METIS II

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

Deliverable D5.1
Draft Synchronous Control Functions and Resource Abstraction Considerations

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Abstract

This deliverable contains draft concepts on synchronous control functions and associated resource abstraction considerations, where the latter area aimed to foster air interface (AI) variant (AIV) overarching operation of the former. The presented initial findings and analyses are the first essential stride towards an agile resource management (RM) framework for the fifth generation (5G) communication system pursued by METIS-II work package (WP) 5. Also, the deliverable is deemed to serve as a means for fostering discussions with other 5G Infrastructure Private Public Partnership (5G PPP) projects on relevant aspects.

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Executive summary

This Deliverable D5.1 presents draft considerations on synchronous control functions and resource abstraction along with initial analyses and results, and depicts the main research directions that are followed by work package (WP) 5 of 5G PPP METIS-II project. It further highlights the initial concept of the agile resource management (RM) framework for 5G, which is one of the key innovation pillars that are being developed by METIS-II. Additionally, it aims to serve as a solid basis for future discussions and collaborations with other 5G PPP projects.

Herein, we first outline the scope of the work comprising the motivation and the linkage of D5.1 with other METIS-II deliverables that describe the envisioned 5G radio access network (RAN) design and landscape. A conceptual and draft description of the agile RM framework investigated in METIS-II is then provided. The agile RM framework provides holistic RM solutions and air interface (AI) abstraction models that consider and exploit the novel aspects of 5G systems, such as, very diverse service requirements, existence of multiple AI variants (AIVs) in the overall AI, dynamic topologies, and novel communication modes. Within the context of agile RM, METIS-II extends the notion of a resource beyond conventional radio RM (RRM) and aims to attain the optimum mapping of 5G services to any available resources when and where needed within this extended realm of resources. For the optimum mapping, traffic steering schemes are proposed to be more dynamic as compared to the legacy systems that factor in the peculiarities of different AIVs in the overall AI. In terms of the AIVs, the optimum mapping also takes into account the tight interworking between novel 5G AIVs and evolved legacy AIVs, e.g., long-term evolution (LTE). The extended realm of resources includes the unlicensed bands the usage of which shall be adaptive and be coupled with the changing radio topology. Further, agile RM enables the sharing of a common RAN by multiple network slices. Advanced cooperative techniques can improve cell-edge user throughput by mitigating interference in very dense deployments considering both fixed and dynamic radio topologies. Cooperative techniques can also be utilized to moderate RAN to attain energy efficiency gains taking into account different frequency duplex options. Consequently, functional extensions and changes in the device measurement context are needed to enable such new functionalities tailored to different 5G use cases (UCs), while taking into consideration the device performance.

The agile RM framework is constructed by functionality frameworks, which are defined in terms of sets of identified building blocks. In this deliverable, the foundations for the functionality frameworks are described. To this end, the technology components (TeCs) that constitute the building blocks as enabling technologies are presented. Furthermore, this deliverable includes a preliminary analysis for the positioning of the enabling technologies in the 5G landscape. In addition, the initial inter-relation map of the TeCs and building blocks is depicted.

As a conclusion, the way forward is analyzed, in which this deliverable forms the foundation for future work of WP 5 and the final deliverable D5.2 *“Final synchronous control functions and resource abstraction considerations”* (due in March 2017).

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List of Abbreviations and Acronyms

3GPP	Third Generation Partnership Project
5G	Fifth Generation
5G PPP	5G Infrastructure Private Public Partnership
AaSE	AIV agnostic Slice Enabler
AC	Admission Control
AI	Air Interface
AIV	AI Variant
ARP	Allocation Retention Priority
AN	Access Network
AN-I	Access Network-Inner
AN-O	Access Network-Outer
API	Application Programming Interface
BH	Backhaul
BS	Base Station
BSS	Business Support Systems
C-RAN	Centralized/Cloud RAN
CA	Carrier Aggregation
CBR	Constant Bit Rate
CDF	Cumulative Distribution Function
CDMA	Code Division Multiple Access
CH	Cluster Head
CN	Core Network
CoMP	Coordinated Multi-Point
CP	Control Plane
CQI	Channel Quality Indicator
C-RS	Cell specific Reference Signal
CSI	Channel State Information
D2D	Device-to-Device communications
D-RAN	Distributed Radio Access Network
DL	Downlink
DPB	Dynamic Point Blanking
DPS	Dynamic Point Selection
DRX	Discontinuous Reception

DTX	Discontinuous Transmission
E2E	End-to-End
EE	Energy Efficiency
eICIC	Enhanced Inter-Cell Interference Coordination
eNB	Evolved Node B
EPC	Evolved Packet Core
F-OFDM	Filtered OFDM
FBMC	Filterbank Multi-Carrier
FBR	Front to Back Ratio
FDD	Frequency Division Duplex
FEC	Forward Error Correction
FFS	For Further Study
FQAM	Frequency and Quadrature Amplitude Modulation
FSK	Frequency Shift Keying
GBR	Guaranteed Bit Rate
GFDM	Generalized Frequency Division Multiplexing
GNSS	Global Navigation Satellite System
GSM	Global System for Mobile communication
HSPA	High Speed Packet Access
HTTP	Hypertext Transfer Protocol
ICI	Inter-Cell Interference
ICIC	Inter-Cell Interference Coordination
IDC	In-Device Coexistence
ITU	International Telecommunication Union
JR	Joint Reception
JT	Joint Transmission
KPI	Key Performance Indicator
LAA	Licensed Assisted Access
LBT	Listen Before Talk
LL	Low Latency

LTE	Long-Term Evolution
LTE-A	Long-Term Evolution Advanced
LWA	LTE-A WLAN Aggregation
MAC	Media Access Control (Layer)
MANO	Management and Orchestration
METIS-II	Mobile and wireless communications Enablers for the Twenty-twenty Information Society-II
MIMO	Multiple-Input Multiple-Output
mMTC	Massive Machine-Type Communications
mmW	millimeter Wave
MU-MIMO	Multi-User Multiple-Input Multiple-Output
NFV	Network Function Virtualization
NN	Nomadic Node
OFDMA	Orthogonal Frequency Division Multiple Access
OOB	Out-Of-Band
OSS	Operations Support Systems
PCEF	Policy and Charging Enforcement Function
PDCCH	Physical Downlink Control Channel |
PDCP	Packet Data Convergence Protocol
PDN-GW	Packet Data Network – Gateway
PGIA	Pre-emptive Geometrical Interference Analysis
PHY	Physical (Layer)
PPI	Power Preference Indicator
PRACH	Physical Random Access CHannel
QAM	Quadrature Amplitude Modulation
QCI	QoS Class Identifier
QoS	Quality of Service
RAN	Radio Access Network
RAP	Radio Access Point
RAT	Radio Access Technology
REST	Representational State Transfer
RLC	Radio Link Control
RLF	Radio Link Failure
RM	Resource Management
RRH	Remote Radio Head
RRC	Radio Resource Control
RRM	Radio RM
RSC	Resource Sharing Cluster
RSCP	Received Signal Code Power
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RSSI	Received Signal Strength Indicator
SDN	Software Defined Networking
SDWN	Software Defined Wireless Network
SINR	Signal-to-Interference-plus-Noise Ratio
SLA	Service Level Agreement
SON	Self-Organizing Network
SotA	State of the Art
TA	Tracking Area
TDD	Time Division Duplex
TeC	Technology Component
TN	Transport Network
TTI	Transmission Time Interval
UC	Use Case
UDN	Ultra-Dense Network
UE	User Equipment
UF-OFDM	Universal filtered OFDM
UL	Uplink
uMTC	Ultra-reliable Machine-Type Communications
UP	User Plane
UR	Ultra Reliable
UTRA	Universal Terrestrial Radio Access
xMBB	Extreme Mobile Broadband
WP	Work Package

1 Introduction

The explosive growth in capacity and data rate demands, together with novel and challenging service types envisioned for the time frame beyond 2020 towards extreme Mobile Broadband (xMBB), massive Machine Type Communications (mMTC), and ultra-reliable Machine Type Communication (uMTC), are the main motivation for the development of 5G technologies. 5G will consist of technologies that have to fulfill ambitious requirements driven by the vertical industries, which are interested to use radio networks for wireless connectivity and control. It is envisioned that, in 5G, the overall air interface (AI) will comprise AI variant(s) (AIVs)[1] that are optimized, e.g., for the specific frequency bands of operation (below 6 GHz, centimeter wave, millimeter wave, etc.) and for the one or more target use cases (UCs) [MET-II16-D11][MET-II16-D22][2][MET-II16-WP]. While there could be different AIVs, it is expected that the resource management (RM) framework should be agile to operate in an AIV overarching manner [BPB+15]. This means that the functionality framework for RM could remain agnostic to the design of the physical layer design of the AIVs that are involved. Developing such an agile RM framework is one of the main goals of the METIS-II project, and the target of work package (WP) 5 in particular.

In terms of interference conditions, the 5G networks would be more challenging due to the ultra-dense deployment of cells. It is expected to have novel interference constellations originated by a much wider use of beamforming, flexible uplink/downlink (UL/DL) frame configuration, in-band self-backhauling and device-to-device (D2D) communication. The need to support ultra-reliable and latency-critical applications, along with the network slicing concept will add a new dimension to the problem of efficient resource allocation within such networks. The agile RM framework is expected to take those aspects into account and leverage the degrees of freedom offered by the availability of multiple links and layers (in terms of frequency bands, AIVs, cell types, etc.). In this report, we present the initial considerations of the proposed technology components (TeCs) and research directions to enable the development of such a framework. The state of the art (SotA), the overview of enabling technologies along with building blocks and future considerations for the development of these concepts are described in the following.

1.1 Scope

METIS-II aims to develop an agile RM framework that will operate over a multi-AIV environment comprising both 5G and evolved legacy AIVs [MET-II16-D41]. A fundamental part of the

[1] An AIV is defined as the RAN protocol stack (i.e., PHY/MAC/RLC/PDCP/RRC or 5G equivalents, or subset thereof) and all related functionalities describing the interaction between infrastructure and device, and covering a subset of services, bands, cell types etc. that are expected to characterize the overall 5G system.

[2] The publication date of METIS-II deliverable D2.2, which describes draft overall RAN design, is one month later than that of this deliverable D5.1.

framework is the orchestration of resources based on availability and user needs. By the term “resources”, we herein do not only refer to the classical definition as in the context of radio RM (RRM), e.g., available licensed spectrum and time resources. We also incorporate an extended definition of resources, such as hardware resources (e.g., number/type/configuration of antennas, existence of nomadic access nodes in an area or mobile terminals that can be used as relays) and software resources (e.g., software capabilities of network nodes and devices, such as storage and processing). Apart from these resources we also model additional context information that is required by them (e.g., hardware and software configuration, interference levels, congestion levels, and use case (UC) [MET-II16-D11] related information). In the considered heterogeneous 5G environment, an appropriate modeling of these resources is required. The main objectives of this work highlighted in D5.1 can be outlined as:

- Efficient and effective use of any available resources when and where needed,
- Extension of the notion of a resource beyond conventional RRM,
- The optimum mapping of 5G services to the resources taking into account target performance metrics, e.g., energy consumption, and
- Network slice[3] -specific RM comprising inter-slice and intra-slice RM schemes.

To this end, RM strategies taking into account availability and specific use of additional spectrum bands are investigated. Furthermore, due to the integration of service-tailored user plane (UP) protocols, it may be required to revisit existing functionalities or to introduce new functionalities from the lower layer protocols (e.g., new scheduling paradigms to enable end-to-end slicing on radio access network, RAN, side). By this, the delay (in terms of signaling and processing required) of new interference management schemes can be minimized, while the total throughput can be considerably enhanced. Although, some first steps towards the design of synchronous control functions have been considered in previous research efforts, herein, a study of the synchronous control plane (CP) functions in a holistic way is targeted along with the aim of further advancing their capabilities. Accordingly, we expect that the work considered herein is carried out to substantially contribute to the overall CP design (see [MET-II16-D61][4] for the current considerations).

The framework to be designed in METIS-II focuses on flexible configurations of UP and supporting synchronous CP functions. For instance, for some UCs a separation and flexible assignment of CP and UP to the resources, given by the multiple layers and multiple radio links, are needed (e.g., control signaling communicated only through the macrocell). Alternatively, for certain services (e.g., mMTC or uMTC) also a joint and integrated transmission of control and

[3] A network slice, namely “5G slice,” supports the communication service of a particular connection type with a specific way of handling the CP and UP for this service and is seen from a customer perspective as a separated logical network [NGM15][MET-II16-D22][MET-II16-WP].

[4] The publication date of METIS-II deliverable D6.1, which also describes draft overall control plane design, is one month later than that of this deliverable D5.1.

user data may be needed to minimize the communication delay and the overhead. One of the expected results of the work is to provide a classification of which control functions and modifications are necessary with respect to the system deployment.

On this basis, two main directions for the work are defined in this document:

The first direction (followed in Task 5.1 (T5.1)) is the *Design of Synchronous Control Functions for Resource & Traffic Management*. The main goal of this direction is to design and evaluate the essential synchronous CP mechanisms for the 5G RAN so as to define an agile RM framework. These mechanisms are expected to be used in multi-link, multi-layer (including multi-hop communication) and multi-node mode of operation.

The second direction (dealt with in Task 5.2 (T5.2)), which is closely coupled with the previous one, is the *Design of a Resource Abstraction Framework.* The main goal of this direction is to provide a resource abstraction framework that will be also taken into account when defining the interface between the synchronous and asynchronous control functions, which are applied to different AIVs. Since this framework is used to foster the usage of control functions, e.g., in an AIV- overarching manner, apart from the resources, it is also aimed to define and model additional information that is required by these functions (e.g., interference levels).

It is worth noting that the ultimate goal is to design an agile RM framework which will be a harmonization of the different enabling technologies that are investigated in the above-mentioned tasks. On this basis, Figure 1-1 illustrates the development of this framework starting from TeCs going towards the final framework via building blocks and functionality frameworks. As can be seen by the focus bars below, this deliverable D5.1 places the focus on the development of TeCs and the associated building blocks while providing the foundations for functionality frameworks along with the first vision on the agile RM framework. The final deliverable D5.2 will place the focus on the further refinement of functionality frameworks and inter-relations of the building blocks towards the final design.

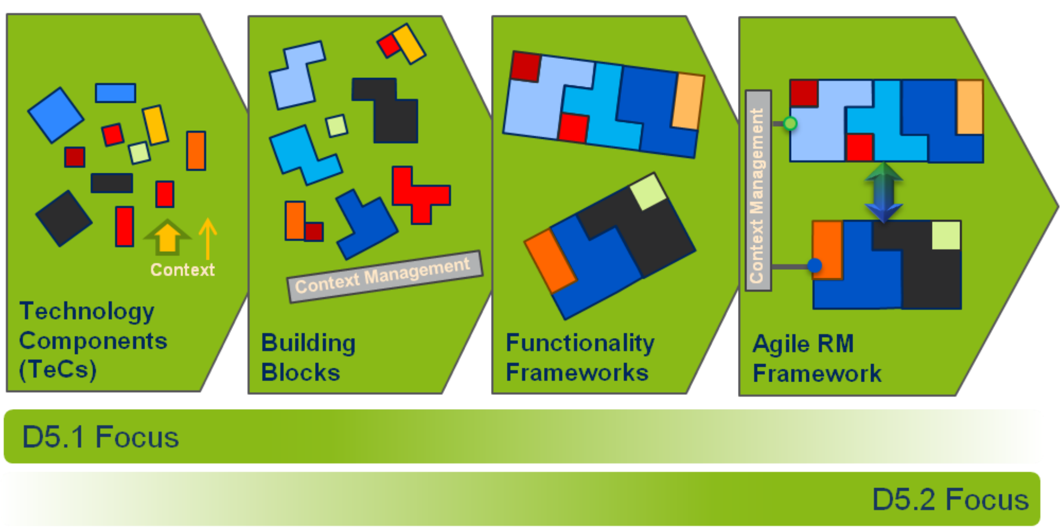


Figure 1-1 Development of agile RM framework and focal points of deliverables.

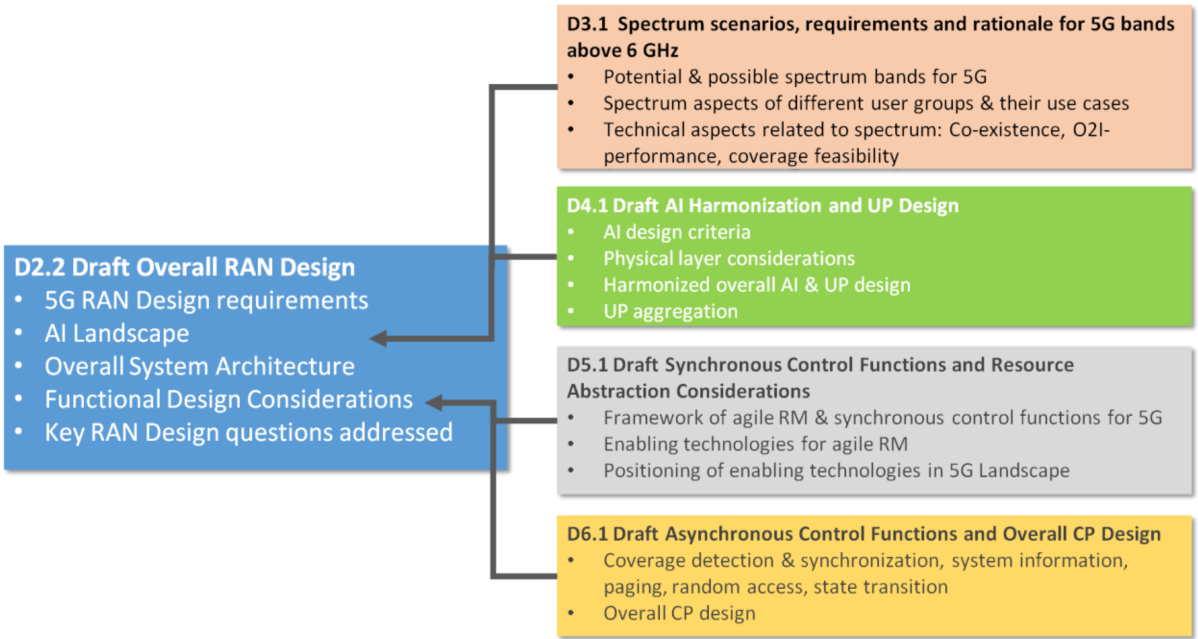


Figure 1-2 Positioning of D5.1 with respect to other METIS-II deliverables.

Figure 1-2 illustrates the role of D5.1 with respect to other METIS-II deliverables. In particular, *D2.2 Draft Overall RAN Design* [MET-II16-D22] provides an overall picture of the 5G RAN design, linking and integrating the technical issues, concepts and solutions covered in detail in each of the other deliverables.

1.2 Objective of the Document

The objective of the deliverable is to present the draft building blocks and enabling technologies required for developing the 5G agile RM framework as highlighted in the scope section. The document provides the initial description of the framework for resource abstraction, context management and synchronous control functions for resource and traffic management in 5G. It also offers an introduction to the future research directions currently planned for developing the target framework.

1.3 Structure of the Document

The structure of the document is as follows. In Section 2, the high-level description of the framework for agile RM and related synchronous control functions is provided. In Section 3, the enabling technologies for the agile RM framework are described in detail. The positioning of the enabling technologies in the 5G landscape and a brief overview of RAN design implications per building block are explained in Section 4. The conclusions and future outlook of the work are presented in Section 5. Finally, Annex A includes further details and analyses of various TeCs.

2 Framework of Agile RM and Synchronous Control Functions for 5G

METIS-II aims to define a new multi-link, multi-layer network ecosystem as part of the 5G landscape. It is foreseen that new flavors of CP and UP integration and protocol adaptation in the 5G landscape can provide opportunities to re-design various functions (e.g., interference management, power control, and RAN moderation) so as to meet the wide range of requirements imposed by diverse new services and applications. Accordingly, assigning services and applications to the most suitable resources is expected to be of paramount importance to fulfill the requirements in an efficient and effective way. To this end, METIS-II aims to develop an agile RM framework. A high-level conceptual illustration for that framework, considering the current assumptions and ongoing investigations, is shown in Figure 2-1. In particular, the agile RM framework operates in the 5G landscape consisting of different and novel deployment options (e.g., ultra-dense networks ,UDNs, and dynamic radio topology based on nomadic nodes, NNs), novel communication modes (e.g., unicast or multicast D2D communication) and new duplexing schemes (e.g., dynamic time division duplex (TDD) in UDN). Further, it is expected that the wide range of requirements from envisioned diverse services and applications will be fulfilled by an overall AI, which comprises different AIVs spanning a variety of spectrum usage types, spectrum bands, and cell types. Accordingly, the agile RM framework aims to dynamically and efficiently assign services to the most suitable resources capitalizing on the available context information. Besides, network slicing is seen as a key enabler for new 5G businesses that support one or more services with their associated constraints and, therefore, RM for network slices is also investigated within the agile RM framework in an AIV-overarching manner.

On this basis, one essential goal is the design of 5G synchronous control functions for the RAN. A synchronous control function [MET15-D64] is coupled with a time-frame structure, e.g., scheduling and power control. That is, the processing of a synchronous control function is time-synchronous with respect to the radio interface in terms of time slots. More specifically, within the framework of agile RM, the aims are

- to investigate a resource abstraction model that provides the means for the efficient integration of the 5G synchronous control functions operating on novel 5G AIV(s) and the legacy ones (e.g., those of evolved Long-Term Evolution (LTE) and Wi-Fi),
- to improve the operation and the performance of typical synchronous control functions (e.g., interference management, short-term spectrum usage, and RAN moderation), and
- to study to which extent AIV-specific and AIV-agnostic RM functionalities are beneficial for the overall RAN design.

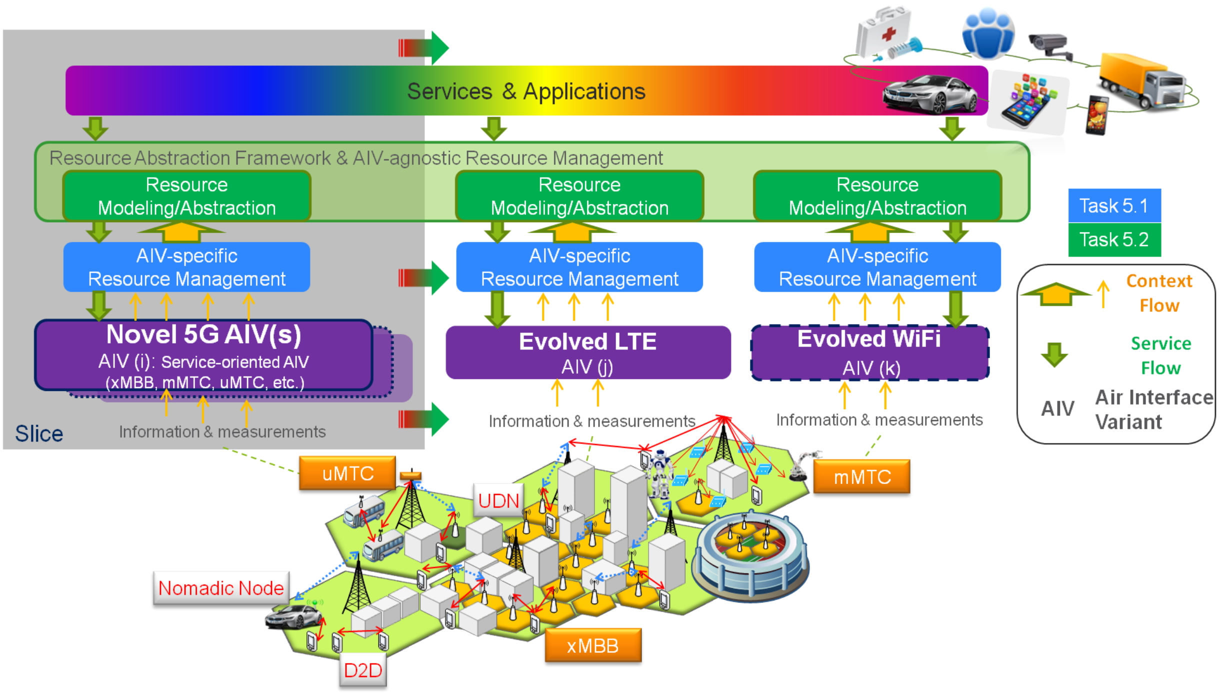


Figure 2-1 Conceptual illustration of the agile RM framework[5] that is investigated in METIS-II.

