTC**.

- **T4.2-TeC13.1 – Network assisted small cell discovery:** This TeC proposes a solution where UE obtains assistance information from the network to target the search of small cells. This information consists of radio fingerprints of the coverage carrier (e.g. the reference signal received power of neighbouring macro cells, which can be obtained power-efficiently as part of UE's normal operation during a cellular connection) that correspond to a small cell location or a handover region. Relevant for **xMBB** and **Dynamic RAN**.

- **T4.2-TeC13.2 – Small cell discovery in mmW small cell networks**: This TeC provides a solution for network-assisted small cell discovery in the mmW band. Assuming that an mmW band BS is serving also a low-frequency carrier, the UE detects whether there is LoS link between the UE and the BS based on measurements of the low frequency signal. This is used to control the measurements on mmW carrier. Detection of LoS is based on received signal characteristics (channel impulse response, root mean square delay spread, etc.) on the low-frequency carrier where the UE is primarily connected. Relevant for **xMBB** and **Dynamic RAN**.

- **T4.2-TeC14 – Context-aware smart devices and RATs/layers mapping**: This TeC improves resource utilization through a context-aware RRM algorithm. Different kinds of context information, e.g. number of established links, system capacity, is collected and exploited at BS for a more efficient mapping of RATs/layers. Regarding different types of services and devices, different KPIs are taken into account in order to reasonably optimize the network performance. Relevant for **Dynamic RAN** and **Localized Contents and Traffic Flows**.

- **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 **mMTC**.

- **4.2-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 the context of **xMBB**

- **T4.3-TeC1.1—1.2 – New management interface between the operator and the service provider:** This TeC gives service providers access to SON-based functionalities of the network and they can tailor specific network setting towards better scalability and availability of the resources for nomadic nodes. Therefore, this TeC is relevant for **Dynamic RAN**.

- **T4.3-TeC2 – Clustering Toolbox:** This TeC is an enabler for flexible network deployment. Based on the network coverage and the capacity requirements from the users, the cells may be clustered and used for optimization of the network. The TeC can be used for clustering and performance optimization of nomadic nodes and is relevant for **Dynamic RAN**.
- **T4.3-TeC3.2 – 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 UEs. 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 in composite Fading/Shadowing Environments while considering Co-channel Interference. Relevant for **Dynamic RAN**.
- **T4.3-TeC4.1 – 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. Relevant for **Dynamic RAN** and **Lean System Control Plane**.
- **T4.3-TeC4.2 – Activation and Deactivation of small cells in UDN:** This TeC provides dynamic activation and de-activation of small cells to provide network connectivity at all desired locations and sufficient bandwidth to satisfy clients' communication needs, eliminating the wasting of network and energy resources. The de-activation of small cells is triggered when there is too high coverage overlap, while the capacity usage ratio is too low. In the case of low coverage, low Channel Quality Indicator or even high blocking probability, the activation of one or more small cells is checked attempting to provide more resources wherever it is necessary. Relevant for **Dynamic RAN** and **Lean System Control Plane**.
- **T4.3-TeC5 – Energy savings for Phantom Cell Concept Systems:** This macro-assisted scheme can allow the system to get rid of the energy consumption overhead caused by signalling-based state of the art schemes where nomadic cells have to turn on their RF receiving chain to be able to intercept connection requests from UEs or to periodically turn on their RF transmitting chain to send beacon signals in order to be discoverable. Relevant for **Dynamic RAN** and **Lean System Control Plane**.
- **T4.3-TeC6 – Framework for control/user plane design with over-the-air signalling for UDN:** This TeC proposes two variants of control plane over-the-air signalling to enable centralized operations. In the first variant, the control plane is completely handled between macro and UE except physical layer related signalling, and small cells overhear the control plane signalling to know which resources to transmit on. In the second variant, the control plane towards UE is handled by the small cells and the macro cell provides instructions to small cells on how to use resources. Relevant for **Lean System Control Plane**.

A.4 WP5: Spectrum

- **WP5-TeC02 – Flexible spectrum use for moving networks:** This TeC provides mechanisms for the flexible use of spectrum when a vehicular node changes its mode from a relay to a base station, and vice versa. Depending on the desired behaviour (e.g. in-vehicle coverage or coverage extension outside the vehicle) this TeC enables better spectrum utilization in **xMBB** and **Dynamic RAN**.

- **WP5-TeC03 – Inter-operator separation rule for non-cooperative spectrum sharing:** This TeC belongs to the research studies that could be potentially formed to an algorithm useful for UDN deployments, thus applicable for **xMBB**.
- **WP5-TeC04 – Coordinated multi-carrier waveform based sharing technique:** In this TeC a common subcarrier grid is defined for operators sharing a band. Each operator activates parts of subcarriers in this grid according to the partition decision of a central spectrum manager entity. Additionally, this concept assumes freedom to adapt actual subcarrier spacing, pulse shape and signal frame structure. Relevant for **xMBB**.
- **WP5-TeC05 – Co-ordination protocol for interaction between operators supporting the use of limited spectrum pool and mutual renting:** Spectrum sharing can be realized by book keeping of spectrum usage favours given and received by the operators. Proper definition of the types of spectrum usage favours will shape the performance of the limited spectrum pool and mutual renting type of coordination protocols and results in better spectrum utilization in **xMBB**.
- **WP5-TeC09 – Inter-UDN coordinated spectrum sharing:** This TeC presents a link-specific coordination context scheme to avoid severe interference between different networks and a coordinated blanking concept to enable inter-UDN spectrum sharing with less overhead. This TeC is especially applicable to maintain high reliability of cell edge users in systems operating in mmW bands, which makes it very relevant for **xMBB**.
- **WP5-TeC12 - Spectrum opportunity detection and assessment:** This TeC introduces an operating channel assessment functionality providing a set of prioritized spectrum opportunities that is passed on to the radio resource management (RRM) functionality. This TeC can be applicable in particular to **xMBB**, but also to **mMTC** and **uMTC**.
- **WP5-TeC14 – Spectrum sharing & mode selection for overlay D2D communication:** A potential D2D device 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. Measured energy below the threshold indicates that there is not much ongoing D2D communication and D2D mode is selected. Otherwise, the D2D devices select infrastructure-based mode. Relevant for xMBB.
- **WP5-TeC20 – Prepared and database-assisted URC communication for V2V:** This TeC proposes mechanisms improving the availability of URC in the context of vehicle-to-vehicle communication. Exploiting knowledge over the trajectories of moving vehicles or over the locations where URC is required. This TeC allows for the optimal selection of URC mode. Hence, it is relevant for **uMTC**.
- **WP5-TeC22 – Multi-operator D2D operation:** This TeC investigates mechanisms for multi-operator D2D communication and device discovery. It proposes a new network entity – Multi-operator D2D Server – which assumes management functions and enables the direct communication between subscribers of different network operators. Hence, this TeC allows for a wider communication reach in the context of **xMBB**, **mMTC** and **uMTC**.