It is expected that there will be constraints caused by the different timings of the AIVs, different deployment options and the imposed limitations of the legacy networks. One of the goals is then to give insights into control functions and the necessary modifications with respect to the system layout and deployment type. This will in turn assist the work on the definition of the boundaries between synchronous and asynchronous control functions.

In 5G, the notion of a resource cannot be anymore confined to be strictly related to RRM, but instead the considered realm of resources can expand beyond the conventional options[6], such as frequency (i.e., licensed band), time, and power, as visualized in Figure 2-2. Accordingly, the extended notion of resource includes the following five basic types, in addition to the conventional radio resources:

1. Further dimensions of spectrum resources
2. Transmission points (Tx points) along with radio frequency (RF) equipment
3. Soft capabilities, such as processing resources, storage and memory resources
4. Transport network resources
5. Energy

[5] A previous version of this illustration has been published in [BPB+15].
[6] A conventional resource is defined as the resource that is typically used by well-established RRM schemes, e.g., in legacy networks.

A radio resource is already typically considered as part of the conventional notion of resource. It is characterized by time (the duration of the transmission), frequency (the carrier frequency and the bandwidth), and the transmit power. A radio resource is associated with a Tx point to perform a radio transmission. It is possible that a Tx point allocates a radio resource to multiple devices, e.g., by separating them with the help of codes (code division multiple access, CDMA) or spatially (multi-user multiple-input multiple-output, MU-MIMO). The Tx point can be of various kinds: it can be a typical static access node (e.g., a small cell, a macrocell or a remote radio head, RRH, in case of centralized/cloud RAN, C-RAN, deployments), a dynamic access node (e.g., NN) or a device in case of D2D communication. A radio resource can be located in a licensed spectrum band or in an unlicensed spectrum band as a further spectral dimension of radio resources.

Processing, memory and storage resources, which are referred to as soft capabilities herein, are required to perform the processing on the different protocol levels. There is a tendency towards specialized signal processing resources at lower layers, whereas higher layer processing can be executed in general purpose processing resources. The processed data is transmitted and received using RF equipment (such as digital / analog converters, amplifiers, and antennas) through one or multiple radio resources.

Data from and to the core network (CN) needs to be transported to / from the antenna site using a transport network (TN). Transport capacity (e.g., expressed by a bandwidth and a latency requirement) needs to be reserved for this purpose.

The operation of any network element consumes energy, which needs to be managed in order to reduce the overall energy consumption of the network as well as of the devices. In particular, managing energy is important for nomadic (battery-powered) devices.

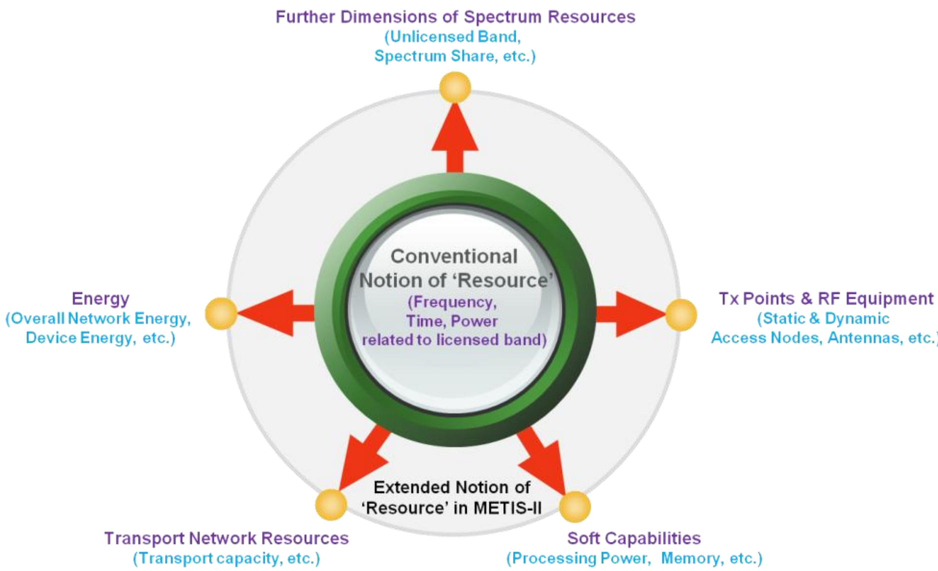


Figure 2-2 Extended notion of a resource in METIS-II including conventional RRM resources.

As mentioned before, the agile RM framework comprises functionality frameworks that are supported by context management. A functionality framework is defined by a set of building blocks that are based on one or more TeCs (see also Figure 1-1). Accordingly, two functionality frameworks are identified, namely, an intra-AIV RM functionality framework and an AIV-overarching RM functionality framework. The AIV-overarching functionality framework takes into account the overall AI comprising various AIVs and, thus, encompasses the considerations on resource abstraction and AI-agnostic RM schemes, while the intra-AIV RM functionality framework operates on a target AIV. It is worth noting that a TeC[7] may relate to one or more synchronous control mechanisms. It is worth further noting that the functions in intra-AIV RM functionality framework can be tailored for specific AIVs and, thus, are resulting in the AIV-specific RM illustrated in Figure 2-1.

The current building blocks are briefly described below and will be detailed in Section 3. It is worth emphasizing that, in the scope of deliverable D5.1, the provided draft descriptions for the functionality frameworks are considered to be the *foundations;* the final design, which will be built on these foundations, will be detailed in deliverable D5.2.

The building blocks within the foundation for **intra-AIV RM functionality framework**:

- **Interference Management:** The techniques for interference management are expected to be essential for 5G networks not only to ensure high capacity and wide coverage of high end-user data rates but also to ensure high reliability for uMTC services. The developed schemes need to cope with the aforementioned 5G landscape and the associated new interference conditions, e.g., due to dynamic radio topology. Also, to materialize the theoretical gains of network coordination in practice, the dependency and impact of the interference management schemes on the X2* interface (see [MET-II16-D22] [MET-II16-WP] for architectural details) between access nodes shall be optimized.
- **Flexible Short-term Spectrum Usage:** While METIS-II expands the notion of resource, the traditional radio resources, such as the available spectrum, are of paramount importance. On this basis, the available resources in the licensed and unlicensed bands are taken into account while addressing the requirements of the target services. To this end, the flexible usage of unlicensed bands takes into account dynamic radio topology that may change by the availability of moving access nodes, such as NNs. Further, the duration and the extent of the usage of unlicensed bands depend on the uncontrolled source of interferers and the dynamicity in topology changes; hence, unlicensed spectrum usage may be adapted in short-time intervals.
- **RAN Moderation:** RAN moderation takes into account the existing network topology and different duplex schemes, and aims at enabling fast on/off switching of small cells to reduce energy consumption while ensuring that service requirements are met.

[7] TeCs are tagged by dedicated IDs, i.e., T5.*x*-TeC*y* where *x* and *y* indicate the numbering, for the sake of easy tracking throughout the report. Furthermore, when an enabling technology has implications on both research directions in T5.1 and T5.2 (see Section 1.1), two IDs are assigned to that enabling technology.

The building blocks within the foundation for **AIV-overarching RM functionality framework**:

- **RM for Network Slices:** Considering the envisioned AI consisting of multiple AIVs, services and the vision of network slicing [MET-II16-D22][MET-II16-WP], RM techniques for inter-slice and intra-slice resources are captured in this building block.
- **Tight Integration with Evolved Legacy AIVs:** This building block analyzes the interworking between novel 5G AIV(s) and evolved LTE. The envisioned resource abstraction framework aims at efficient interworking. Various interworking approaches including possible integration at radio protocol stack are outlined.
- **Holistic RM and AI Abstraction Models:** The agile RM framework operates on a complex multi-link, multi-layer, and multi-AIV 5G landscape. Accordingly, this building block aims to construct a holistic view of the RM. On one hand, RM approaches to deal with the very different service requirements and novel communication variants in a flexible way are highlighted. On the other hand, the protocol stack implications of the split between AIV-specific and AIV-agnostic RM functionality and potential of AI abstraction models are considered.
- **RM for Inter-Network Collaboration:** This building block utilizes software defined networking (SDN) principles towards RM for inter-network coordination among different operator networks and/or different AIVs considering various usage scenarios.
- **Dynamic Traffic Steering:** The mechanisms to enable mapping of a service flow through the right AIV(s) taking into account the envisioned 5G landscape along with the evolved legacy networks are captured in this building block. It is important to note that, herein, mechanisms towards traffic steering aim at fast time-scale RM rather than, e.g., slow time-scale handovers between access nodes and/or AIVs.

Context Management schemes need to be in place for the synchronous mechanisms to operate efficiently in the demanding 5G environment. That is, means to support effectively and efficiently a fast RM are required, where the context data include the ones from users, access nodes, and CN. The trade-off between the amount of data to be gathered, the complexity of RM algorithms and the corresponding enhancements in terms of network performance shall be considered.

3 Enabling Technologies for Agile Resource Management

This section describes the enabling technologies in the format of TeCs for the agile RM. In the following, each identified TeC is introduced and categorized into relevant sections and then described at great length. Section 3.1 describes the TeCs related to intra-AIV RM functionality framework, such as synchronous control functions of interference management and RAN moderation, while Section 3.2 elaborates on the TeCs related to the AIV-overarching RM functionality framework by including TeCs, such as RM for network slicing, tight integration with evolved LTE, holistic RM and AI abstraction models and dynamic traffic steering. Finally, Section 3.3 handles the context management.

3.1 Foundation for intra-AIV RM Functionality Framework

One of the main goals of METIS-II is to develop synchronous control functions which could be used for resource and traffic management over multiple AIVs that form the 5G RAN [MET-II16-WP]. Some of the key considerations for these functions include interference management, dynamic spectrum usage, and RAN moderation. Those functions as presented in this section are employed considering a single AIV, i.e., they are TeCs that need to be specifically tailored to each AIV. Furthermore, with the dynamic nature of the 5G environment and due to the added constraints such as the frequent reconfiguration of the radio links introduced by the use of multiple AIVs in UDNs, adaptive interference management techniques that operate on a very fast time scale may be required. Similar constraints are applicable for spectrum and traffic management which needs to be implemented in a dynamic and adaptive manner in order to satisfy 5G requirements. Specific solutions targeting these factors are discussed in detail in the following sub-sections.

3.1.1 Interference Management

Co-channel interference is an inherent limitation of wireless systems employing universal frequency reuse, i.e., a frequency reuse factor of one. While it maintains high spectrum utilization, the interference limits spectral efficiency and thereby network and user performance, unless some type of interference management is employed. Overcoming interference is therefore essential in ensuring high capacity and wide coverage of high end-user data rates, as well as robust and efficient communication.

A common objective of most interference management schemes relates to improving cell edge user throughputs, coupled with varying levels of network coordination [PSQ+13][HRT+14]. For instance, Inter-Cell Interference Coordination (ICIC) introduced in LTE Release 8 aims to improve cell edge signal-to-interference-plus-noise ratio (SINR) through frequency and power allocation. In a later LTE release, the backward compatible enhanced ICIC (eICIC) framework for heterogeneous networks provides the ability to mitigate interference on data and control channels in frequency or time domain. In the time domain, interference avoidance within eICIC is facilitated using Almost Blank Subframes (ABS) by scheduling the intended and interfering signals on different subframes These schemes were complemented by further enhanced ICIC (feICIC) from Release 11 [3GPP15-36300], mainly focusing on interference handling on user side (via interference cancellation schemes). In frequency domain, Carrier Aggregation (CA) introduced additional degrees of freedom that can be exploited for interference management purposes, as interference is avoided by scheduling the control channels of the macrocell and small cells on different carriers. Fast cross-carrier scheduling of the data can also help to reduce interference when there is a strong aggressor cell present. With Coordinated Multi-Point (CoMP) [3GPP13-36819] it is possible to take a network-wide approach at interference management by considering a larger set of cooperative radio nodes, where the set (cluster) can be either fixed or dynamic. 5G RAN will enable the facilitation of multi-layer multi-node connectivity over one or more AIVs resulting in much higher data rates and additional degrees of freedom for the fast synchronous control. The performance gain of CoMP depends to a large extent on the tightness of the coordination. It is known that CoMP is sensitive to backhaul latency for the signaling, knowledge and accuracy of channel state information (CSI), and large communication overhead, which is the reason why much of the theoretical gains are hard to materialize in practice. In the end, designing a proper interference management scheme depends on the UC, deployment scenario, and size of the cooperative set, while maintaining a reasonable degree of flexibility for the RM.

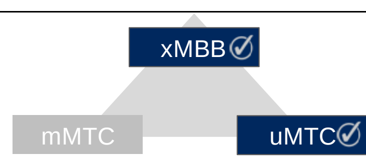
The following TeCs are considered herein:

- T5.1-TeC3: 5G User-centric Interference Management in UDNs
- T5.1-TeC8: Flexible Interference Management for 5G AIVs
- T5.1-TeC11: Interference Coordination/Cancellation Strategy

T5.1-TeC3 provides centralized and adaptive DL interference coordination and cooperation mechanisms focusing on dynamic and heterogeneous ultra-dense topologies while T5.1-TeC11 focuses on a more decentralized approach due to eased requirements on the backhaul. Furthermore, T5.1-TeC8 aims to alleviate high inter-cell interference for cell edge users via Frequency and Quadrature Amplitude Modulation (FQAM) and BS cooperation by altering the stochastic characteristics of interference to a non-Gaussian distribution. Other CoMP schemes can also be used in the context of dynamic cell switch-off for energy consumption reduction during low-traffic hours or with dynamic TDD operation, which are both treated in Section 3.1.3.

5G User-centric Interference Management in UDNs

TeC ID	T5.1-TeC3
Abstract	This work focuses on ultra-dense heterogeneous RAN, where a mixture of fixed (e.g. macrocell) and unplanned (small cells, NNs, etc.) access nodes utilize the same spectrum to enhance spatial reuse. To this end, the flexible

	centralization of Interference Management with low signaling overhead and low complexity is critical to meet the 5G requirements in 5G RAN dense urban deployments, assuming variable backhaul and heterogeneous access technologies with multiple KPIs. In particular we aim to provide different cooperation (CoMP) and coordination mechanisms (ICIC) among heterogeneous access nodes in 5G RAN to mitigate interference in a user-centric and service-oriented manner. A case study with a dense NN deployment in hotspot areas, under a macrocell umbrella was presented. Using system level simulations (assuming 3GPP-compliant parameters), preliminary results show gains of more than 150% in terms of mean cell-edge user throughput when deploying NNs with CoMP and dynamic frequency partitioning, compared to macrocell only deployments.
SotA	In 4G, ICIC [PSQ+13] and CoMP [3GPP13-36819]) were investigated for dense small cell deployments [HRT+14]. In 5G, there are some factors which make the present interference management technologies crucial to meet key 5G requirements. In particular: • The provision of more dense urban cell deployments with overlapping coverage areas and heterogeneous access nodes. • The introduction of dynamic radio topologies (e.g., NNs and cellular-assisted D2D) [MET15-D11] within 5G RAN. • The network slicing concept [NGM15] which allows different UCs to be mapped to different network slices with different KPIs, hence, may result in different levels of interference per slice. • The provision of wireless backhaul between access nodes, especially in higher frequencies (mmW radio) can enable new opportunities for cooperative communications, but also provides challenges regarding the backhaul channel conditions and availability.
Use Case	UC1 “Dense Urban Information Society” [MET-II16-D11]
5G Service Type	
RAN Design Implications	• Impact on the protocol design: There are minimal impacts on the overall RAN protocol design. • Potential interface needs: Mainly new functionalities and interfaces will be required for inter-cell RM and for the coordination of the dynamic radio topology (e.g., due to NNs). The backhaul link measurements and activation commands imply new signaling elements on the wireless backhaul link. Further implications on the RAN design such as inputs / outputs will be further analyzed and elaborated in later stages of the project.

In ultra-dense heterogeneous RAN deployments, we aim at the improvement of the spectral efficiency by enhancing the spatial reuse. To this end, shared spectrum among different access technologies could be a potential solution in order to enable more efficient handling of resources. However, in such case, a holistic inter-cell RM framework is highly required to allocate RAN resources in a way that interference is mitigated while keeping the spectrum utilization high.

The concept of this work is to provide UE-centric interference management by means of selecting overlays of access nodes that can serve users individually, given their diverse service requirements (e.g., having xMMB and uMTC service types). On top of that, coordinated resource allocation and joint transmission are adaptively applied based on the backhaul conditions, the load constraints and the service type.

Here, we provide a case study for a hotspot area and a 5G RAN consisting of NNs under a macro-cell umbrella. In particular, we consider a dynamic network topology comprising non-static access nodes, which emerges as a promising notion enabling flexible network deployment and new services as highlighted in [NGM15]. Within the framework of dynamic network topology, NNs can enable demand-driven service provisioning to increase the network capacity and/or to extend the cell coverage area. NNs can be mounted on cars within a car-sharing fleet, taxi fleet or on privately owned cars. Further, NNs can be considered as a complementary enhancement to today's heterogeneous networks. This case study focuses on the xMBB case, where the target KPI is the enhancement of cell edge user throughput. At later stage, we will provide some additional solutions for uMTC, where the target KPI is to achieve high reliability (99.999%) and to support high number of connections with low data rate requirements.

Figure 3-1 shows an exemplary system model where a number of NNs are activated in hotspots to enhance capacity and coverage and to also offload traffic from the macrocell. Such on-demand activation of NNs implies dynamic densification of the network. Therefore, the NNs are activated at the target service regions only for the required time frame. To this end, the selection of the NNs to be activated can be performed based on the wireless backhaul link quality between the NNs and serving macrocell when the backhaul (BH) link is non-ideal [BRZ+14]. In particular, under composite fading/shadowing conditions (e.g., Rayleigh-lognormal channels), NN selection can be done considering short-term or long-term measurements. Measurements on different frequencies imply a trade-off between the achievable gains and the signaling overhead [BRZ+14].

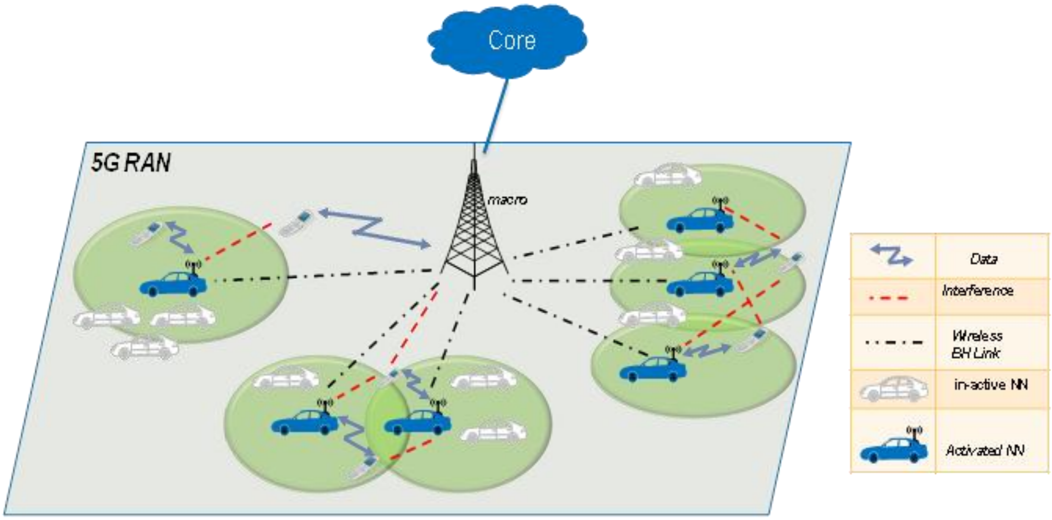


Figure 3-1 5G RAN exemplary model with on-demand activation of NNs.

The key interference management mechanism applied is Joint Transmission (JT) between the access links of NNs (i.e., between NNs and users) when it is possible. Only one mode of JT (coherent / closed-loop) is assumed in our case study, since we assumed static users and the backhaul to be ideal. The selection of candidate users for JT is based on their channel measurements (e.g., Reference Signal Received Power, RSRP) from serving and neighboring NNs. In particular, the metric that was used to help us decide whether a user should be candidate for JT was $\Delta RSRP$:

$$\Delta RSRP = RSRP_{serving\_NN} - RSRP_{neighboring\_NN}.$$

According to [NGM_CoMP15], a reasonable ΔRSRP threshold for CoMP cell selection may be 3~6dB. In this study we defined a threshold of 6dB; hence users with lower delta than 6dB were selected as candidates for JT. Applying JT to many users has some practical limitations regarding the NN load and the BH rate requirements. So the number of the users to whom JT is applied is restricted in practice to a subset of this candidate list (otherwise, the gains by JT would be huge but unrealistic).

Given the number of users with low channel quality, a number of resource blocks (RBs) is reserved for JT and resource allocation between different NNs is performed. For the rest, coordinated scheduling is applied, where dynamic frequency partitioning (or muting of resources for some NNs) is performed. The dynamic frequency partitioning that is used in this study is based on [PSQ+14]. This paper presented a graph-based optimization framework based on interference condition between any two users in the network assuming they are served on similar resources. The optimization problem was decoupled into dynamic graph-partitioning based sub-problems across different sub-channels and the authors proposed solutions using optimal and heuristic approaches. At the final stage, cluster-based resource allocation per sub-channel was applied to find candidate users with maximum total weighted sum-rate.

In this work, this solution framework is applied to the aforementioned scenario with cooperative and overlapping NNs, and will be further extended in later stages of the project to mitigate interference assuming different services with diverse KPIs.

The results are demonstrated in Figure 3-2. The bars show the mean user throughput, in case we activate NNs and also if we perform interference management on top of that. For the BH between macro and NNs, we assumed out-band wireless BH (ultra-low latency, high capacity); hence the BH conditions in our simulations can be seen as ideal and do not affect the per-NN throughput. Interference management is crucial since as the number of NNs increases, the performance is degraded due to interference from surrounding NNs. So, adaptive interference coordination and cooperation (e.g., coordinated scheduling, joint transmission, dynamic NN selection) mechanisms improve spectral efficiency in dynamic radio topologies as well as the user throughput.

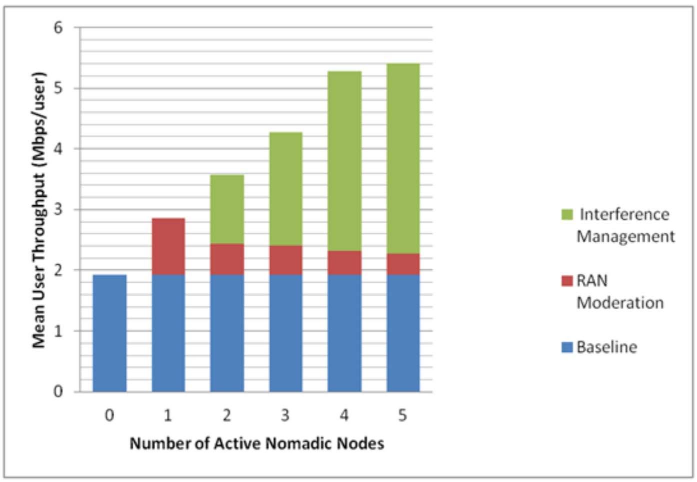
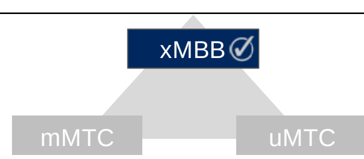


Figure 3-2 Mean user throughput for different NN activations.

Flexible Interference Management for 5G AIVs

TeC ID	T5.1-TeC8
Abstract	One of the key requirements for 5G is the enhancement of what is classically known as “cell edge” performance, to ensure that every user is supported with consistent experience anywhere in the network. Conventional approaches to enhance the performance mainly focus on managing interference (e.g. interference cancellation or interference avoidance), by dealing with interference as a Gaussian element. It is known that the worst-case additive noise in wireless networks with respect to the channel capacity has a Gaussian distribution. From this observation, one can expect that the channel capacity can be increased by an interference design which makes Inter-Cell Interference (ICI) non-Gaussian. In practice, the distribution of ICI depends on the modulation schemes of the interfering BSs. Therefore, an active interference design to improve anywhere performance, particularly in the low SINR regime, can be achieved by

	applying a new type of modulation called FQAM [SAM15]. Furthermore, and as will be shown, FQAM can be applied along different dimensions of the radio resources, namely frequency, space and time, as follows: i) for a frequency-based split of resources, a flexible FQAM resource pool is negotiated among base stations; ii) for a spatial split of resources, advanced beamforming algorithms are incorporated to the use of FQAM, and iii) already established time-based procedures (e.g., ABS) are enhanced with FQAM-based subframes to effectively improve the data rate of the edge users experiencing heavy interference. Using these observations, an RM framework is examined where clusters of mutually interfering cells (and the users therein) are grouped accordingly, such that low-SINR users can benefit from the new type of modulation scheme in interfering BSs to improve performance.
SotA	The performance of a wireless communication network has been inherently limited by interference. There is a quite rich literature on interference mitigation techniques including interference randomization, interference cancellation as well as interference coordination among multiple contending cells in both macro and small cell environments. However, recently, there have been new attempts to investigate the stochastic characteristics of interference in wireless networks. In particular, it has been shown that the distribution of ICI is near-Gaussian in presence of Orthogonal Frequency Division Multiple Access (OFDMA) with QAM when all sub-carriers are fully loaded. This has been proved to be the worst-case scenario [SA13] in interference-limited environment. So, it has motivated research on methods to alter distribution of interference into non-Gaussian forms. Recent studies show that combining QAM with Frequency-Shift Keying (FSK) into FQAM can be advantageous to improve the performance of users in low SINR regime [HSL+14]. From standardization perspective, the reader is encouraged to review the first two paragraphs of Section 3.1.1 where a comprehensive survey of interference management techniques is provided.
Use Case	UC1 “Dense Urban Information Society”
5G Service Type	
RAN Design Implications	• The coordination between the cells when using the frequency-based FQAM method is simplified by not exchanging interference management information (such as X2 RNTP in LTE [3GPP16-36.213] or any X2AP messages in general) in cases when it is not suitable or critical for performance, thereby reducing signaling and delay. Furthermore, signaling information exchange among BSs via supporting protocols is required to determine the beams or the subframes where FQAM should be applied, this exchange being feasible both using a distributed or a centralized approach. • The necessary notification between adjacent cells can be on X2* or can

	be facilitated by multi-connectivity (e.g. low frequency AIV), in particular, if one leg of multi-connectivity can achieve a higher visibility of interference pattern per contending zone via UE reports. As a result, they can facilitate setting the size of reserved pool per contending zone per interferer, per FQAM beams, or per FQAM-based subframes by sending a broadcast (or customized) message(s) to such cells. • Extra information regarding the perceived level of interference, topology of network, and X2* status can be received from other layers or TeCs (in the same building block) in dynamic topologies with volatile inter-node status even though the algorithm may also act in a standalone manner. • The framework leads to reduced signaling messages and procedures that can impact the existing specifications (to modify and expand towards these findings). In particular, exchanging new information like size or location of common or individual reserved pools via multi-connectivity enabled low-band support can be further explored.

The main motivation behind T5.1-TeC8 is to achieve more consistent performance and user quality of experience as the users move across the network from interference-free zones closer to certain BSs towards critical zones with contention from neighboring cells. Here we provide an initial description of FQAM-based interference management approaches across the frequency, space, and time dimensions to improve performance of low-SINR users, thus leading to a flatter architectural design for different 5G AIVs.

1) *Frequency-based FQAM approach:* Interference management via FQAM can be achieved by allocating dedicated spectrum to FQAM transmissions in interfering cells where the UEs in victim cells will be served from. We intend to build an efficient and agile RM strategy on interference management to enable fast yet flexible overhead interference control between clusters of mutually interfering cells (or users therein). To achieve the benefits of FQAM in the cell edge of victim cells while maintaining high throughout in interfering cells, an agile RM can be adopted where low-SINR users are scheduled from a flexible and adaptive reserved resource pool, negotiated between neighboring cells as depicted in Figure 3-3.

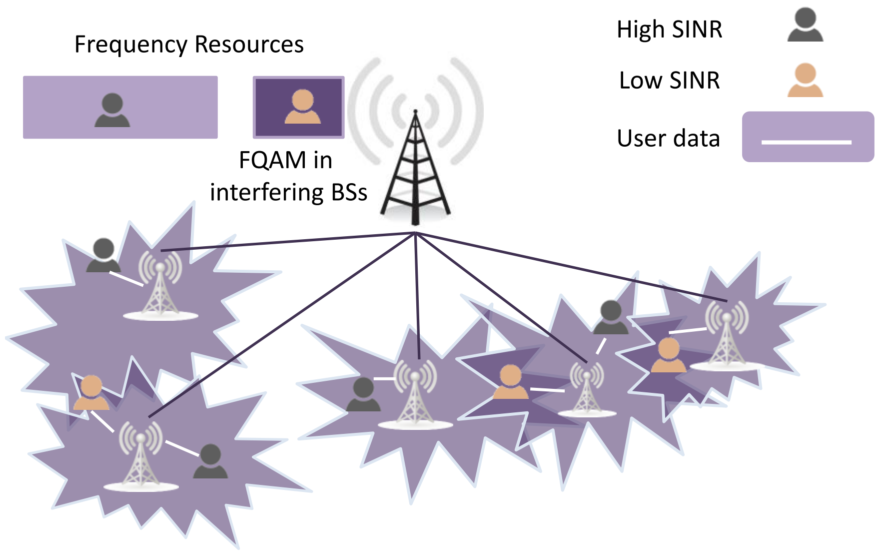


Figure 3-3: Frequency-based FQAM for flexible interference management.

2) *Space-based FQAM approach:* Beamforming is a spatial signal processing technique used in wireless communications for directional signal transmission or reception. Multiple beams can be formed to transmit multiple data streams orthogonal to each other and then different modulation schemes can be employed separately. Therefore, beams can also be regarded as resources, which creates a new degree of freedom to dimension FQAM and QAM resources in an orthogonal manner. As a result of highly directive transmission and reception in beamforming, it is unlikely that a user receives ICI from a large number of interfering small cells, which makes FQAM a suitable solution to tackle the ICI in such a case. When a small cell is able to transmit multiple data streams via multiple beams, different modulation schemes can be used depending on the interference situation, e.g., QAM and FQAM are used for low and high interference cases, respectively, as shown in Figure 3-4. Each cell transmits using two independent beams to two different UEs, e.g., S1 to $U_{1,1}$ and $U_{2,1}$, respectively. Some of the beams, e.g., the light purple beams, do not cause interferences. On the contrary, the dark purple ones cause interferences to other UEs when transmitting to the associated UE. For example, dark purple beam of S3 generates interference to $U_{1,1}$ and $U_{2,1}$ while transmitting to its own associated $U_{3,1}$. While at the same time, $U_{3,1}$ also suffers from the interferences generated by S1 and S2. Actually, since UEs associated with dark purple beams are located in the overlapping area, each cell is an aggressor as well as a victim in such a scenario. Thus, FQAM can be activated for all dark purple beams to achieve improved performance.

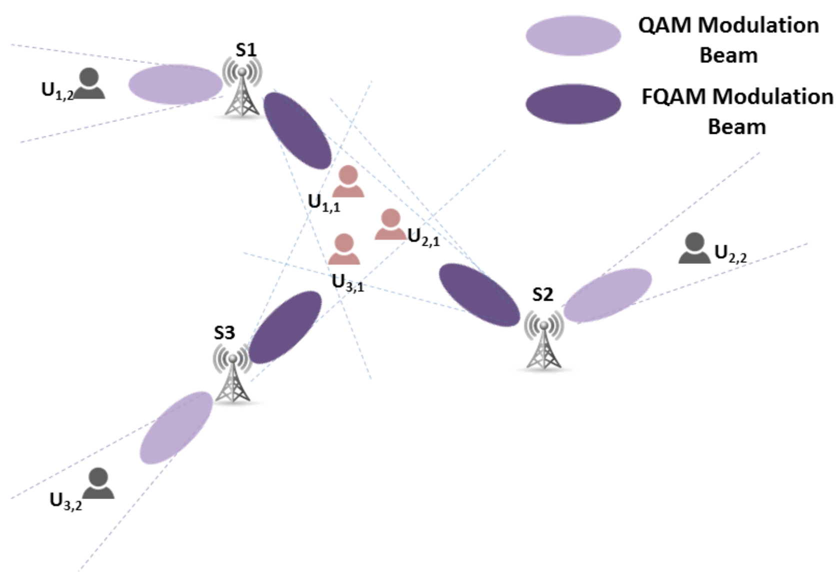


Figure 3-4: Beamforming-based FQAM interference management.

3) *Time-based FQAM approach:* Finally, a time domain approach which employs flexible modulation can be implemented using similar idea as ABS. Instead of keeping macrocell completely silent (in the sense of not transmitting any UP data) in certain subframes, FQAM-based subframes can be employed where macrocells are allowed to transmit using FQAM so that the UEs in the small cells still receive interference but their robustness to interference increases as a result of the usage of FQAM.

The way of applying different modulation schemes to different frequency, space or time resources can additionally be affected by the type of synchronization / co-ordination that exists between cells in question.

Light Coordination

If cells are tightly synchronized but lightly co-ordinated then the proposed mechanism is particularly well suited. If cells are not synchronized, whether to apply the proposed mechanism can be decided based on additional factors, such as the level of ICI perceived by the users as well as the target Quality of Service (QoS) level.

The interference management is mutually incorporated in the above lightly-coordinated cases among cells by reserving a common resource pool that will be agreed in a static or semi-static manner. Any low-SINR users can be served from the common reserved pool wherein all interfering BSs apply FQAM as modulation for active interference management as shown in Figure 3-3.

The size and location of this common reserved pool with respect to the total system resources can be pre-determined and entered into a look-up table, minimizing the exchange of information between interfering cells. Alternatively (or in addition), the location of the common reserved pool can be determined using a hopping pattern known to all the participating cells, again minimizing the need for information exchange while ensuring frequency diversity. This provides an additional degree of freedom for scheduling of users in participating cells – since now the location of common reserved pool changes, participating cells are not required to assign FQAM to the same users all the time; rather than shifting around the resource allocations for users who are assigned FQAM, it could instead assign FQAM to users who happen to be allocated resources in the common reserved pool.

Medium Coordination

As an extension of the scheme to more dynamic (coordinated) cases, the size of common resource pool between participating cells can be dynamically adjusted based on the level of load in this area. Hence, if more users are concentrated in critical zones, or if the level of interference experienced by certain users is above a certain threshold regardless of the absolute number of users, the reserved pool can be expanded whereas in low-load / low-interference (acceptable QoS) scenarios with less contention, the reserved pool can be reduced.

Additional parameters can influence the dynamics in the size of reserved pool including: X2* link status (availability of and delay on the link; e.g., if X2* link is unavailable or if the exchange of interference management information over it would incur unacceptable delay then light coordination is better suited), spectrum characteristics (such as quality due to existing interference or changing propagation environment).

High coordination

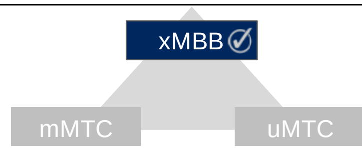
Instead of defining a common resource pool across all cells in question, each interfering cell may adjust the size of reserved pool based on the level of interference introduced to other cells in highly coordinated cases. Therefore, the reserved pool (with FQAM) will not be uniform across interfering cells, i.e., high interferers may have larger reserved FQAM pool to protect victim cells whereas others may have smaller reserved pool with FQAM.

A flexible reserved pool as above requires more individualized interference updates from participating cells. If an interferer receives multiple notifications from neighboring victim cells, it should set the size of reserved pool based on the request with maximum demand.

Interference Coordination/Cancellation Strategy

TeC ID	T5.1-TeC11
Abstract	T5.1-TeC11 defines a procedure for orthogonalizing the transmissions of neighbor cells, forming a “cell cluster”, by means of spreading and scrambling precoding. This will enable the mobile station to undo the precoding procedure, if the coordination pattern used in the precoding is known, and therefore receive the target cell transmission without interference from any other cell in the cluster. The procedure will be implemented by means of a control plane based interference management (i.e., without requiring actual UE data to be present in several base stations) between cells involved in a cell cluster and

	mobile stations in a cell border edge position. This control plane-only based procedure enables enough flexibility to easily adapt its behavior to a dynamic scenario, in which the optimal coordination cluster may change over time. The control plane information required in each cell cluster is just the coordination and scrambling pattern to be used, therefore it represents a low overhead procedure. The spreading and scrambling precoding is applied over the complex baseband symbols, currently transmitted in the scheduled OFDM time-frequency grid, but similar procedure could be applied to similar waveforms such as F-OFDM, GFDM, FBMC, UF-OFDM, etc., described in [MET-II16-D41]. This TeC provides also an increased SINR over any other signal from any cell even if it is not part of the coordination cluster, in which case signals are not orthogonal, but are protected by the spreading factor used. Another characteristic of this spreading mechanism is that it provides a coordination mechanism that does not require the schedulers to be coordinated within the access points in the clusters. Therefore, schedulers in different cells keep the flexibility to select the optimal time frequency assignments to their served UEs, accordingly with their CSI and throughput requirements.
SotA	Different strategies may apply to different scenarios: • **Static interference management**. In which no information exchange is needed between different access points, since the procedure is static. This is the case for example in basic ICIC defined in LTE Rel.8, in which the frequency band is partitioned and assigned to access points so as to avoiding the use of the same frequency by two access points with overlapping coverage areas. • **Control plane interference management**. In which the information exchange between the different access points does not require to include the actual data served to the UEs, but control plane information of radio resource split. This is the case for example in eICIC used in LTE-A, in which a procedure for signaling ABS is defined, allowing a semi-static coordination of radio resources with a Time Division Multiplexing mechanism. • **Data plane interference management**. In which actual UE data plane information is exchanged between the different access points, as well as the appropriate control plane. This is the case for example in CoMP JT technology (as described in [3GPP13-36819]), in which data to a UE is (coherently or non-coherently) simultaneously transmitted from multiple points (cooperating cluster) in a time-frequency resource, to improve the received signal quality. Static interference management provides suboptimal solutions, since they do not adapt resource split taking into account the scenario dynamism, offering a coarse resource split in which the system capability is to some

	extent underused. On the other hand, user plane interference management requires very low latency and high throughput backhaul, as well as additional processing at the access points, therefore significantly increasing the costs associated to network deployment, and also hindering the introduction of changes in the access point cooperating cluster or the adaptation to new deployments (e.g. heterogeneous networks).
Use Case	UC1 "Dense Urban Information Society", and to some extent UC3 "Broadband Access Everywhere".
5G Service Type	
RAN Design Implications	From the point of view of the interchange of new overhead control information between access points and UEs, the implementation of this TeC will require the following steps: • Procedure for designation of a coordinator of a cell cluster. This coordinator should decide on cells belonging to the cell cluster, the scrambling patterns, and the order of the involved cells. This procedure needs to be standardized if base stations from different vendors are present, otherwise it could be based on proprietary solution. • Using the X2* interface between neighbor cells the cells will successively communicate to each other the common scrambling pattern and the spreading patterns already selected from previous cells. Initially, in a cluster with M cells in which the transmission of N subcarriers is intended to be coordinated, the number of possible spreading patterns is M*N. After the first cell selects a spreading pattern (any random algorithm based in the cell ID could be used) there are a remaining number of (M-1)N patterns orthogonal to it, and so successively until the last cell selects the only orthogonal pattern available. This process should be completed for all successive cells in the cluster, accordingly with the order planned by the coordinator. • The UEs at the cell border, for which this procedure is intended to be used (in each cell a mix of UEs served with and without the application of this TeC can be freely mixed up) should be aware (a down link control channel like LTE PDCCH could be used for this indication) of both the common scrambling pattern used in the cell cluster, and the spreading pattern used by the cell to which the UE is connected.

T5.1-TeC11 is based on the clustering of cells, with the presence of UEs being in the coverage area of several cells, and therefore susceptible of being interfered by them.

The main idea is to create a mechanism to orthogonalize the signals transmitted from a specific time/frequency grid zone from all the cells in the cluster. This time/frequency grid zone will be determined for a number of subcarriers and a number of symbols duration, and will contain all the symbols used for the UEs in cell edge, i.e., UEs that could be interfered by one or several cells in the cluster.

The names of the values used in this TeC are:

- M as the number of cells composing the "cell cluster" to be coordinated;
- N as the number of subcarriers in which the orthogonalization process will be carried out;
- T as the number of symbol time slots (in the time/frequency grid) in which the orthogonalization process will be carried out.

The TeC procedure consists of applying to the complex symbols, in the selected time/frequency grid of the OFDM-like signal, a precoding composed by the application of a scrambling and spreading mechanism. This precoding is based on a scrambling pattern common to all cells, and cell-specific spreading patterns, which are orthogonal between each pair of cells in the cluster.

The spreading mechanism is based on M·T-length DFT of the complex symbols in the time/frequency grid selected, as graphically shown in Figure 3-5. Therefore, the complex symbols originally planned for information to the UEs in the cell edges, corresponding to a[i,n], being i the number of subcarrier, are spread over M consecutive transmission time intervals (TTIs). The M·T symbols transmitted and named as b[i,m] for each subcarrier are obtained by the following DFT:

$$b[i,m] = M \sum_{n=0}^{T-1} a[i,n]\, e^{\left[-j2\pi(M\cdot n + k_i)\frac{m}{(M\cdot T)}\right]}$$

Being k_i a natural number 0< k_i < (M-1), comprising the coordination pattern of each specific cell. Therefore, the coordination patterns are orthogonal coordination vectors, one for each of the M cells included in the coordination cluster. These coordination vectors are composed by N pseudorandom values, each one being any value from 0 to M-1, i.e., the M coordination vectors will be:

$$k_i^1 = [k_0^1, k_{12}^1, \ldots\ldots, k_{N-1}^1] \quad \text{cell 1}$$

$$k_i^2 = [k_0^2, k_{12}^2, \ldots\ldots, k_{N-1}^2] \quad \text{cell 2}$$

....

$$k_i^M = [k_0^M, k_{12}^M, \ldots\ldots, k_{N-1}^M] \quad \text{cell M}$$

The orthogonality is achieved by selecting patterns which guarantee that:

$k_i^a \neq k_i^b$ for different cells $a \neq b$, and for any value of subcarrier i.

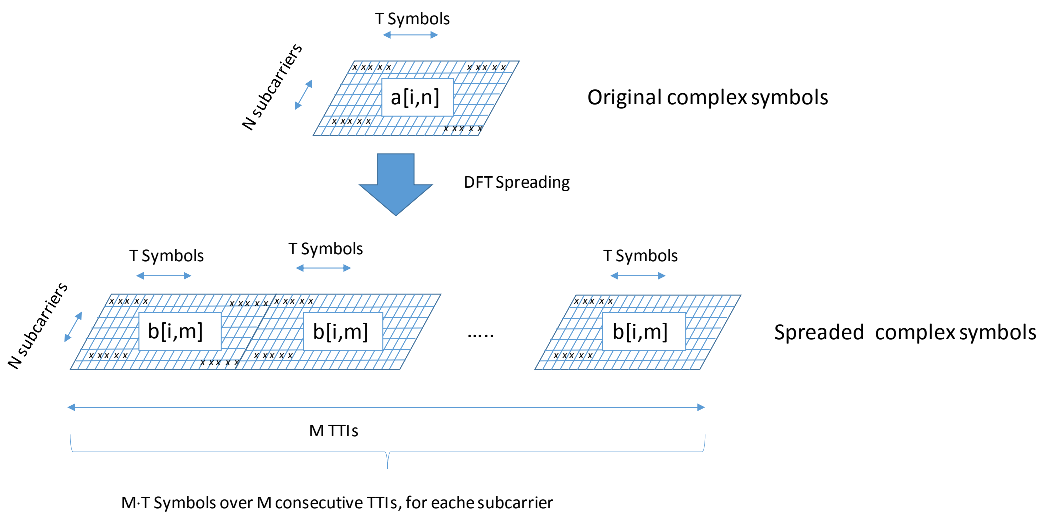


Figure 3-5: Signal spreading over M TTIs.

It should be taken into account that the number of cells in the cluster M is identical to the number of TTIs in which the original complex symbols are spread by the DFT, and it therefore impacts the additional latency introduced by the TeC.

After the described spreading procedure, the complex symbols are scrambled previous to their transmission. The scrambling is based on a randomizing pattern common to all the cells within the coordination cluster, and takes place with all the symbols initially spread over M consecutive TTIs. This scrambling operation (based on a pseudo-random pattern characteristic of each coordination cluster) avoids the occurrence of the periodical pattern associated with the DFT nature of the spreading operation.

Figure 3-6 shows the procedures which will need standardization, in order to incorporate this TeC to current OFDM RAN technology. It shows the procedures for expanding from initial OFDM complex symbol $a(i)$ to M symbols $b(i)$ split over M different TTIs, as well as the de-spreading procedure in the UEs. Further details on the evaluation methodology are provided in Annex A.1.

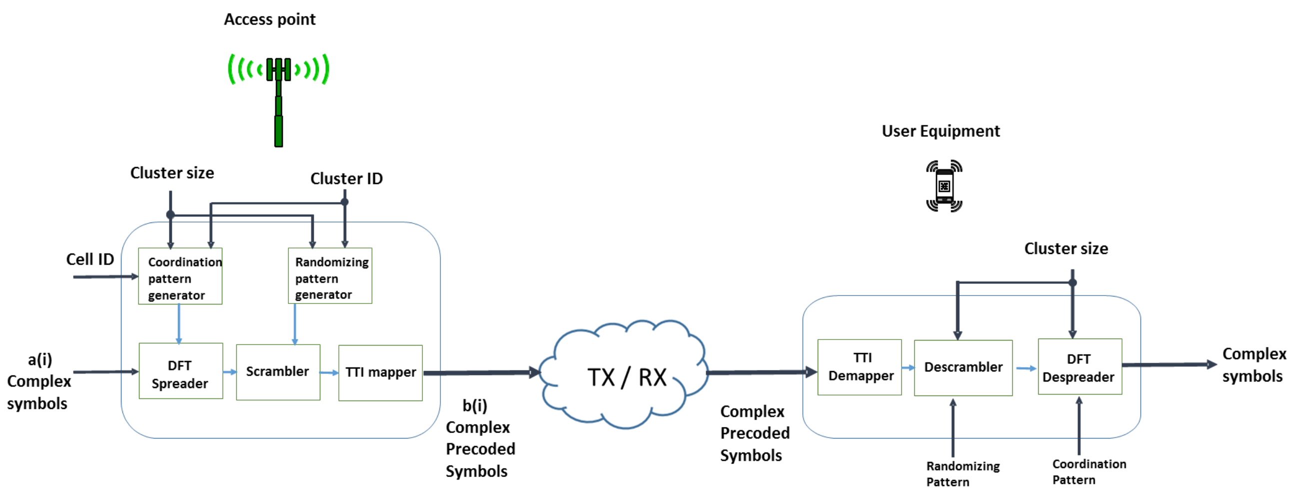


Figure 3-6: Access point to UE DL with interference coordination.

The drawback of the proposed TeC will be the increase in minimum AI latency, since several TTIs will be required to decode a single transmission. However, the TeC is to be applied only on UEs in the cell border experiencing ICI. It is worthy to note that this TeC also requires time domain synchronization, as it is also required in more advanced ICIC mechanisms as LTE Rel.10 eICIC, in which ABSs are used for interference coordination.

3.1.2 Flexible Short-term Spectrum Usage

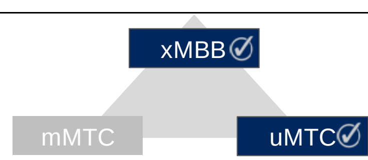
Within this building block, novel control mechanisms are discussed and evaluated by examining new solutions of fast spectrum usage, such as the introduction of a virtualization layer that achieves a fast and seamless fragmented spectrum usage, including low and high frequency bands. Adaptations of the control mechanisms are necessary to support efficient and fast resource allocation because of the different degrees of integration of the AIVs on one side and the set of available radio front-ends and frequency bands on the other side. One possible way to support seamless fragmented spectrum usage is the introduction of spectrum virtualization because it decouples the strong relationship between the physical layer resources with the RF units. It will allow flexible fine-grained allocation of frequency resources for optimum transmission of short and long data bursts in case of separation of UP and CP.

The following TeC is considered herein:

- T5.1-TeC4: Carrier Aggregation and Coordinated Resource allocation

T5.1-TeC4 provides centralized and adaptive RM when aggregating both licensed and unlicensed bands in dynamic ultra-dense heterogeneous topologies, where the usage of unlicensed resources may be adapted in short time intervals, to cope with un-controlled interference sources and dynamic radio topologies.

Carrier Aggregation & Coordinated Resource Allocation

TeC ID	T5.1-TeC4
Abstract	The fast CA between 5G AIVs and Licensed Assisted Access (LAA) in dynamic radio topologies is a new challenge which is investigated thoroughly in this TeC. There are two open questions to be answered: 1) At first, how to efficiently allocate extra resources to users from a resource pool of unlicensed bands, so as to meet the service specific requirements, especially when these users support different services. 2) Moreover, how the control information and the signaling for the CA are handled dynamically, assuming heterogeneous access point and dynamic radio topologies (e.g. NNs, cellular-assisted D2D). Therefore, this TeC proposes the aggregation of additional resources from a pool of unlicensed bands which, due to high interference from other sources, need to be coordinated. The problem of this study is how to optimally select these extra shared resources in order to 1) optimize the preferred KPI per service (or slice) and 2) avoid interference from the simultaneous utilization of the same bands by neighboring access nodes. In other words, this can be seen as a multi-objective cross-carrier resource allocation problem, subject to the aforementioned constraints and given the inputs from our proposed interference management TeC T5.1-TeC3.
SotA	In literature, CA is widely investigated [PSW+13][HVM14]. In this direction, LAA can be seen as a good candidate to boost LTE coverage using small cells in both licensed and unlicensed bands in a cost efficient manner. In this context, the licensed channel remains the primary carrier, and the unlicensed can be used for best effort service upon availability. LAA is being standardized by 3GPP in Rel. 13 and can offer LTE DL speeds up to 450 Mbps. One of the key challenges in LAA is to ensure fair co-existence of LTE in unlicensed bands with other technologies like WiFi. To this end, mechanisms like Listen-Before-Talk (LBT) could effectively co-exist with WiFi and provide high spectral efficiencies. With LBT, the BS can more dynamically occupy the channel based on the detected medium status, which can both alleviate the delay issue and effectively balance the channel occupancy among co-existing transmitters. In this study, we propose interference-aware, opportunistic, and dynamic cross-carrier RM which is based on different 5G service requirements and the availability of LAA in dynamic radio topologies. The signaling and coordination of heterogeneous access points (e.g. NNs [MET15-D11], small cells) will be also the focus of this work so as to provide fast scheduling decisions in an ultra-dense heterogeneous 5G RAN deployment.
Use Case	UC1 “Dense Urban Information Society”
5G Service Type	

RAN Design Implications	This approach will provide minimum impact on the protocol design. Mainly new interfaces for the coordination between access nodes belonging to different access technologies (e.g., NNs) will be provided. In particular interfaces between NNs and NNs with macro / small cells need to be studied. For the effective and efficient utilization of the unlicensed spectrum, AIVs should allow interference estimation also on the unlicensed bands. The inputs / outputs as well as the potential impact on standardization will be further analyzed in later stages of the project.

In this study, coordinated scheduling of the RAN resources is under investigation, where unlicensed spectrum is utilized on top of the initial inter-cell RM mechanisms which are investigated in T5.1-TeC3. To do this, we need to identify which access points are utilizing shared unlicensed bands and coordinate them in time and frequency domain so as to minimize interference and maximize the target KPI gain. Otherwise, the uncoordinated use of these resources will create severe interference and limit the gains of the extra spectrum assignment. Here, another key parameter is the presence of multiple service types, which may have different KPIs. In other words, the assignment of extra resources is prioritized in a per-slice manner so as to ensure that their requirements are met. In this direction, the signaling and complexity requirements will be also investigated.

In particular, the unlicensed spectrum in 5GHz bands via dynamic radio topologies (e.g., NNs, cellular-assisted D2D) is investigated.

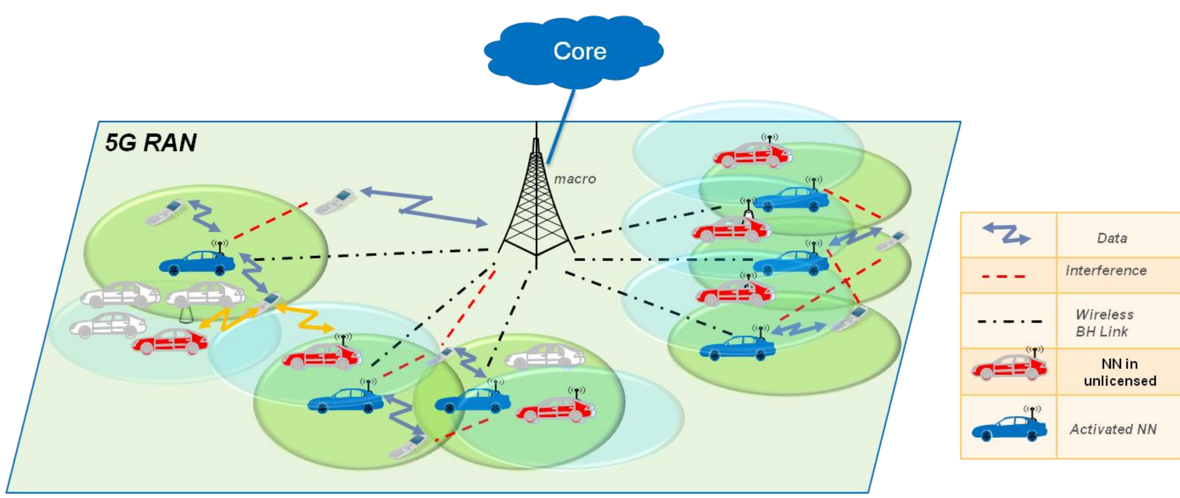


Figure 3-7 5G RAN exemplary model with NNs operating in licensed / unlicensed bands.

Figure 3-7 shows an exemplary system model where a number of NNs are activated in hotspots to enhance capacity and coverage and to also offload traffic from the macro. One of the major limitations when employing a large number of NNs in close proximity is the interference which can be created by other NNs sharing the same spectrum. The operation of NNs in both licensed and unlicensed bands, when the interference in licensed bands is critical, could be a potential solution meeting the tight KPI requirements for different services. Nevertheless, to achieve high gains in practice this operation should be coordinated.

Figure 3-8 shows a scenario, where a macrocell uses licensed bands for 5G AIVs and the NNs use both licensed and unlicensed (5 GHz) bands. Here, other types of small cells might be also included apart from NNs. The scheduling of resources in both licensed and unlicensed bands can be performed after coordination in distributed or centralized manner; and the placement of such decisions are further investigated.

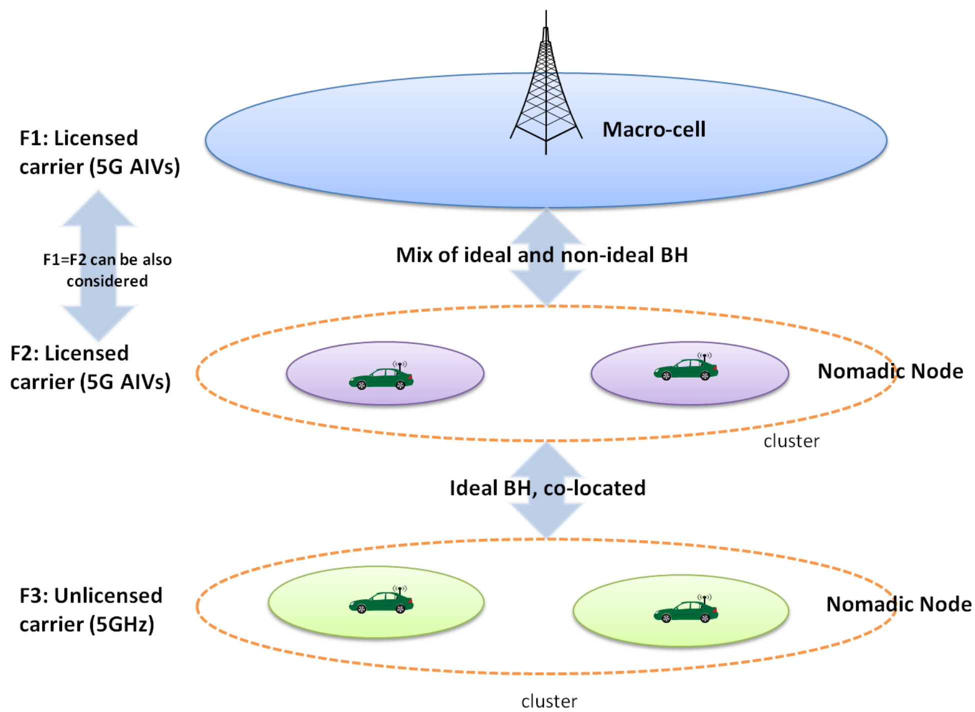


Figure 3-8 Carrier Aggregation scenario using NNs.

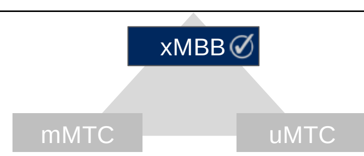
3.1.3 RAN Moderation

The main goal of RAN moderation is to operate the optimal amount of nodes under optimal traffic, DL/UL frame structure and interference conditions. In the following, RAN moderation in 5G networks, especially considering UDNs, is realized through two types of approaches. The first approach proposes to use a scalable resource allocation algorithm using dynamic TDD and joint transmission / reception techniques to improve the performance of active users in neighboring cells. The aim is to increase the energy efficiency with no negative impacts on the throughput performance. Through the second approach, the use of dynamic point selection and joint transmission techniques to optimize the number of active 5G cells for energy savings. In this approach, a centralized scheduler is assumed to control a group of cells, enabling short term cell discontinuous transmission (DTX) strategies. Both approaches are targeting optimal utilization of the resources in each cell either through distributed or centralized schemes. Those enhancements are essentially intra-AIV functionalities.

The following TeCs are considered herein:

- T5.1-TeC6: Multi-cell Coordination for Ultra-Dense Network Employing Dynamic TDD
- T5.1-TeC10: Dynamic Cell Switch-off

Multi-cell Coordination for Ultra-Dense Network Employing Dynamic TDD

TeC ID	T5.1-TeC6
Abstract	In cases of low traffic where some BSs may not have a user to serve, multi-cell coordination, in terms of CoMP joint transmission or joint reception, in the context of dynamic TDD can be employed to improve the performance of active users in nearby cells. Determining which BSs to use to help a certain cell (either in UL or DL) and which ones should remain “idle” is an important RM problem, in which user throughput and energy efficiency are in a trade-off relationship. This TeC proposes a scalable resource allocation algorithm and evaluates the trade-off between the two metrics.
SotA	The following aspects have been considered in the past with respect to dynamic TDD: • Importance of centralized coordination in UDN [VHM+14] • Feasibility and performance in local area and UDN with very low network utilization [JRK12][CS15][AHT+11] To the best of our knowledge, the combined problem of dynamic duplexing and joint transmission or joint reception remains largely unexplored in literature.
Use Case	UC1 “Dense Urban Information Society”, UC2 “Virtual Reality Office”
5G Service Type	
RAN Design Implications	• Minor implications on the RAN design are expected. Signaling information will need to be exchanged between BSs operating in TDD possibly at fast time scales to indicate cases of low load and high interference in time slots. Additionally the type of cooperation would need to be signaled. • Information exchange between adjacent cells could be carried out over the X2* interface.

T5.1-TeC6 focuses on scalable RM for UDNs in dynamic TDD operation, whose feasibility in dense networks is well-studied [VHM+14][JRK12][CS15]. Dynamic TDD refers to systems where the switching point in the radio frame is flexible and adaptable to fast (instantaneous) traffic variations. Fast-changing traffic is expected to be more common in UDNs where network utilization, on average, can be low. More adaptive time-resource allocation combined with the lower network utilization can bring about considerable performance gains. The flexible resource allocation in each TTI (or longer) means that new types of co-channel interferences such as user-to-user and BS-to-BS are generated. These cross-link interferences originate from the UL-DL traffic asymmetry as UL and DL transmissions take place in the same frequency-time resources, mostly on the back of cell edge users. Low average system utilization also implies that some BSs may not even have a user to serve. Those BSs can instead be employed to improve the performance of existing users by means of multi-cell coordination and CoMP joint transmission or joint reception, which is the focus of this TeC. The concept is illustrated in Figure 3-9 for a simplistic three-cell network. A distributed solution may be preferred in UDN from a scalability viewpoint. In addition, further details on the evaluation methodology are given in Annex A.2.

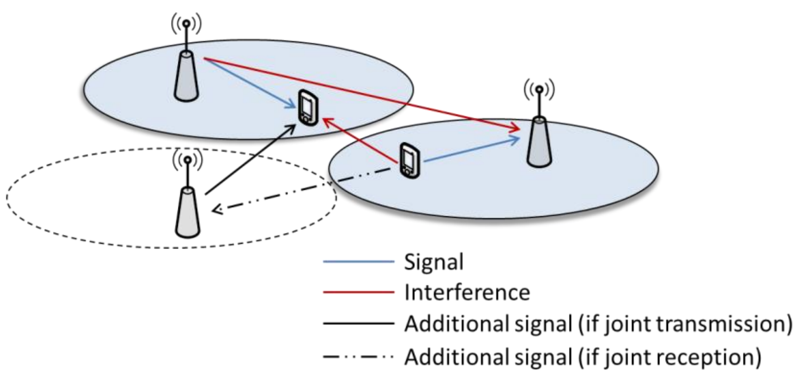


Figure 3-9 Three-cell network example of the proposed concept.

The half-duplex nature of BSs and user equipment considering a TDD system means that there will be a mix of single transmissions, single receptions, joint transmissions, and join receptions in the network. For active cells the transmit direction is determined by the instantaneous traffic demand, whereas for “idle” cells it will depend on what maximizes the system objective the most. The performance is evaluated using a greedy search algorithm with the condition that an “idle” BS is only added if the system performance, either network throughput or network energy efficiency, is also improved. While including more BSs can improve the performance of some vulnerable users, in the DL it will also introduce more interference, thereby offsetting some of the potential gain.

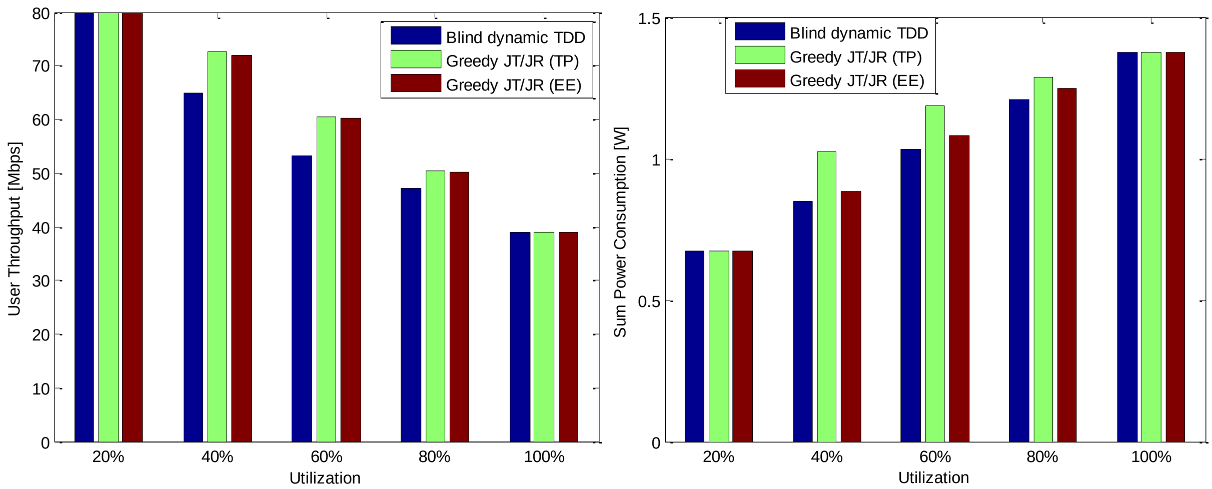


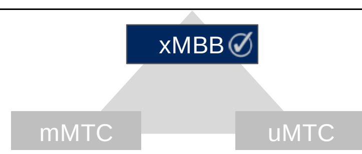
Figure 3-10 (a) Average user throughput (left); (b) Network power consumption (right).

The average user throughput with varying levels of utilization is shown in Figure 3-10 based on the deployment and environmental indoor office scenario from [MET-II16-D11]. As a baseline, blind dynamic TDD is employed (see [CS15]) which refers to a system where no inter-cell coordination is involved. To model the low network utilization associated with UDN, the number of active users is assumed to be less than or equal to the number of BSs in average sense. In theory, increasing the number of data streams for a single user (20% utilization in this case) should always benefit the system performance from throughout perspective. In practice, though, this is not the case when the received signal level is already high and above some SINR threshold, as shown from Figure 3-10(a). Highest MCS is assumed to be 256-QAM with maximum spectral efficiency of 8 bits/Hz per data stream. Adding more BSs may therefore not provide the expected high performance gain when traffic demand is exceptionally low. On the other hand, when traffic load is moderate, interference is present, and the received signal is within the range for accurate detection and estimation, the non-coherent power gain shows 6-14% system performance improvement in our simulations.

This gain comes at the expense of increased network power consumption as depicted in Figure 3-10(b). The trade-off is most visible at lower network utilization, where adding more BSs in theory is always preferred even if throughput gains are minuscule and relative power consumption increase is high. When network energy efficiency is taken as the cost function, performance gains for the average user throughput remain high for the considered use case, while at the same time keeping energy costs down.

At full BS utilization, the gain is non-existent since there are no more “idle” BSs to add. So, while this type of scheme may be beneficial in low to moderately loaded networks, at full network utilization the performance reduces to that of the baseline scheme.

Dynamic Cell Switch Off

TeC ID	T5.1-TeC10
Abstract	Network densification is recognized as one of the main enablers to face the increasing amount of traffic that will characterize future networks. Cell densification could be achieved through the deployment of heterogeneous networks where the traditional macro coverage is enhanced through a dense layer of small cells deployed where traffic requests are higher. By exploiting a C-RAN architecture, a high level of coordination can be achieved between the cells. In particular, scheduling of the traffic can be done at a centralized level so that when traffic is below the peak only the required amount of radio nodes are activated. Moreover, by exploiting coordination approaches like JT, the number of cells that should be activated can be further reduced. This approach has been studied for 4G networks, and has been further investigated considering enhanced power models that will be available with 5G BSs.
SotA	Energy consumption in mobile networks has been widely studied [EARTH][5GREEN], and it is expected that future transmission nodes will be able to scale their consumption, based on the actual amount of traffic that is served, in a more efficient way than nowadays a system does. Mechanisms that enable fast on/off switching of nodes already exist, exploiting a “sleep mode” state [EARTH]. In [MET15-D33] it was shown that when a highly dense network is deployed and traffic is below its peak, it is possible to exploit traditional CoMP schemes such as non-coherent JT and DPS/DPB (Dynamic Point Selection/Dynamic Point Blanking) to reduce the number of active transmission nodes necessary to serve the existing amount of traffic. The use of CoMP approaches as a tool to reduce overall energy consumption in heterogeneous networks was also investigated in [LBS+15], where it is shown that putting BSs into sleep mode by proper load balancing and joint resource optimization is an important solution for energy savings.
Use Case	UC1 “Dense Urban Information Society”
5G Service Type	
RAN Design Implications	The solution operates on the Medium Access Control (MAC) layer, implying that scheduling is performed in a central unit that controls resource allocation for a large number of nodes. A C-RAN architecture is therefore preferred. A mechanism to assess channel quality also for nodes that are switched off is needed (e.g. transmission of periodic beacon as presented in T3.2 TeC 15 evaluated in the METIS project [MET14-D32])

The basic concept for the TeC under evaluation is illustrated in Figure 3-11. When the active traffic is not at its peak certain cells could enter a DTX like state (a “sleep” state) to reduce the network energy consumption. The cell can get in and out of this sleep state on a very short time scale, so that the scheduler can activate or deactivate the sleep mode in each subframe. It is possible that certain users that are under the coverage of a cell, which is in sleep mode, could still be served from the remaining cells, exploiting JT in order to improve the quality of the offered service. In the TeC, a centralized scheduler, designed in METIS [MET14-D32], controls a cluster of cells, and decides on every subframe which cell should be in sleep mode and which cell should be used to serve the active users, exploiting DPS or JT whenever is feasible.

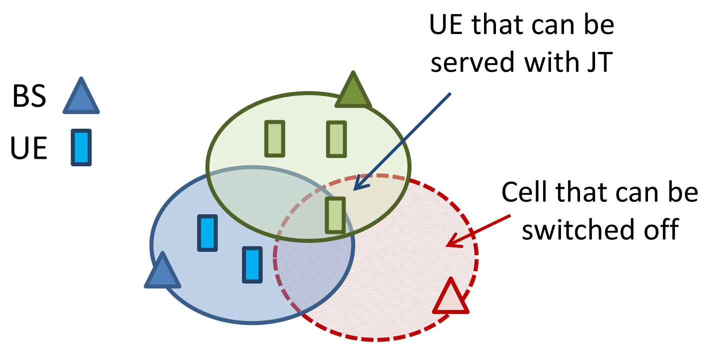


Figure 3-11 Basic concept for dynamic cell switch off with JT

The scheduling approach proposed in [MET15-D33] has been enhanced in order to assess the impact of enhanced power saving capabilities in future network nodes. With this aim, power models for 5G transmission nodes that include enhanced on/off switching mechanism and energy consumption profiles that scale better with the served traffic have been considered. Power models with these characteristics have been recently proposed in [5GREEN], and were also defined in the METIS-II consortium [MET-II16-D12] (see Figure 3-12).

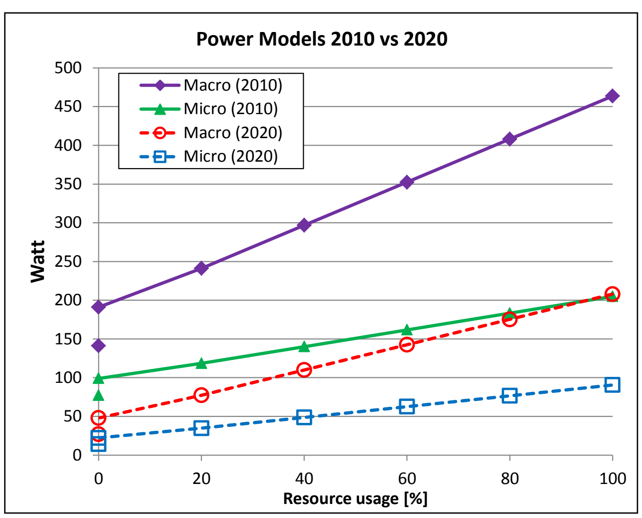


Figure 3-12 METIS-II power models for Micro and Macro Base Station in 2010 and 2020.

As it can be seen, power consumption scales with the amount of radio resources used in transmission. The EARTH project has detailed in [EAR12-D23] how much each element in a BS contributes to this power consumption. BSs in general are made of multiple transceivers (TRXs) with multiple antennas. A TRX comprises an antenna interface, a Power Amplifier (PA), a Radio Frequency (RF) small-signal transceiver section, a baseband processing unit (BBU), a DC-DC power supply, an active cooling system, and an AC-DC unit (Main Supply) for connection to the electrical power grid. While the PA consumption scales significantly (and almost linearly) with used resources, and also the BBU shows a linear, yet less relevant, dependence, the remaining parts of the BS have an approximately constant power consumption. So power consumption in a BS can be divided in a static part, which remains constant regardless of the amount of traffic that is served, and a dynamic part that scales (almost linearly) with the amount of used resources, so that it gets higher when traffic load increases. Note that recent BSs have introduced “sleep modes” that allow to reduce the power consumption when no traffic is served, represented by the discontinuous value shown for 0% resource usage in Figure 3-12, so that also the static part in the overall power consumption can be reduced when no traffic at all is present.

Figure 3-13 summarizes the results obtained in the simplified Madrid Grid scenario that was proposed in METIS-I [MET14-D32]. The scenario reproduces an urban environment with 3 macro BSs and 9 micro BSs, serving 10 users each, and transmitting on a 10 MHz signal bandwidth. To test the capability to switch off unnecessary nodes, different traffic load conditions have been considered, obtained assuming Constant Bit Rate (CBR) traffic sources that generate a given traffic data rate for each user. As a reference, also full-buffer traffic condition has been considered, even if in this case the proposed algorithm cannot switch off any cell, so no gain in energy consumption reduction can be achieved. The figure reports the overall power consumption when no multipoint coordination is exploited between nodes (NoCoord) and when the proposed centralized entity can exploit JT and DPS/DPB to improve Energy Efficiency (EE JT). Each bar representing the total power consumption has been split into two parts, in order to highlight the portion of power consumption that is due to the static consumption part (which therefore does not change with the amount traffic load that is served), and the portion that depends on the dynamic power consumption part. As it was expected the higher energy efficiency of 2020 equipment reflects a drastic reduction of the power consumption, both with and without the centralized entity for coordination. However, the higher dynamicity in power consumption offered by 2020 equipment can be better exploited with the proposed solution, so that in 2020 the power consumption reduction that can be obtained using the EE JT scheme can be as high as 51%, whereas in 2010 only savings up to 31% could be achieved.

More in general, the results show that there is the possibility to exploit traffic steering together with traditional interference management techniques, such as multipoint coordination, to reduce the energy consumption when traffic conditions are favorable. Further details and analyses can be found in Annex A.3.

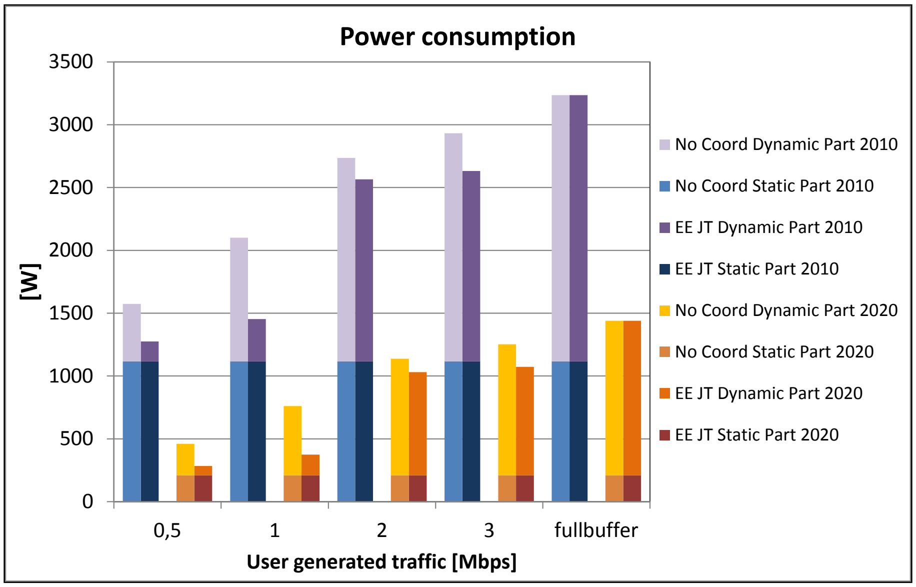


Figure 3-13 Evolution of power consumption from 2010 and 2020, with and without the proposed coordination approach.

3.2 Foundation for AIV-overarching RM Functionality Framework

This section deals with the RRM functionality that is applicable for a multi-AIV environment, comprising both 5G and evolved legacy AIVs [MET-II16-D41], see Figure 2-1. Thus, the RM functionality is AIV-overarching, which implies that the technology components described here remain agnostic to the AIV related physical layer design or operation. The RM framework to be developed will efficiently support the novel modes of communication envisioned in 5G systems (e.g., D2D, self-backhauling, multicast) and the varied set of applications and UCs with very different and demanding performance requirements (e.g., regarding xMBB, uMTC, and mMTC). Furthermore, the AIV-overarching RM functionality should consider the synchronization requirements of the AIVs, as well as different deployments including dynamic topology settings, and the imposed limitations of the legacy networks.

3.2.1 RM for Network Slices

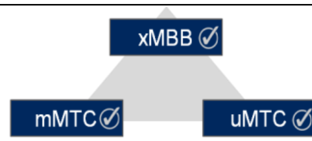
METIS-II intends to develop a RAN design that fulfils NGMN's vision for the overall native SDN/NFV-based 5G architecture (Software Defined Networking / Network Function Virtualization), as described in the NGMN 5G White Paper [NGM15], which is based on the idea of decoupling the software from the hardware platform of the network as well as to decouple CP and UP. The architecture vision includes a new concept which is described as end-to-end (E2E) network slicing. It would be possible to operate different flavored types of virtual networks (slice instances) on the same hardware platform with each virtual network optimized for UCs with e.g. contradicting KPIs. The CP related aspects of the concept, such as different protocol and network functions for different network slices are studied in METIS-II Deliverable D6.1 [MET-II16-D61]. By now, it is not clear how the slicing concept will impact the overall RM of the system. 3GPP has stated that by now it has to be explored if and which new functionality in the RAN part is needed to support the slicing concept [3GPP15-22891]. With respect to the resource abstraction framework, described in Section 2, the slicing concept plays an important role. The responsible entity (it may be part of an access controller) needs enough information about the current instantiated slices from the CN side to allocate available resources in a way that the QoS requirements of the different services within a slice are guaranteed. The following TeCs are being developed to design an AIV-independent RM entity, which abstracts requirements from the CN side as well as AIV-specific control information, to fulfill QoS of different services of different slices:

- T5.1-TeC1 & T5.2-TeC1: Multi-dimensional RM for 5G & Legacy AIs
- T5.2-TeC3: AI-agnostic Resource Abstraction Model for Virtualized 5G RAN
- T5.2-TeC7: Unified RAN Management

All identified TeCs aim to define an abstraction layer to make use of the total available resources in an optimized manner and take into account the requirements of different slices which have to be handled in a 5G system. T5.1-TeC1 & T5.2-TeC1 define the overall concept and thus study the influence of the network slicing concept onto the RAN. T5.2-TeC3 will focus and adapt this for the deployment scenario of an ultra-dense heterogeneous network (assuming also the existence of NNs and small cells). T5.2-TeC7 investigates the operational aspects of such an approach in more detail as well as the requirements to a unified RAN management when AIVs in higher frequency ranges are introduced to the system.

Multi-dimensional RM for 5G & Legacy AIs

TeC ID	T5.1-TeC1 & T5.2-TeC1
Abstract	The NGMN network architecture vision describes the principle of E2E network slicing. Network slicing is a concept for running multiple logical networks as virtually independent business operations on a common physical infrastructure. The TeC "Multi-dimensional RM" specifies an overarching system for resource and QoS management that enables network slicing in the RAN. The TeC mainly consists of a new possible logical entity, called AIV-agnostic Slice Enabler (AaSE). AaSE is aware of the Service Level Agreements (SLAs) of the network slices, QoS requirements of individual data streams as well as the radio conditions of the mobile stations in a certain network segment. AaSE is responsible for monitoring and enforcing SLAs by means of traffic steering and RM.
SotA	This TeC relates to network slicing, which is a new concept in 5G to create logical networks. Network slicing has similarities with network sharing [3GPP15-23251], but goes beyond it. Different virtual networks designed with conflicting characteristics, e.g. for vertical industries, can be created or defined.

Use Case	UC1 “Dense Urban Information Society”, UC2 “Virtual Reality Office”, UC3 “Broadband Access Everywhere”, UC4 “Massive Distribution of Sensors and Actuators”, UC5 “Connected Cars”
5G Service Type	
RAN Design Implications	• Possibly a new logical network element: AIV-agnostic Slice Enabler (AaSE) • Resource availability signaling: • In case an AIV-agnostic RM is operated, the availability of radio resources needs to be signaled to the AaSE. • In case no AIV-agnostic RM is present, AIV-specific context information (e.g. load situation) should be signaled from AIV-specific RM to the AaSE. • A feedback from the AIV-specific scheduler or an AIV-agnostic RM to AaSE concerning the QoS KPIs is required. • The data flows from the CN (e.g., via S1*) need to carry information to which network slices they belong or which SLAs they are associated with. • There can be a feedback from the AaSE to a core entity (orchestrator/MANO) [ETSI-NFV] or to a RAN moderation entity about the SLA status.

One important target of the network slicing concept is to provide E2E QoS for, e.g. business customers from vertical industry sectors (automotive, logistics, health care, etc.). When providing a network slice, a certain SLA is defined and guaranteed. SLAs can especially be in terms of guaranteed data rates and latencies in combination with availability in time.

Running logical networks with different QoS-requirement and SLAs on a common physical radio network infrastructure is challenging. In the RAN the physical resources, especially radio resources such as time/frequency blocks (see Section 2), are scarce and expensive resources. It is therefore important to share physical resources between network slices and to decide on an ad-hoc basis about the current allocation. Besides that, currently within [5GNORMA, 5GNORMAD31] it is explored how far it is possible to share and allocate physical network resources on a broader scope based on the SDN and NFV principles, which is necessary in order to introduce network slicing.

The TeC “Multi-dimensional RM” describes an overarching system for resource and QoS management that enables network slicing in the RAN. The TeC mainly consists of AaSE as a possible new entity which introduces the functionality to support network slice specific SLAs by the RAN. AaSE is aware of the SLAs of the network slices, QoS requirements of individual data streams as well as the radio conditions of the mobile stations in a certain network segment. Based on this information, it is able to decide, which data stream should be transmitted through which BS and AIV (traffic steering). In a more advanced version, it will be also able to take into account radio resources in cooperation with an AIV-agnostic RM. In case there are conflicts between slices (e.g. not all QoS requirements can be met), AaSE is responsible for finding the solution that causes the lowest negative impact (e.g., not delivering the traffic from the network slice with the lowest SLA requirements). AaSE feeds back information about the current SLA status and corresponding KPIs to the network orchestrator or a RAN moderation entity, which can consider adaptations in case of continuous problems. This TeC proposes to implement network slicing in the RAN with the help of a new logical entity. However, since the overall RAN design is not yet finalized, it is for further study if a new logical entity is needed and which new types of interfaces might be necessary or not. Nevertheless the necessity of an additional SLA specific tagging or indexing of each data flow to support network slicing within the RAN has been identified and needs to be elaborated further in detail. One possible solution is described in the following.

Figure 3-14 shows the operations of AaSE without AIV-agnostic RM. The basis of all decisions of AaSE is the knowledge on the current network status, which is obtained in step 0. Here the AIV-specific RM entities (schedulers) provide information about their current status, especially the current load situation and which UCs they are able to fulfill under current conditions. AaSE is aware of data flows that enter the RAN including the information about the originating slice and its SLAs (steps 1 and 2A). In step 3A, AaSE monitors the current situation in the network with respect to the SLAs. It is then decided whether new data flows can be accepted (admission control – AC) and in case yes, an allocation retention priority (ARP) is set, which defines how important this data flow is relative to other flows. AaSE then selects a suitable AIV per data flow (step 3B) and selects a quality class identifier (QCI) from the QoS classes that exist for this AIV (step 3C). It is under the responsibility of the AIV-specific scheduler to handle the data flow then (step 4A) and to report whether the QoS requirements are fulfilled (step 4B). Based on this feedback the SLA status can again be checked (step 3D). As mentioned previously, feedback can be generated which informs the network orchestrator or a RAN moderation entity about the network status with respect to the SLAs (step 2B). An alternative solution can be found in the Annex A.11.

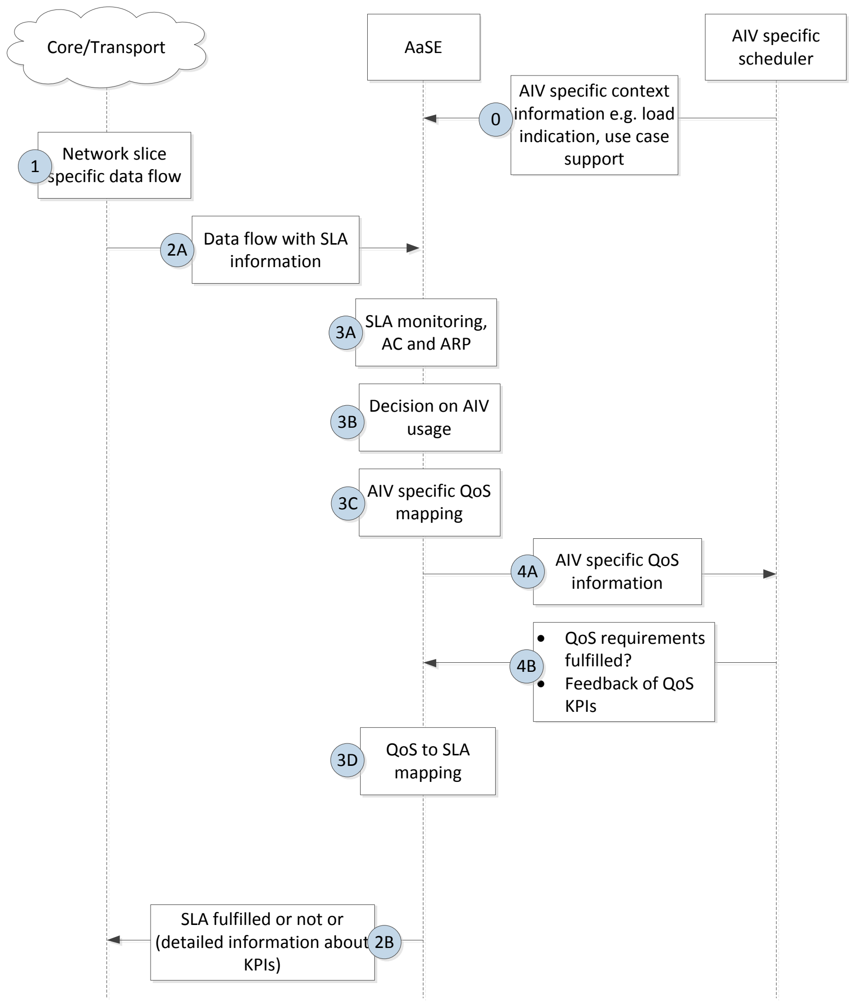
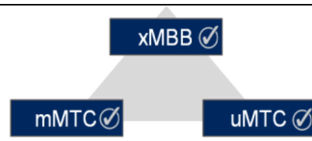


Figure 3-14 AIV-agnostic Slice Enabler without Air-Interface-agnostic RM.

AIV-agnostic Resource Abstraction Model for Virtualized 5G RAN

TeC ID	T5.2-TeC3
Abstract	In an ultra-dense heterogeneous network, consisting of multi-AIV and multi-layer access points under a virtualized RAN umbrella, the pooling and abstraction of resources is of key importance in order to meet the tight 5G requirements for numerous challenging services, which may correspond to different network slices [NGM15]. In such ultra-dense deployment, where multiple network slices might share the same RAN resources, one key solution that is investigated here, is the flexible abstraction of RAN resources (assuming also dynamic radio topologies) in a centralized logical entity to perform Inter-Slice RM. Resource Abstraction here can be interpreted as the slice-aware ranking of the available resources (e.g. based on per-slice requirements), to facilitate mapping of slices to AIVs and access points.

SotA	Network Slicing [NGM15]
Use Case	UC1 “Dense Urban Information Society”
5G Service Type	
RAN design Implications	• This approach will provide impact on the protocol design for the CP functionalities. • RM and scheduling functionalities will need to be modified to support 5G AIVs and new functionality shall be added to orchestrate the whole process in an AIV-agnostic manner. • In a dense urban heterogeneous scenario, a logical controller will be required on top of RAN (similar to AaSE), to support slice-awareness at RAN. • The new interfaces as well as standardization impact will be further analyzed after defining the RAN-5G CN functional split and the level of slice-awareness from RAN point of view

In 5G RAN, focusing on a dense urban heterogeneous scenario with various types of access nodes and multiple AIVs, various types of resources can be defined e.g. for UL, DL as well as for wireless backhaul and different AIVs. Moreover, the high user density together with multi-connectivity and the introduction of multiple network slices might lead to huge signaling and complexity. Therefore, the abstraction and virtualization of resources in an AIV-agnostic manner can be considered as the key enabler in order to simplify this process and make it realistic to handle a multitude of 5G AIVs and evolved legacy access technologies efficiently. An example deployment is shown in Figure 3-15.

Assuming that the coexistence of multiple AIVs introduces some limitations on the access, connection control and resource availability, the RM layer should adapt to take into consideration factors like the heterogeneity of connections, user preferences, the AIV requirements and heterogeneous traffic load. Hence, the problem which is investigated is how to provide a model to calculate and select optimally the available resources for different network slices, such that the E2E requirements per slice can be met.

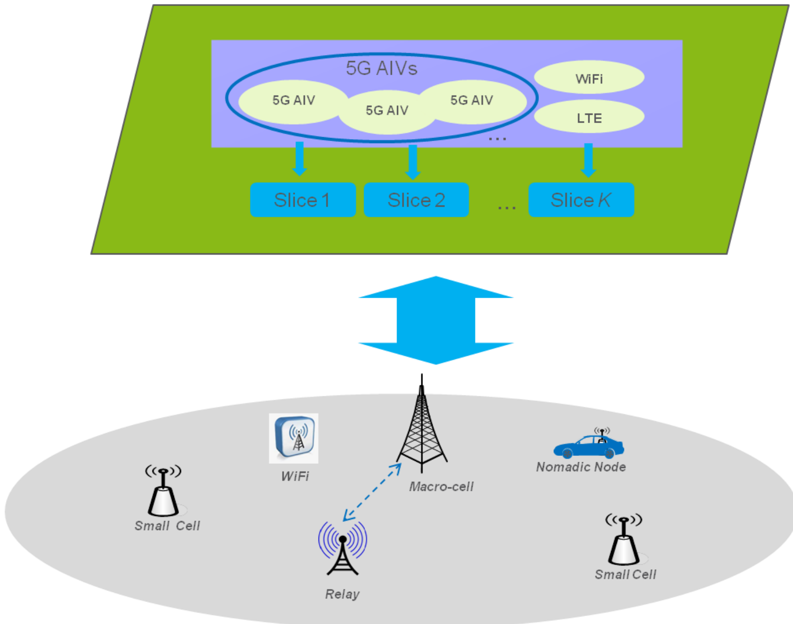


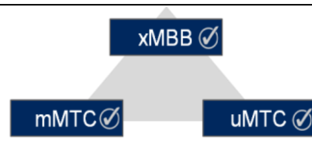
Figure 3-15 Exemplary 5G RAN deployment for the resource abstraction framework.

The TeC T5.2-TeC3 aims to provide an AIV-agnostic RM layer in 5G RAN, assuming multiple 5G AIVs and also evolved legacy AIVs. This model has three key features:

- Identify 5G E2E slice requirements to capture the needs from the 5G RAN point of view.
- Calculate the resources which are available at 5G RAN and rank them based on use case specific requirements. Here, we can also take into account the limitations regarding multi-AIV capabilities per device.
- Optimally select which resources are mapped to which slices taking into account the global objective of meeting the RAN requirements per network slice.

Unified RAN Management

TeC ID	T5.2-TeC07
Abstract	This TeC develops the concept of "virtual AI", in order to facilitate a common framework for radio resource coordination between multiple AIVs. It will enable the 5G operators to share a single operational and maintenance system while targeting different markets and services over multiple AIVs.
SotA	5G systems are required to fulfill conflicting requirements from different foreseen services, such as xMBB, uMTC and mMTC. In order to optimally cope with these requirements, and also considering the very different propagation properties of the envisioned 5G frequency bands, it is likely to expect the coexistence of several AIVs jointly fulfilling different requirements over the same coverage area. If several AIVs are to be used, not only due to 5G requirements but also to

	enable the integration of LTE-A evolution as one possible AIV, there is a need to provide common procedures to enable a unified management to the mobile network operators. This common management procedure will enable the coordination of resource usage by different AIVs, and offering a single control point for mobile network operators.
Use Case	UC1 “Dense Urban Information Society”, UC2 “Virtual Reality Office”, UC3 “Broadband Access Everywhere”, UC4 “Massive Distribution of Sensors and Actuators”, UC5 “Connected Cars”
5G Service Type	
RAN Design Implications	The context information, with resource utilization and UEs demand, are the basic information elements needed for the AIVs coordinator for the resource scheduling among the different AIVs. This information is also planned to be obtained for many of the other TeCs, as well as used in some self-organizing network (SON) functionalities on different AIVs.

The concept of this TeC T5.2-TeC7 is to provide the enablers for AIVs over-the-air coexistence, defining a “radio encapsulation” procedure with the following advantages:

- Reducing operators Operations Support Systems & Business Support Systems (OSS/BSS) costs by means of unifying different AI OSS/BSS tools and systems in one single virtual AI framework.
- Flexible adaptation of radio resources to services’ demand, enabling the dynamic assignment of radio resources to different AIVs, according to the operator service needs in different areas.
- Provision of future-proof framework for the deployment of new AIVs, decreasing the time to market of radio innovations.
- Inclusion of legacy systems as LTE-A, as part of the technologies to provide service.

The proposed TeC aims to provide a framework for inter-AIV collaboration, allowing the inclusion of AIVs with different characteristics and numerology. It will enable keeping the flexibility in the design of multiple AIVs by introducing a procedure for encapsulating radio resources’ usage of different AIVs.

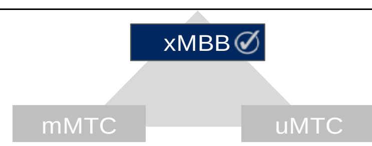
This TeC will develop the concept of AIVs resource usage coordinator, with access to the full context information and able to establish requirement priorities.

3.2.2 Tight Integration with Evolved Legacy AIs

5G is expected to operate in a wide range of frequency bands, probably using also very high frequency bands compared to 4G. This implies, for example, lower diffraction and higher outdoor-to-indoor penetration losses, which means that signals will have more difficulties to propagate around corners and penetrate walls. Also, the initial deployment of 5G will be rather spotty. The state-of-the-art integration between two different AIs is hard handover [3GPP15-36300]. The major drawbacks with inter-RAT hard handover e.g. between 3G and 4G are the rather long delay and service interruption as well as the low reliability. A tighter integration with LTE may therefore be crucial in order to ensure ultra-high reliability and extreme bit rates in a 5G system. The following TeC is considered herein:

- T5.1-TeC2, T5.2-TeC2: LTE & 5G Tight Integration and RAN Moderation

LTE & 5G Tight Integration and RAN Moderation

TeC ID	T5.1-TeC2, T5.2-TeC2
Abstract	To overcome the drawbacks with state-of-the-art hard handover between AIs, we propose to investigate several concepts that integrate LTE and 5G more tightly than hard handover. We plan to investigate concepts based on higher layer integration (i.e., common LTE and 5G Packet Data Convergence Protocol (PDCP) or Radio Resource Control (RRC) level) or and on lower layer integration.
SotA	Inter-AIV hard handover and LTE Rel. 12 dual connectivity [3GPP13-36842]
Use Case	UC3 “Broadband Access Everywhere”
5G Service Type	
RAN Design Implications	The current concepts for tight integration between LTE and 5G utilize PDCP as aggregation/split layer. The tight integration concepts described in this TeC are fast UP switch and dual connectivity. Both concepts assume a common S1* CN/RAN interface for LTE and 5G. This means that CN signaling is not needed for the tight integration between LTE and 5G. Both concepts may benefit from possibly new UE measurements per AIV (LTE and 5G) in order to make an optimal scheduling decision, preferably on milliseconds basis if the backhaul allows it. Also, metrics for enabling both load balancing and traffic steering between LTE and 5G can be beneficial but require new measurements over X2* interface between LTE and 5G. How to do this and how often is left for further study (FFS) and may impact the standardization. Adding and deleting a new CP connection in dual connectivity to a user must be very fast and need only lightweight signaling to support ultra-reliability requirements. Details are FFS.

The first evaluated concept is a fast UP switch at the (common) PDCP layer, see Figure 3-16. At first, it is assumed that the control plane is using “dual connectivity” with LTE and 5G, while the UP is switched at PDCP level to either LTE or 5G. If the CP is connected to both the LTE node and the 5G node, no signaling is required and the UP switch may be almost instantaneous. Also, we assume a common S1* CN/RAN interface for LTE and 5G. This means that no extra CN/RAN signaling is needed for a UP switch. The fast UP switch can be based on normal handover measurements such as RSRP. This is also the case for the simulations shown below. However, at a later stage it is interesting to investigate what kind of UE measurements (and possibly new signaling) is necessary to efficiently optimize the performance of the fast UP switch. Note that since the CP is active in both LTE and 5G, the reliability of the connection should increase compared to normal hard handover. Adding and deleting connections to new nodes may be based on LTE dual connectivity mechanism, i.e., based on the best connection for the UE (DL or UL), but it can be also based on the load of the nodes or other triggers. A drawback of having multiple flows of the CP is the increased overhead.

A second concept to investigate is when both UP and CP are connected to both LTE and 5G (similar to "dual connectivity" in LTE) and the UP data is aggregated (or split) at PDCP layer, see Figure 3-16. Also for this solution we assume a common S1* CN/RAN interface for LTE and 5G. This means that no extra CN/RAN signaling is needed to add or delete a secondary node. An alternative to the dual connectivity solution is to use MAC layer for aggregation, as in CA for LTE. In this case, the scheduler can then use resources in an optimal way, at least if the UE is configured and able to send measurement information about all carriers (i.e. both LTE and 5G carrier). However, measurements and signaling to support this should also be possible to develop for the dual connectivity solution (still using PDCP as aggregation/split layer). This is planned for future investigations.

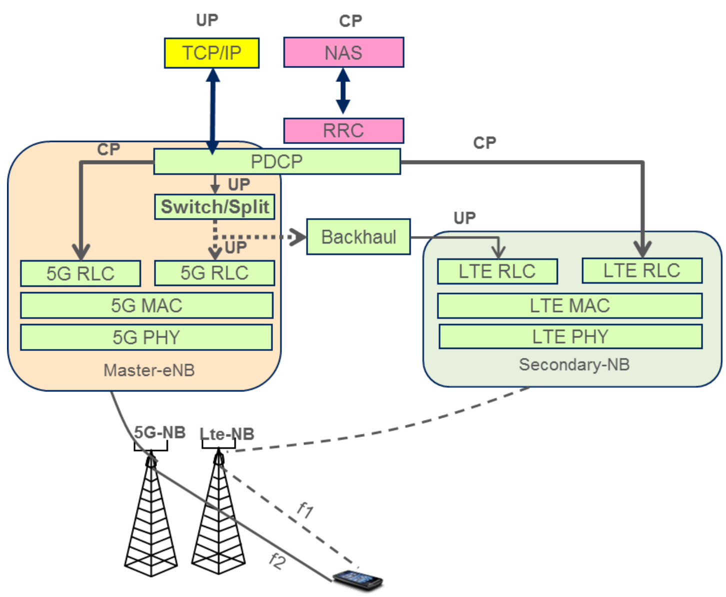


Figure 3-16 LTE and 5G Tight integration alternatives: fast user plane switch and dual connectivity (downlink example). In case of fast switch user plane concept, the user plane is switched either to LTE or 5G. In case of dual connectivity, the user plane is split at the PDCP layer to both LTE and the 5G nodes.

A benefit to use the PDCP layer to aggregate or split the data is the likely similarity between the PDCP layer for LTE and 5G, while the MAC layers may be rather different. Thus, using the PDCP layer will probably require less standardization efforts.

One potential drawback of a dual connectivity solution may be that a multi-connectivity solution for 5G might use a lower layer for aggregation (such as MAC layer). So, coordination between multi-connectivity within 5G together with dual connectivity on higher layer with LTE might require rather different signaling and solutions. Another potential constraint is the backwards compatibility with the LTE RRC/PDCP.

The above tight integration concepts have been evaluated using a system-level simulator. The evaluated concepts are the hard handover (HH), fast switch (FS) of the UP and the dual connectivity (DC) concepts. The LTE and 5G nodes are co-sited and the frequency bands investigated are 2 GHz for LTE and 15 GHz for 5G. In the following, the new 5G AI is referred to as NX. The difference between LTE and NX is a shorter TTI for NX of 0.2 ms as well as fewer sub-bands, see Annex A.44 for more information about the simulation setup and assumptions.

Figure 3-17 shows 10%-ile worst user throughput vs. load for dual connectivity, hard handover and fast UP switch. The stand-alone NX is used for comparison. It uses 15 GHz frequency and a bandwidth of 40 MHz (in contrast to 20+20 MHz for the tight integration cases).

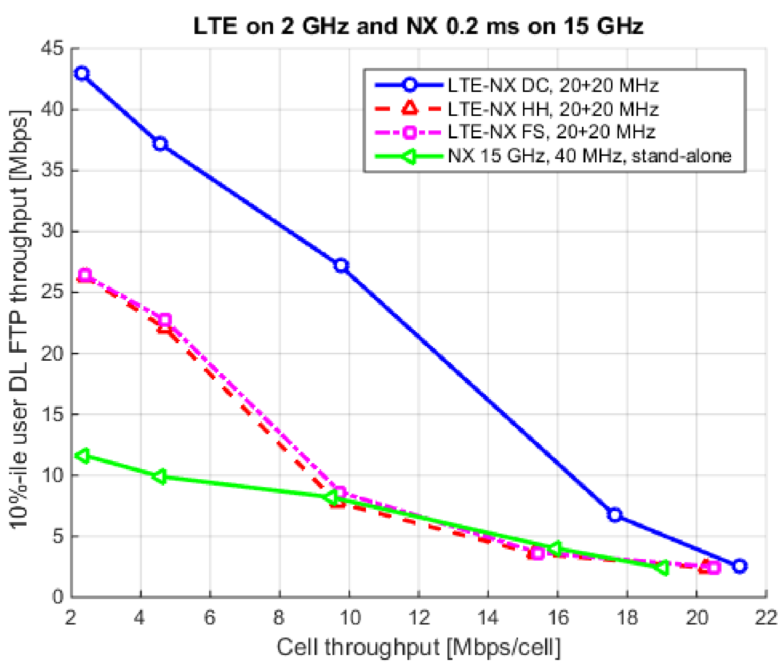


Figure 3-17 10%-ile worst user throughput vs. load for dual connectivity (DC), hard handover (HH) and fast user plane switch (FS)

The dual connectivity concept shows the best performance, around 300% higher user throughput at low load compared to the stand-alone NX case and around 100% higher compared to fast UP switch and hard handover cases. The difference in performance between hard handover and fast UP switch is small, even though hard handover has an interruption delay of 300 ms when a hard handover is performed compared to no delay at all for the fast switch. The reason for the small difference is due to the fact that there are very few hard handovers in this scenario and therefore the performance for hard handover is not affected very much. Also, all RRC signaling is ideal, i.e., all RRC signaling is always received correctly, so there are no (hard) handover failures. More simulation results can be found in Annex A.4.

3.2.3 Holistic RM and AI Abstraction Models

The agile RM framework that is being developed in WP 5 holistically considers the novel and differentiating aspects of 5G systems with respect to previous generations of mobile communication standards, specifically in terms of diverse and challenging services and use cases, existence of multiple AIVs, dynamic topologies, and novel communication modes (e.g., D2D). The goal of this building block is to provide holistic solutions to deal with these novel aspects.

A flexible scheduling framework that is able to simultaneously accommodate users with very different service requirements is presented. It is fully flexible in the sense that it does not require separation and reservation of resources for different services, adapting dynamically to the traffic demands with maximum resource efficiency.

The existence of multiple 5G AIVs requires the study of different integration options, determining what degree of AIV-specific versus AIV-agnostic RM functionalities is needed and at which level in the protocol stack. Furthermore, the abstraction models and RM framework should also facilitate achieving and edgeless user experience in dynamic topology settings. A convergence or abstraction layer can provide a unified and aggregated view of the various AIVs and resources at disposal, and it is therefore the goal of this building block to also analyze these aspects together with the associated architecture and interface implications. A key difference with respect to the related aspects studied in Section 3.2.1 *RM for Network Slices* is that, although not excluding it, a network slicing paradigm is not explicitly considered here.

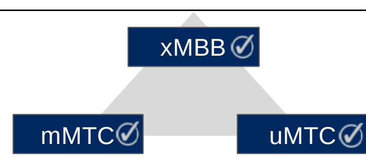
5G systems will also natively support novel communication variants, such as D2D or self-backhauling, and a holistic RM framework shall consider them. Although the scope of these technologies is wide, some key considerations are provided here, especially those related to RRM and synchronous control functions.

More specifically, the following TeCs are considered herein:

- T5.2-TeC5: Holistic RM Framework
- T5.2-TeC6: Abstraction Models for 5G AIVs
- T5.2-TeC4 RM for 5G D2D

Holistic RM Framework

TeC ID	T5.2-TeC5
Abstract	This TeC aims at developing a holistic RM framework for 5G systems, comprising scheduling design fundamentals to flexibly accommodate diverse service types (xMBB, mMTC, uMTC) and protocol stack implications to integrate the RM functionality of different AIVs. The scheduling proposal

	is based on a flexible frame structure with variable TTI size that allows simultaneous support of users with very different service requirements. The functional enablers and requirements needed to support the framework are analyzed. The proposed design covers a wide range of use cases and scenarios envisioned in the 5G time frame.
SotA	The new challenges introduced in 5G systems in terms of novel interference constellations (through ultra-dense deployments, UL/DL cross-interference with flexible TDD, D2D), novel modes of communication (e.g., D2D, multi-cast, self-backhauling) and more diverse and stringent application requirements (e.g., latency-critical applications) have not been traditionally considered in the design of cellular systems. It is well known from the existing literature that there are fundamental tradeoffs between scheduling users to maximize their spectral efficiency, coverage, latency, or reliability [SMP+14] [WN+03]. This calls for flexible scheduler functionality that allows scheduling each user in coherence with its desired optimization target. One option allowing the former, is to design the 5G system to support scheduling with different TTI sizes [PBF+16]. The LTE QoS and RRM framework has been mainly optimized for mobile broadband use cases and does not consider the existence of spectrum bands in higher carrier frequencies, with 5G AIVs optimized for operation in these bands. New possibilities arise in terms of multi-band interaction and coordination.
Use Case	UC1 “Dense Urban Information Society”, UC2 “Virtual Reality Office”, UC3 “Broadband Access Everywhere”, UC4 “Massive Distribution of Sensors and Actuators”, UC5 “Connected Cars”
5G Service Type	
RAN Design Implications	The physical layer and scheduling functionality should support the following features: • Variable TTI size configuration per user, including options for asymmetric link operation, where a user is scheduled with different TTI sizes in the DL and UL (especially relevant for macro-cellular scenarios at lower carrier frequencies). • Continuous and non-continuous allocation in the frequency domain. Time-frequency extent of each allocation controlled dynamically per scheduling instant. • The scheduler shall support multiplexing of larger number of users per carrier to ensure efficient radio resource usage. This calls for a highly scalable design of radio resources for transmitting scheduling grants to avoid control channel blocking. • Users can be configured to only monitor control channel scheduling

	grants on a subset of the resources. The UE effort for searching for scheduling grants (i.e., DL control channel detection) shall be manageable, both in terms of number of search options and energy consumption. • Punctured scheduling, supporting both implicit and explicit signaling options. • Native support of D2D and self-backhauling. Design aspects such as frame structures, waveforms, etc. should strive for commonality and reusability with cellular UL/DL to ensure a seamless integration of these novel communication variants since the beginning of 5G system design. Other protocol stack aspects related to AIV-agnostic vs. AIV-specific RM and synchronous control functions are to be further studied for Deliverable D5.2 (due by the end of March 2017).

The holistic RM framework is designed to efficiently support the varied set of 5G services and use cases, with very different and demanding performance requirements (i.e., xMBB, uMTC, and mMTC), and to natively integrate novel modes of communication such as D2D and self-backhauling. It will take into account a wide range of scenarios, from macro deployments operating at carrier frequencies below 6 GHz to novel interference scenarios, like UDNs and deployments with dynamic TDD configuration operating also at higher frequencies.

It will be also the goal of this TeC to study the integration of the different 5G AIVs from a RRM and synchronous control functions perspective, determining what degree of AIV-specific versus AIV-agnostic RRM functionalities is needed and at which level in the protocol stack. Some first considerations on these aspects are provided in the Annex A.5, while in the following the focus is on the flexible and simultaneous support of users with different services and performance requirements.

The fundamental trade-offs existing among latency, reliability and throughput in wireless system design lead to performance degradation in one dimension when optimizing another one. For instance, optimizing the system for low latency and high reliability will have high cost in terms of lower system throughput, which is not desirable [SMP+14]. Instead, the scheduler should target optimizing each link in coherence with its associated QoS requirements, and providing flexible and adaptive support per user.

One way to enable the latter is through a flexible frame structure that allows variable TTI size scheduling per user [PBF+16]. This enables scheduling uMTC users with short TTI to optimize their latency, at the expense of increased control overhead and lower channel coding gains (e.g., user #1 in Figure 3-18 a); MBB users can be scheduled with longer TTIs and wider frequency allocations to cope with the high data rate demands (e.g., user #4); and mMTC users can benefit from narrow bandwidth allocation and long TTIs, which are attractive characteristics from cost and coverage perspectives (e.g., user #5). In addition, the possibility to set the TTI size per scheduling grant offers the possibility to optimize MBB services with TCP. Short TTI duration can be used at the beginning to reduce the round trip time of the flow control mechanism in the slow start phase of TCP, and later longer TTIs can be configured to maximize the spectral efficiency when steady operation is reached.

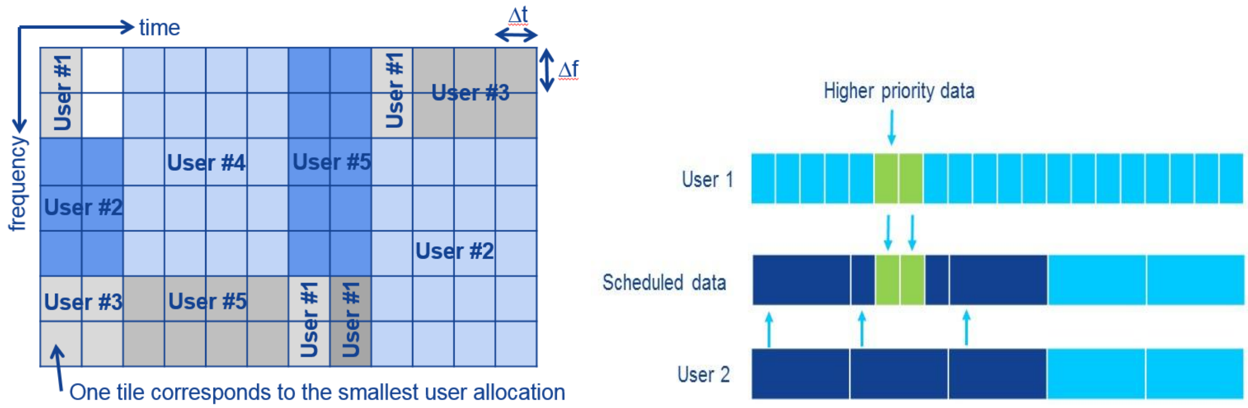


Figure 3-18 a) Time-frequency multiplexing of users with variable TTI size, and b) principle of punctured scheduling for latency-critical data.

The flexible scheduling framework supports the following features: variable TTI size configuration per user; continuous and non-continuous allocation in the frequency domain; time-frequency extent of each allocation controlled dynamically per scheduling instant; users can be scheduled (both control and data) on a fraction of the bandwidth; and users can be configured to only monitor control channel scheduling grants on a subset of the resources. More details on these aspects and control channel considerations can be found in [PBF+16].

Standard scheduling algorithms and principles used for LTE can also be employed in 5G for basic scheduling and multiplexing of users with the same TTI size. Proportional fair, max throughput, various guaranteed bit rate (GBR) and Min-delay schedulers, etc., can be reused to prioritize among active users. HARQ retransmissions shall be normally prioritized over new transmissions, and uMTC traffic should get priority over MBB and mMTC traffic (i.e., avoid queuing of uMTC traffic and use the best available radio resources for it).

However, with variable TTI size duration (with TTI start-finish occurrences that can be different among users) some challenges and scheduling dilemmas appear. For instance, a user (e.g., with MBB traffic) that is scheduled with a long TTI will occupy resources for some time, while it is still needed to ensure that there are always available resources for immediate scheduling of uMTC users. The simplest solution could be to schedule and multiplex users with same TTI size on a joint set of resources, e.g., separating some frequency resources for long TTI users and others for short TTI users, but this could result in an inefficient use of resources with some of them left unused. If there is no uMTC traffic, the resources reserved for short TTIs could also be used for MBB traffic, at the risk of latency-critical uMTC traffic that may arrive and need to be immediately served, while a long TTI MBB transmission is occupying the resources originally reserved for uMTC.

In order to overcome the above constraints, it is proposed that the scheduler also has the option to immediately accommodate latency-critical traffic that may arrive while a MBB user is already occupying the scheduling resources in a longer TTI, without having to wait until the end of that longer TTI duration. The idea is illustrated in Figure 3-18 b), where two users (user 1 and user 2) compete for the same resources. User 2 is scheduled with long TTIs (could be a MBB user) and user 1 is better served with short TTIs (latency-critical user). When data for user 1 arrives, it is immediately scheduled, overwriting (i.e., puncturing) part of the ongoing data transmission for user 2. User 2 may be unaware of the puncturing, and it attempts to decode the received data, with the possibility of being successful or not depending on the forward error correction (FEC) efficiency, SINR conditions, etc. Other schemes that include explicit signaling of the punctured slots to help with the decoding can also be considered.

The overall scheduling algorithm will therefore include all the previously explained mechanisms, which allows full flexibility of resource usage and TTI length configuration without requiring strict separation of resources among service types. The scheduling principles used in LTE for scheduling users with the same TTI length can be reused here, together with some basic prioritization rules among services and transmission types. Finally, the punctured scheduling option is available if latency-critical traffic needs to be immediately accommodated and there is a lack of available resources. This overall scheduling algorithm is illustrated in Figure 3-19.

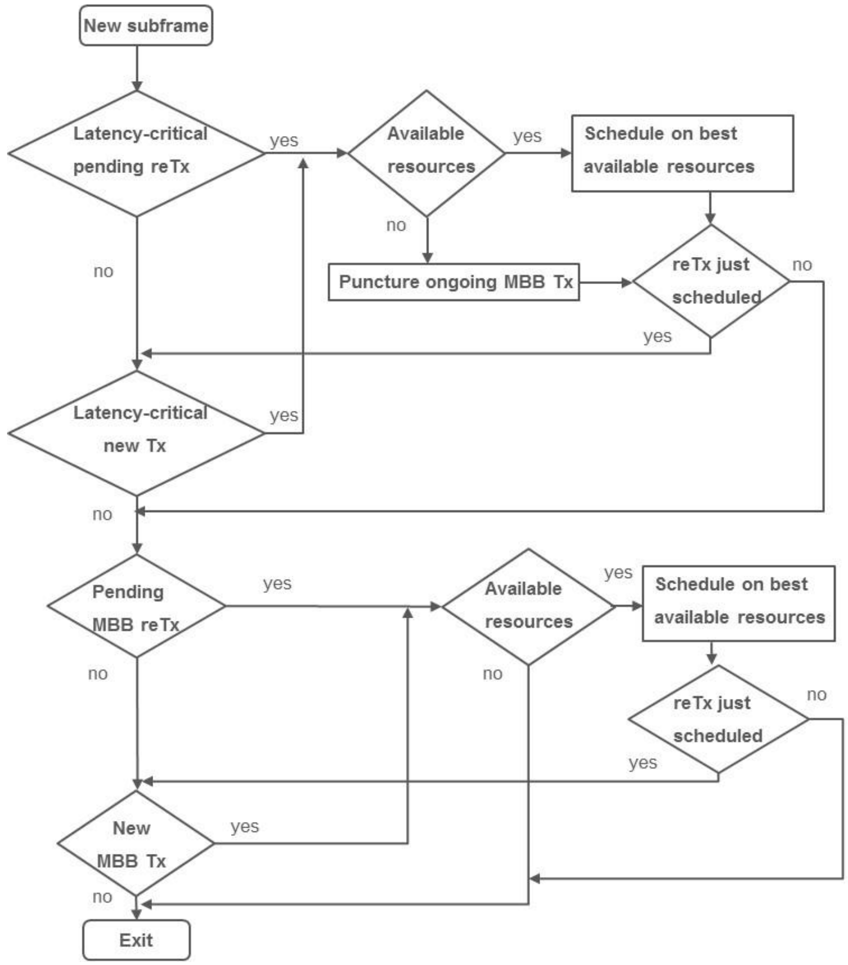
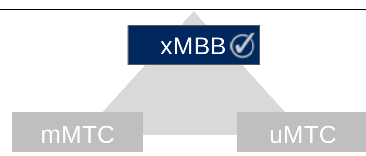


Figure 3-19 Scheduling algorithm to prioritize and multiplex different users and services.

Abstraction Models for 5G AIVs

TeC ID	T5.2-TeC6
Abstract	5G networks are expected to provide uniform and seamless connectivity while supporting a wide variety of services and scenarios with challenging performance requirements. Two key features of the envisioned 5G RAN are an effective interworking and interaction of different novel 5G AIVs with evolved LTE-A AIVs, and a dense dynamic RAN topology where the conventional notion of a static cell will progressively evolve to a more user-centric edgeless scenario with nodes flexibly forming dynamic cells that place the user at its center. This evolution towards a more flexible and agile architecture needs to be complemented by a higher degree of network flexibility to utilize the network resources. To achieve the above mentioned goal of network flexibility, in this TeC we aim at developing abstraction models for a variety of 5G AIVs and their associated RM functionalities that are suitable for a dynamic topology scenario. Flexibility of the overall system is increased by means of providing

	tools, i.e., abstraction models, that allow the management of very heterogeneous RATs and deployments, which, in addition to the former, are also dynamic. For this, it is critical to identify to what degree and how tightly different AIVs can be integrated, as well as a suitable split between AIV-agnostic and AIV-specific AI features and functionalities. Furthermore, we investigate the architectural implications of these abstraction models in realistic dynamically coordinated multi-node settings that are characteristic of dynamic topologies, i.e., how different splits work in those scenarios when practical deployment considerations are taken into account.
SotA	The overall topic of abstraction models for cellular systems has been gaining interest with the introduction of 5G due to its stringent requirement on increased flexibility to concurrently support multiple instances of differently parameterized network functions [SAM15]. Those functions include the necessary architectural constructs and procedures to manage different types of 5G AIVs in a scenario with a highly dynamic topology [MET-II16-WP]. Although the harmonization of diverse 5G AIVs is currently an open debate where different possible options are being discussed [METISII+16-WP], some prior art has already explored concepts where architectural abstractions have been proposed to manage dynamic topology deployments where an edgeless user experience is sought to prevent cell edge degrading effects [RCK+13], [HPY+13].
Use Case	UC1 “Dense Urban Information Society”, UC2 “Virtual Reality Office”, UC3 “Broadband Access Everywhere”
5G Service Type	
RAN Design Implications	This TeC will provide non-negligible impact on the RAN protocol design of current cellular systems as there is currently no abstraction model implemented to handle heterogeneous AIVs. However, the impact will be significantly lower once it is agreed the level of harmonization and related AIV-agnostic vs. AIV-specific split that will be required to manage different 5G AIVs. The level of impact will also depend on the coordination mechanism that is employed among the nodes: No significant impact should be incurred for techniques operating on the same layer, but other solutions may operate at different layers of aggregation for different AIVs and this should be taken into account. In addition, introducing the logical entity of virtual cell will require some modifications at the network management level, both on a distributed architecture (D-RAN) and a centralized architecture (C-RAN). Regarding the interface needs, the exchange of messages between physical base stations can take place on the X2* interfaces, or can be facilitated by multi-connectivity (e.g. using a lower-frequency AIV). This applies for both forming and managing the virtual cell as well as for providing service to users. Some level of modifications may be required to

	exchange messages using a harmonized protocol stack, but these changes may need to happen for 5G independently of this TeC. At the standardization side, this TeC leads to novel functionality that can impact specifications dealing with RAN protocols as stated above. Particularly, specifications implementing RAN abstraction models for harmonization and virtual cells could be affected.

The main objective of this TeC is to propose the use of abstraction models to increase the flexibility of the RAN to meet the highly diverse requirements of 5G networks. To this end, we propose abstracting the definitions of 5G AIVs' key features and functionalities relevant to the management of the diverse AIVs taking into account architectural implications for 5G systems. By abstracting the definitions of features it is meant to establish a classification of key RRM-relevant AIV features such as frame structure, waveform, target frequency band, etc., identifying AIV-agnostic as well as AIV-specific features and using parameterizable (i.e., abstracted) definitions of the AIV features wherever possible. Similarly, abstracting the definition of functions such as interference and RM, scheduling, etc. refers to the ability of using the abstract features mentioned above in the context of network functions, particularly in those RRM-related. The different possible AIV-agnostic vs. AIV-specific splits and their corresponding protocol stack mapping have implications in the operation of these functions, particularly when a number of network nodes need to cooperate to execute any of the above referenced functions. The study of these trade-offs associated with different splits is one of the objectives of this TeC.

At the same time, today's network deployments have cell edges and these edges give rise to undesirable effects such as low throughput, high interference, service interruptions, and call drops. Denser deployments lead to even smaller cells which in turn may lead to a larger number of edge-related challenges as the ones stated above. An additional important goal for next generation systems therefore will be to eliminate this edge problem, which can be achieved by employing user-centric virtual cells. A primary goal of these virtual cells is to provide a uniform quality of experience to users anywhere in the system, by "eliminating" the edge, i.e., to provide uniform SINR, eliminate handover, and provide a sustained TCP throughput for a uniform service experience regardless of the user location. In contrast to static configurations with predefined central controllers, a user-centric virtual cell achieves this by utilizing a group of cooperating nodes wherein a user is served by one or more dynamically assigned nodes, and the virtual cell is continuously reformed trying to keep the user at the centre of the cell.

Figure 3-20 shows an illustration of the TeC concept. The introduction of dynamically cooperating sets of nodes which potentially use heterogeneous 5G AIVs brings in new challenges with respect to the utilization of suitable AI abstraction models. Firstly, different functionality splits between AIV-agnostic and AIV-specific features and functionalities as described above will have different impacts on different cooperative multi-node technologies, a characteristic that requires careful further study. For example, L2 functionalities such as handover or authentication within the virtual cell could be made transparent to higher layers by performing L2 virtualization and no signaling would be needed if a physical BS attachment change within the virtual cell is produced. Secondly, the dynamism of the topology, i.e., deciding when and how the BSs forming the virtual cells will be updated, constitutes a challenge in itself. The virtual cell itself only goes as far increasing the effective cell radius experienced by the user without incurring any handover. But even a virtual cell has its edge so based on UE's movement, the virtual cell is continuously reformed so that the UE does not need to perform handover while moving. An important design goal for virtual cell reformation is that the user should always find itself adequately covered. Hence, appropriate procedures are required for dynamic reformation. However, those will unavoidably be influenced by the AI abstraction model and the implemented functionality split scheme, hence creating a coupled problem. Finally, the performance of the developed abstraction models will be also influenced by practical impairments that will determine the feasibility of applying certain architectural abstractions. Hence, those will be the topic of further study.

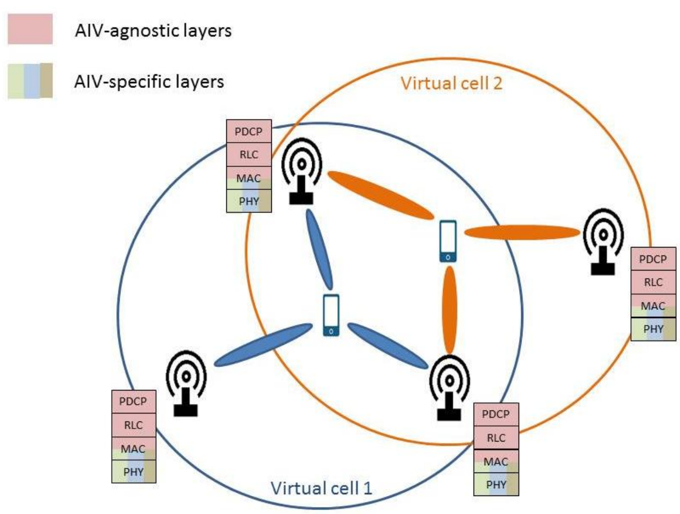
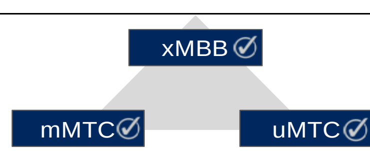


Figure 3-20 Illustration of the TeC concept.

Resource Management for 5G D2D

TeC ID	T5.2-TeC4
Abstract	While a set of D2D features is supported by 3GPP LTE systems, the targets on 5G systems require significant improvements and new technical features of proximal communications. Indeed, supporting point-to-point (rather than broadcast) D2D connections in licensed spectrum bands, taking advantage of advanced antenna techniques both at infrastructure nodes and user devices, exploiting higher frequency bands and managing the diversity of in-coverage and out-of-coverage scenarios require the development of new RRM schemes and associated protocol support. In this TeC we propose some design considerations and solution approaches for D2D, and D2D RM in particular, that can improve the performance of D2D communications beyond what is feasible with the currently standardized D2D schemes.
SotA	In LTE, a rudimentary support for broadcast based D2D communications was first added in Release 12 [ADF+12] [3GPP13-22803]. The main functionalities were developed for the public safety (PS) use case, including intra- and inter-cell (in-coverage), outside network coverage and partial network coverage scenarios. For non-public safety use cases only discovery within network coverage was supported. For Release-13 and Release-14 the scope of D2D communications will be extended both for PS and commercial use cases, including support for V2X communications [3GPP15-22885]. However, the currently supported LTE D2D communications technology components are not designed to fully harvest the potential of the coverage, capacity and delay gains that D2D communications are expected to deliver [METIS15-D43]. METIS [METIS15-D43] investigated several D2D aspects. For example, mechanisms for device discovery in- and out-of-network coverage, selection of appropriate mode of transmission (directly between involved devices or via radio access infrastructure) as well as algorithms for power control and SINR settings.
Use Case	UC1 “Dense Urban Information Society”, UC2 “Virtual Reality Office”, UC3 “Broadband Access Everywhere”, UC4 “Massive Distribution of Sensors and Actuators”, UC5 “Connected Cars”
5G Service Type	
RAN Design Implications	This TeC will have a major impact on the RAN design in terms of how to discover D2D UEs, sidelink design, relaying, broadcast information and scheduling. The impact on the RAN protocol design is limited.

In 5G, the D2D communications capabilities should be supported as an inherent part of the system rather than as an “add-on” feature. The basic rationale for D2D communications as a technology component is that D2D transmission should be used whenever it is (1) more efficient in terms of spectral efficiency, energy efficiency, achievable latency or reliability or (2) can provide a better service experience than traditional cellular communication.

In addition to the features supported by Release 12-14 of LTE, the D2D concept should be able to support additional features that are motivated by new use cases, requirements or performance enhancements. To summarize the D2D scenarios and to establish some basic D2D related requirement list, Figure 3-21 is included below. These scenarios may be helpful to identify key requirements and design options, but D2D technology components under discussion are not and should not be tightly connected to or limited by these scenarios. Note that not all scenarios and use cases will be investigated by METIS-II.

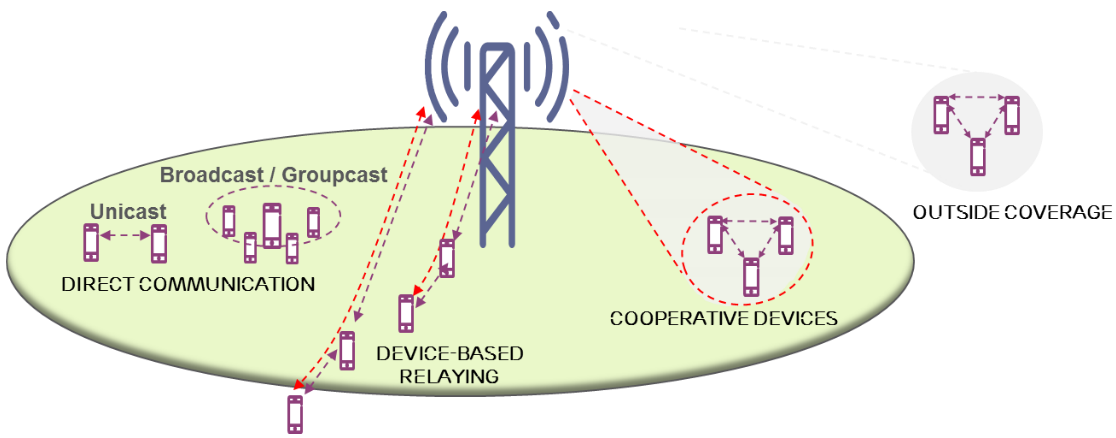


Figure 3-21 The D2D concept should support diverse scenarios including unicast, group cast, D2D based relaying, cooperative communications and D2D outside of cellular coverage situations.

Table 3-1 lists requirements related to D2D and compare their current status with how they can evolve in 5G. Unicast (point-to-point) D2D communication can be seen as a base case, that – when mode selection, resource allocation and power control are properly applied – can much strongly improve the network performance when proximal communication opportunities exist [BFJ+15], [METIS15-D42]. Although multicast and broadcast communications by means of D2D are supported in 3GPP Release 12, there may be performance enhancements to support a longer multicast/broadcast range and higher rates without affecting the cellular layer. Support for D2D based relaying in partial network coverage situations exists already in Release 12, but the performance both in terms of range extension and achieved E2E rates should increase by adding appropriate relaying device selection and RRM functions [SFM+14].

Table 3-1 Some D2D related use cases and their new requirements applicable in 5G D2D systems

Use case	Status	New requirement
Unicast communication in cellular coverage (in licensed spectrum)	Not currently in 3GPP	Unicast D2D in cellular spectrum should be supported. Cellular layer must be protected.
Group-cast/broadcast in cellular coverage (in licensed spectrum)	Available in 3GPP	Performance enhancements (in terms of SE/EE/ delay/reliability)
D2D based relaying	Available in 3GPP (R13 on-going)	Performance enhancements (in terms of SE/EE/delay/reliability)
Cooperative devices in 5G coverage	Unavailable in 3GPP	Research in literature is available.
D2D/Adhoc NW outside 5G coverage	Available in 3GPP (for group-/broad-cast, no UE-UE relay)	All the above when no NW assistance is available

Cooperative communications enabled by network controlled and assisted D2D communications can take many different forms at various layers of the protocol stack, such as distributed device based content caching and distribution, cooperative MAC protocols and, for example, network coding enhanced cooperative relaying [AFT+15]. The potentials of these areas specifically in 5G networks are proposed for future studies. Likewise, some forms of D2D communication outside NW coverage is supported already in Release12 (e.g. multicast/broadcast), but in 5G D2D can be further developed to cover larger areas in, for example, disaster situations and provide higher bit rate services even in (temporarily) out-of-coverage areas [FPS+14]. Table 3-2 lists some of the design principles for D2D RM that could be applied for 5G.

Table 3-2: Some of the proposed design principles and their application to D2D

Design Principle	Implications on D2D design
Utilize all available resources	Take advantage of UL/DL flexibility: no explicit restriction to constrain D2D to UL resources

Avoid slow configuration and reconfigurations	Enhance CP reliability and flexibility to support multi-hop/mesh D2D
Support high-frequency friendly D2D	Take advantage of advanced antenna solutions, high processing capabilities, and large storage available in devices
Network controlled D2D when applicable	Take advantage of the network knowledge when possible, both for licensed spectrum and unlicensed spectrum.

Further details of this TeC is found in the Annex A.6.

3.2.4 RM for Inter-Network Collaboration

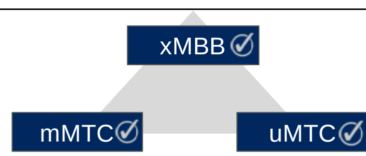
Identified in the research community as potentially one of the best ways to allow innovation and quicker evolution of the architecture, the Software Defined Wireless Access Network (SDWN) approach has been recently studied in the academic community [ACO+13][OFE+13].

While the corresponding transition to a software defined approach has now somewhat solidified in the networking world reaching wide spread commercialization, the same concepts are still quickly evolving in the wireless access world. First and foremost, while this approach cleanly separates functionalities across elements and leads to easier-to-write, globally-optimum algorithms, it comes at the cost of scalability and latency. In particular, two fundamental issues arise which did not appear in the SDN reference world:

- SDWN requires a neighborhood view in order to take effective choices for common control parameters such as channel, power, modulation schemes, etc., as nearby network and base stations will also affect expected behaviors.
- Different time scales for different operations and functionalities (e.g. scheduling *ms*, high-priority users/traffic, fast Ack *<1ms*, etc.) lead towards a division between logically centralized management vs. local (e.g. on BS) based on time scale requirements to support both of them.

In order to approach these problems, it is planned to extend previously studied Application Programming Interfaces (APIs) and mechanisms. This will allow us to implement a number of inter-network coordination techniques and RRM algorithms and cover larger number of usage scenarios, such as multi-operator coordination or simply multi-technology coordination across a single operator, e.g., 5G AIV, WiFi and LTE.

Interface API and RadioMap towards Inter-Network Collaboration

TeC ID	T5.2- TeC8
Abstract	Starting from a previously developed architecture for network-assisted spectrum coordination called “SAVANT” [SAV] that defines a CP API for RANs such as WiFi, WiMAX and LTE, a framework for network-assisted dynamic spectrum access that can be applied to emerging 5G scenarios will be developed. The currently available framework exposes a set of APIs to control a number of radio parameters and introduces basic inter-network protocol for negotiation of cooperative spectrum policies and algorithms. The plan is to extend this and implement a number of inter-network coordination and RRM algorithms. This will allow us to cover larger number of usage scenarios and provide both simulation and experimental evaluations of the proposed methods, both in terms of potential improvements in spectrum efficiency and performance as well as to extend this approach to cover emerging 5G radio air interfaces.
SotA	Open Base Station [BSR+11], HetNet (i.e., use of multiple access technologies in a wireless network) and multi-path support (i.e., enabling the simultaneous use of several device interfaces by exploiting different combinations of the available data paths).
Use Case	UC1 “Dense Urban Information Society”, UC3 “Broadband Access Everywhere”
5G Service Type	
RAN Design Implications	At the core of the design of the entire APIs and RadioMap framework, there is desire to define a fully technology-agnostic architecture for intra- and inter-network collaboration. This generates the requirement of separating as much as possible the desired functionalities from the underlying transport layers, normally used as an interface between different network elements. Motivated by these goals, we base our design on the assumption that a fully IP based environment is available at the exit point of the different AIVs (them being current LTE evolved Node Bs (eNBs) or future 5G Access Points). IP provides the right level of flexibility to support the requirements defined by the API. Later on, we will show how this could be adapted to the interfaces currently available across different wireless technologies. Starting from the general assumption that the control APIs and RadioMap are implemented on top of common IP based protocols (e.g., HTTP based REST Interface), we identify properties and requirements that are necessary to deploy the framework. These requirements can be identified mostly across reliability and performance characteristics. For example, REST APIs rely on HTTP to reliably perform any operation guaranteeing in order delivery of requests/responses. As the move to a sole IP based architecture would be drastic and might

	require incremental deployment, our solution can be adapted to existing protocols and interfaces. Considering as an example the LTE architecture, we could implement our APIs on top of current interfaces (e.g. S1, for eNB to controller communications). With the exception of the introduction of the new distribution of resources and entities (e.g., employment of a controller), we envision a minimum impact on the architecture design, with a higher impact on logic distribution of functionalities.

Two core components will be studied as part of this TeC: The first one lays the ground on previously performed research and will focus on extending the concept of an Open Base Station; the second one will look to exploit such design to extend available APIs with particular focus on power control functions and a way to produce a detailed RadioMap to be used in inter-network cooperation scenarios,

Open Base Station. Based on an ongoing research effort [BSR+11] aimed at developing a software-defined CP framework for wireless networks, similar in spirit to SDN/OpenFlow standards developed for wired networks over the past few years. It is believed that the future 5G architecture will benefit from the concept of “open base stations” and “open access points” which interface to a common (“software defined wireless network”) CP that can be used to support a wide range of RRM and access network functionalities. The proposed open/software-defined wireless network approach has many advantages for 5G including the ability to support multiple radio AIs within the same framework while enabling a clean separation between PHY/MAC and networking or management functionality. Open Base Station uses REST-based API which is available through UP and facilitates common CP support across AIs (so far WiFi, WiMAX and LTE). For the METIS-II collaboration, it is intended to follow the CP discussion closely and evolve the open base station/wireless SDN architecture to match the requirements of 5G, by contributing to the architectural design and using experimental systems to evaluate METIS-II UCs.

SDN APIs and RadioMap. Towards the development of the Open Base Station concept, it is planned to design and evaluate a set of APIs that would allow controlling the most common parameters such as frequency, power and a concept of RadioMap information retrievable through such API. This RadioMap would allow the collection of the previously mentioned neighborhood view, necessary towards fully deploying coordination techniques in inter-network and inter-technology scenarios.

Further analysis will be dedicated towards understanding how to divide the aforementioned APIs across three core groups based on the time scales of such functionalities:

- A set of Direct Control (DC) APIs used to define explicit rules/actions to be performed by network elements (e.g., UP setup, Wireless Access Control, Power control management at BS or UE).
- A set of Policy Based Control (PBC) APIs to be applied for locally decided operations (e.g., scheduling).

- Statistics and events collection similar in spirit to counters in SDN.

Figure 3-22 shows such division in the SDWN architecture. In addition, further details on evaluation methodology are given in Annex A.7.

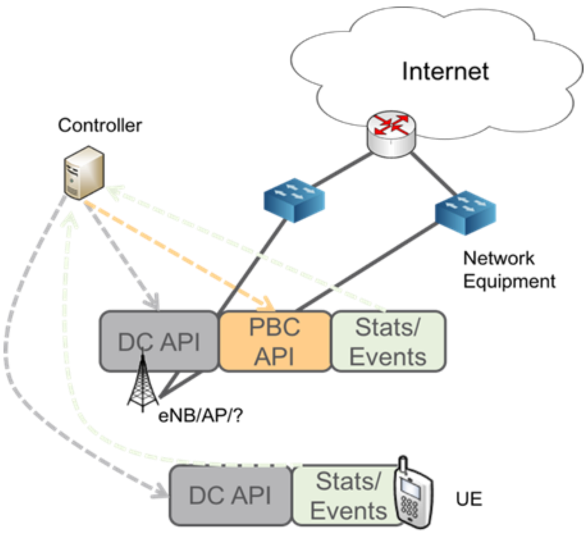


Figure 3-22 Direct Control (DC) or Policy Based Control (PBC) APIs for variety of air interfaces/common functions towards SDNization of wireless access network.

3.2.5 Dynamic Traffic Steering

The main goal of traffic steering is to enable the RAN to serve the right application and related data flows using the most suitable AIV or combination of AIVs. The traditional approach in terms of traffic steering has been to do load balancing, etc., on an asynchronous time scale, whereas here we consider the dynamic traffic steering and adaptation on a synchronous time scale. Techniques in LTE such as CA which enables scheduling of traffic over multiple carriers in the same eNB with multiple remote radio heads, and dual connectivity which enables inter-eNB traffic splitting with independent RRM operations within the eNBs, do not explicitly consider dynamic traffic steering to achieve the QoS targets of the user. The application of such techniques would be especially relevant with the presence of higher frequency bands and with the ultra-dense deployment of small cells. Dynamic traffic steering techniques are envisioned to be important enablers for ultra-reliable, low-latency and extreme mobile broadband features.

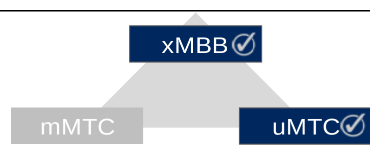
For achieving dynamic traffic steering, two distinct approaches are considered here. The first approach, considers the dynamic adaptation of the traffic flow to multiple AIVs in order to fulfill 5G requirements, based on real-time feedback from the access points. The second approach, proposes the use of an interference assessment before mmW transmissions and possible counter measures to minimize the interference in the network, while taking into account the heterogeneous nature of the network environment. The traffic steering component of both approaches is AIV-agnostic and can work using any of the AIVs currently being considered for

5G. Both approaches also consider the presence of a higher layer of RAN functions, which takes care of traffic steering.

The following TeCs are considered therein:

- T5.1-TeC7: Multi-AI Dynamic Traffic Steering Framework
- T5.1-TeC9: RM and Traffic Steering in Heterogeneous Environments

Multi-AI Dynamic Traffic Steering Framework

TeC ID	T5.1-TeC7
Abstract	The 5G network is anticipated to comprise of multiple AIVs, which connect the UE to the CN. Such multiple AIVs would enable the network to achieve key 5G goals such as extreme mobile broadband (1000 times higher capacity) and ultra-reliable communication (99.999 % reliability). Such a networking paradigm where the UE is connected to multiple access points is called multi-connectivity. For efficient RAN moderation within these interfaces and to ensure that the QoS requirements of the traffic flows are fulfilled, a multi-AIV traffic steering framework is proposed. The framework takes real-time feedback from the multiple AIVs currently serving the UE, in order to adjust the traffic flows on a synchronous timeframe. Thus, the idea is to provide an ‘outer loop’ RAN moderation framework with a global 5G RAN view, in order to enable better RAN moderation within each AIV. Here the synchronous time scale is not necessarily linked to the TTI used in the system. The QoS requirements could be similar to the ones defined in 4G in terms of delay, packet loss, bit rates, etc., with 5G specific constraints and different enforcement policies. In this TeC, the details of such a dynamic traffic steering framework, based on a dynamic QoS framework exploiting the multi-connectivity paradigm, are defined. Detailed performance evaluations are also conducted, to show the performance gains from having the mechanism in the 5G network.
5G Service Type	
SotA	For traffic steering in wireless networks, the following prior studies have been done: • Mobility based traffic steering enhancing mobility performance in HetNets [MBL+13]. • The potential of dynamic inter-AI traffic steering between high speed packet access (HSPA) and LTE is done in [JLW11] • Studies related to traffic steering using absolute priorities framework in LTE macrocell scenario is done in [FMC+13] • We also consider the current LTE QoS architecture [3GPP14-23203] as a baseline assumption in this work.

	The focus of traffic steering in legacy radio access technologies have been mainly on load balancing or static long-term traffic flow adjustments. In 5G, it is envisioned that real-time traffic steering would be a key enabler for the diverse set of requirements and use cases.
Use Case	UC1 “Dense Urban Information Society”
RAN Design Implications	• There are minimal impacts foreseen on the overall RAN protocol design. But there would be impacts on for e.g., the HARQ protocol design, in order to accommodate the delivery of high priority packets over multiple AIVs. The HARQ process ID and related mechanisms should be modified in 5G in order to incorporate such features. • The interface between the Access Network-Inner (AN-I) and Access Network-Outer (AN-O) should be enhanced with new information elements defined to communicate the real-time radio condition feedback, in order to do the dynamic traffic steering. The level of information that could be exchanged for e.g., abstract radio condition information vs. real-time channel state information, would also depend on the protocol split option considered between the AN-O and the AN-I layer. • The QoS policies would be the input for the AN-O layer from the core network. The real-time radio conditions of each user would be the input expected from the AN-I layer. Both these inputs would enable the real-time traffic steering framework, with the dynamic traffic routing over the multiple AIVs as the output of the framework. • Potentially new information elements defined over the standardized interface between AN-I and AN-O. Modifications of the HARQ protocol design in order to support the multi-connectivity framework would also need to be standardized. The dynamic QoS framework would require new functional splits between CN and RAN, for e.g., the QoS policies that are sent from the CN to the RAN and how they are enforced through the definition of QoS parameters of the various service flows that are established.

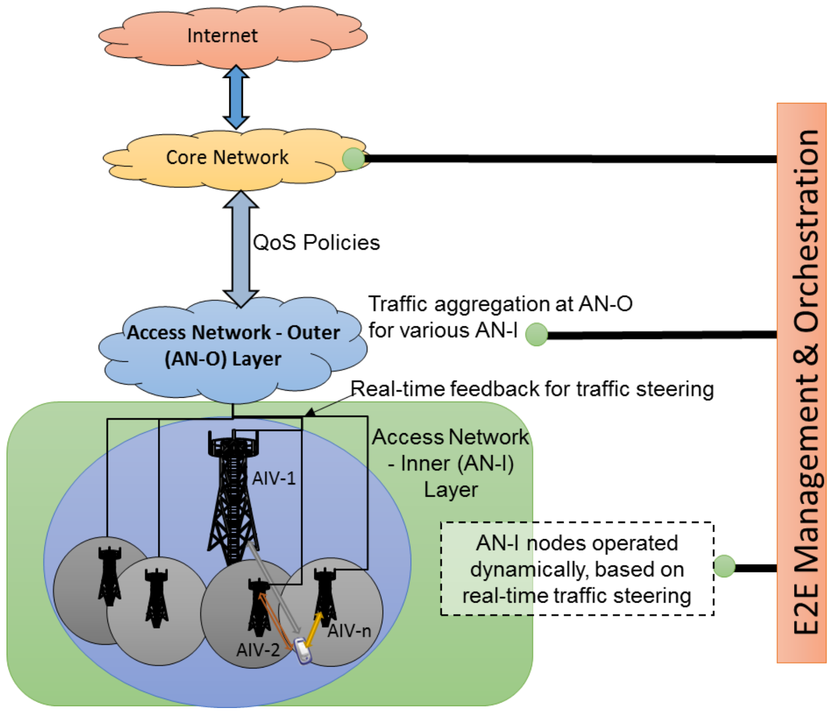


Figure 3-23 The overall system model considered with 5G multi-connectivity [PME+16].

The overall system model considered for this technology component is as shown in Figure 3-23 [PME+16]. Here the functional decomposition considerations linked to the E2E management and orchestration (MANO) framework, are based on the architecture presented in [NGM15]. The QoS policies are sent from the CN to the AN-O layer, where the traffic aggregation is assumed to happen. In 5G, due to the stringent service requirements and due to the relative unpredictability of the radio links (especially on the higher frequency bands), it is assumed that the traffic steering is enforced in the lower layers of the protocol stack, for e.g., in the Radio Link Control (RLC) or MAC layers. This will enable the faster time scale rerouting that would be required to fulfill such requirements. Thus, the dynamic traffic steering framework is then implemented in the outer layer, in order to do a fast traffic re-routing to the various AIVs in the AN-I layer. Here the steering is assumed to happen based on real-time feedback (per-TTI or periodically over a few TTIs) from the AN-I layers. In the example instantiation of the framework considered here, we assume that CSI feedback from each UE for all the established service flows is sent to the AN-O layer by the AN-I, in order to do the traffic routing. Here the AN-I layer is operated with an optimal amount of active links engaged in multi-connectivity with the 5G UE, in order to achieve the QoS targets of the service flows.

The service flow delivery mechanism using the proposed traffic steering mechanism is as shown in Figure 3-24 [PME+16]. Here the traffic steering framework, based on the link-level quality feedback and with the knowledge of the priority levels of the various service flows to be delivered to the users, routes traffic accordingly to various APs. Due to the relative unreliability of the involved links, the feedback is required real-time, in order to do a fast traffic rerouting, in case a link failure is detected. Current LTE radio link failure detection and recovery mechanisms would take several seconds in order to re-establish the radio bearer, and since this is unacceptable for high-priority, high-reliability traffic, the dynamic traffic steering framework will ensure that the QoS policies received from the CN are successfully enforced.

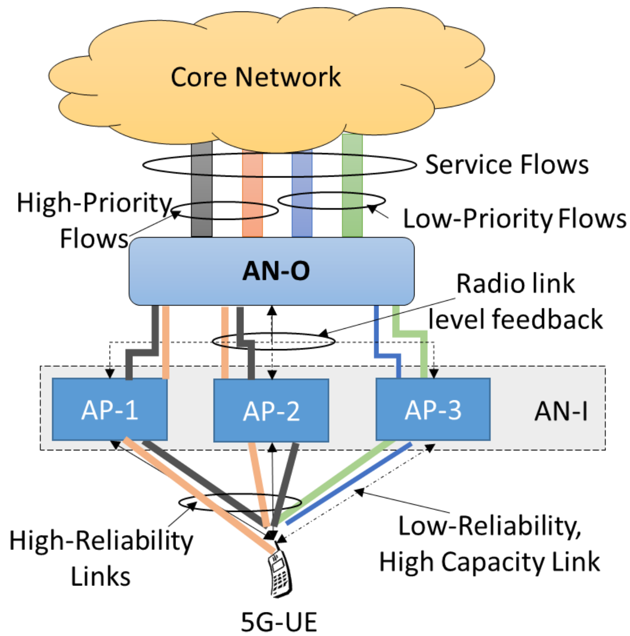


Figure 3-24 Service flow delivery mechanism considered using the proposed dynamic traffic steering framework [PME+16].

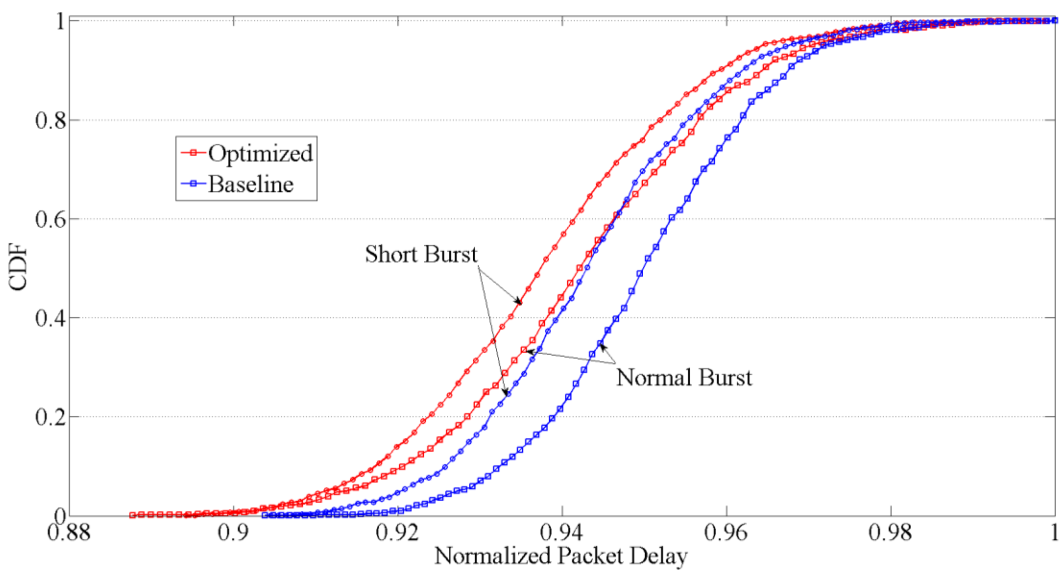


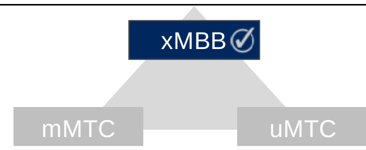
Figure 3-25 Normalized CDF distribution of packet delivery delay.

Simulations were also conducted using a dynamic system-level simulator, in order to evaluate the potential gains that can be achieved using the dynamic traffic steering framework. The evaluations presented here are similar to the ones shown in [PME+16]. The detailed parameters used in the simulations are described in the Annex A.8. The CDF distribution curves of the packet delivery delay normalized to the maximum delay for delivering high-priority traffic is as shown in Figure 3-25. The curves indicate how much delay is encountered for delivering a packet using the baseline LTE based mechanism as compared to the optimized 5G based dynamic traffic steering. Here the key difference is that in the baseline mechanism, there is an additional delay of 200 ms for re-routing traffic to a new AI, after link failure is detected. Since a dynamic QoS framework is used in 5G, it is also assumed that the GBR bearer established for the high-priority traffic that is being delivered will also be torn down when the traffic steering framework reroutes the traffic over the other active AIVs.

In the baseline LTE case, since bearers are established by the packet data network – gateway (PDN-GW) located at the edge of the CN, the radio resource reservation mandated by the establishment of such bearers continue, even after a radio link failure occurs, until the radio link failure (RLF) is detected and the traffic flow redirected to the node serving the UE. Such resource reservations are avoided in the 5G dynamic QoS case, since the AN-O layer within the RAN has complete control over the establishment and management of QoS policies within the RAN, thereby leading to efficient radio resource utilization. The relative gains from having the dynamic traffic steering framework is visible in the results, in terms of a reduction in the packet delivery delay as compared to the baseline LTE case. The main focus of the simulation has been on evaluating the viability of the proposed mechanism. As indicated in Figure 3-25, the reliability of the network also improves by the delivery of high-priority traffic over multiple AIVs, thereby avoiding the potential delay due to the link failure over one AIV.

RM and Traffic Steering in Heterogeneous Environments

TeC ID	T5.1-TeC9
Abstract	In a heterogeneous environment where systems operating at mmW and traditional bands co-exist, a proper mechanism to manage resources and cope with interference in mmW bands is under investigation. The idea is to focus on a pre-emptive geometrical-based interference analysis that is able to determine, prior to the establishment of a new transmission link, a set of prospective interfering mmW transmission links allowing the network to implement a suitable resource partitioning mechanism (at scheduler level) or take other alternative measures (e.g., traffic steering) at higher levels.
SotA	For interference handling in mmW bands the following approaches have been studied: • Interference cancellation via coordination (CoMP) or coding [KTC15] • Interference avoidance (e.g. through scheduling) [SMM11] • Interference mitigation via different atmospheric absorption rates of

	different mmW frequencies [Lei14]
Use Case	UC1 “Dense Urban Information Society”
5G Service Type	
RAN Design Implications	A prerequisite is that the geometrical position of all the mmW transmitting/receiving nodes of the cellular network should be known by the network at any time regardless of their mobility. A model of the antenna of each mmW node (e.g., at least the main beam angle and the FBR) is needed for the analysis.

In order to increase the overall capacity of 5G cellular systems, network radio nodes can be designed to operate at frequencies in mmW bands spectrum (e.g., 60 GHz). The mmW bands usage will be, nevertheless, coupled with traditional network connections at cellular bands below 6 GHz in heterogeneous environments [STS+14]. In such a heterogeneous environment, as depicted in Figure 3-26 a system should be able to manage resources (e.g., steer traffic to the proper transmission link), taking into account the specific characteristics of the various potential transmission links and the actual condition (e.g., interference) at the time of transmission.

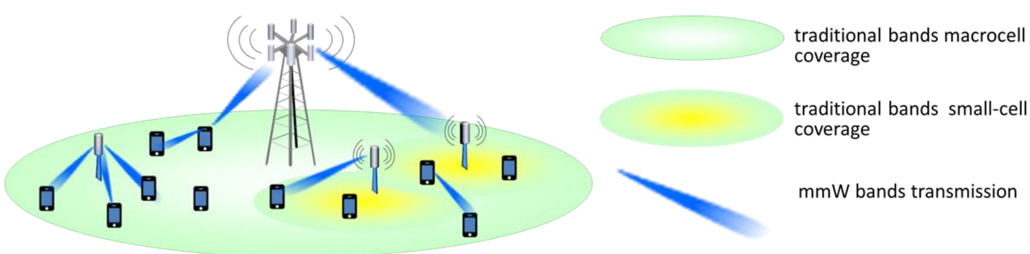


Figure 3-26 Example of heterogeneous environment with mmW-band transmissions

Implementing a system able to manage a heterogeneous and multi-band network requires that a specific architecture is devised. Among various functionalities, a proper mechanism to manage resources and cope with interference will be investigated. The considered algorithm will elaborate on the idea of an assessment of potential interference prior to the actual transmission in order to let the system take appropriate counteractions aiming at solving/avoiding/mitigating the potential problem. The idea is to focus on the pre-emptive identification of the situations in which mutual interference among intra-system communications can occur by means of a geometrical approach. In particular, the proposed solution allows to limit transmission collisions (intended here as transmissions creating a so high mutual interference with neighbor transmission links so as to make the communication impossible) and to limit the subsequent signaling overhead aimed to solve such a problem. This is achieved by means of a geometrical-based interference analysis that is able to determine, prior to the establishment of a new transmission link, a set of prospective interfering mmW transmission links. The analysis allows the network to implement a suitable resource partitioning mechanism (e.g., a time-division multiplexing), at a Short Term RRM (scheduler) level, between the new transmission link and all the existing and potentially colliding transmission links. Alternatively, other measures at higher (Long Term RRM/SON) traffic steering level (e.g., establishing a transmission link on a lower frequency) can be taken. Assuming the adoption of a dynamic RAN scenario, such sets of potentially colliding transmission links should be revised periodically or on an event-triggered basis.

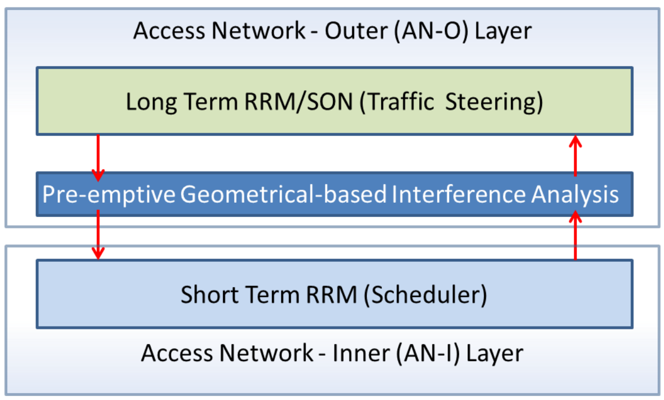


Figure 3-27 PGIA layer between Long Term RRM / SON and Short Term RRM functionalities with AN-0 and AN-I layers classification

In Figure 3-27 the Pre-emptive Geometrical Interference Analysis (PGIA) layer between Short Term RRM (scheduler) and Long Term RRM/SON (traffic steering) is depicted. The new layer computations help both the lower Short Term RRM functionalities (e.g. scheduler) and upper Long Term RRM or autonomous SON functionalities (e.g. traffic steering) to take educated actions before a new transmission link in the mmW band is to be initiated. With reference to the overall system model depicted in the Multi-AI Dynamic Traffic Steering Framework (T5.1-TeC7), the above functionalities are located in the proper Outer or Inner Access Network Layers.

A prerequisite to the algorithm is that the geometrical position of all the mmW transmitting/receiving nodes should be known by the network at any time regardless of their mobility, as well as some information about the mmW antennas. The followed method for avoiding transmission collisions prior to a new mmW transmission is described in the Annex A.9.

Preliminary results depicted in Figure 3-28 show that (under the assumptions described in the Annex A.9) the defined pre-emptive analysis coupled with a simple resource sharing mechanism can significantly reduce the number of interfered links as the number of concurrent mmW links in 1 km^2 increase (in this exemplary analysis, a link is considered interfered with a C/I below 12 dB). Without PGIA, the average percentage of interfered mmW links rises over

95% as the number of concurrent links grows to 200, while with a PGIA and resource sharing mechanism, the average percentage of interfered mmW links is capped around a very low 2.5%.

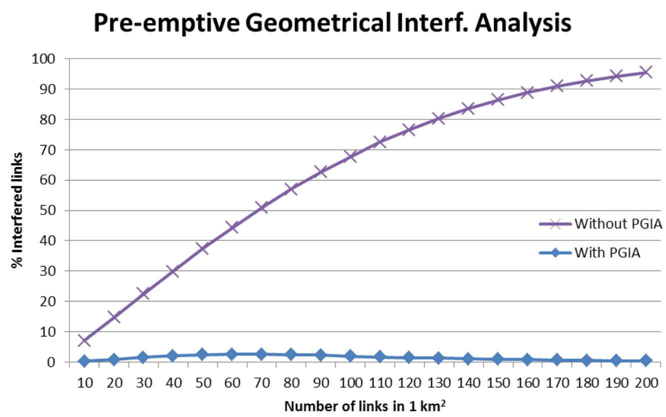


Figure 3-28 Average % of interfered links as functions of the number of concurrent links in 1 square km, without and with PGIA (details in Annex A.9)

Moreover, since the analysis specifies a cluster (or a limited group of clusters) concerned with the potential new transmission, the method is a valid input for closed-loop or open-loop control mechanisms within the upper and lower layers functionalities, and further interactions aimed to optimize the RM of the system can be studied and developed.

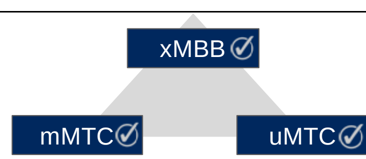
3.3 Context Management

RRM has an important role in wireless network operation in particular controlling the allocation and usage of available spectrum resources. New fast RM for new 5G AIVs will take into account data from services, applications down to physical layer and will have an impact on BS and UE measurements gathering context data for efficiently controlling spectrum resources. [ITU-R15] defines context awareness as delivering context information in real-time on the network, devices, applications and the user and his environment to application and network layers in the context of IMT-2020. This context could be classified on device level state (e.g., battery state level and processing load), user status (e.g., quality of experience preferences, activities, location, and mobility status), current environment (e.g., devices in neighborhood, topology, background activities, and weather) and network status (e.g., load, throughputs, reliability, supported radio technologies, interference and spectrum availability). While 3GPP Release 13 already provides context data as information elements, (for instance, UE power preference indicator (PPI) enabling the BSs to configure properly discontinuous reception (DRX) values, reference signal received power (RSRP), and reference signal received quality (RSRQ) measurements of serving and neighboring cells), there are still many challenges in particular in the exploitation of user/device information for radio resource allocation in heterogeneous 5G networks deploying dense and widespread small cells.

The following TeC is considered herein:

- T5.1-TeC5: UE-centric Fast RM & Context Management

UE-centric Fast RM & Context Management

TeC ID	T5.1-TeC5
Abstract	New fast RM for 5G AIs will have an impact on BS and UE measurements gathering context data for efficiently controlling spectrum resources. In this TeC, we investigate related specifications in ITU-R (e.g., context definition) and 3GPP RAN (e.g., measurement definition, measurement gaps), in order to study the extensions and modifications that are necessary to support the new features of 5G, such as inter-AIV switch and mobility/space configurations.
SotA	Context data are gathered both by the UEs and the access nodes. More specifically, local data will be sent to specific databases in the network. Fast resource and interference management has been explored and standardized for cellular networks so far with a clear impact on UE measurements. For example, in LTE the UE has to measure quantities such as, CQI, RSRP, and RSRQ. Measurements performed by the device are expected to evolve. New AIVs are going to increase considerably this impact raising new challenges to the UE performance and power budget.
Use Case	UC1 "Dense Urban Information Society", UC2 "Virtual Reality Office", UC3 "Broadband Access Everywhere", UC4 "Massive Distribution of Sensors and Actuators", UC5 "Connected Cars"
5G Service Type	
RAN design Implications	Modifications in RRC layer are foreseen to enable the UE to measure new parameters and send the new measurement configurations to the ANs.

In what follows, the possible extensions and changes in the "UE Measurement Context" for 5G shall be studied from the perspective of the impact on the UE while 3GPP Release12 serves as a baseline.

Functional Extensions in "UE Measurement Context":

Based on the understanding and consensus on 5G RAN architecture investigated in [MET-II16-WP], the UE context should be properly extended to adapt to the following new features that are envisioned in 5G:

Inter-AIV switch and multi-connectivity: The future 5G device is expected to run various applications that may fall into different UCs supported by different AIVs and their AIV/numerology. Some UCs have conflicting KPIs so that it is not likely that the KPIs of different UCs can be realized by a single AIV/numerology. Instead, different applications may be supported by different AIVs/numerologies and the integration of multiple AIVs/numerologies is foreseen. Some examples are provided in the Annex A.10. Therefore, different from the hard handover in current LTE (i.e. handover between different BSs within the same AIV), which occurs only when the cell of the UE is changed, the inter-AIV switch (i.e., the switch from certain AIV to another AIV) is expected to occur much more frequently (e.g., due to the change in running applications and the related AIVs, or due to the switching between bands and related AIVs). It is thus necessary that the UE Context is accordingly designed to assist in a fast switch.

Interworking with legacy RATs: To make a continuous exploitation of existing architecture infrastructure, the interworking of 5G and legacy RATs (for example, LTE-A and WLAN) is on the one hand of particular importance. On the other hand, considering the ongoing standardization efforts in 3GPP which are explained in detail in the Annex A.10, we mainly focus on the interworking of 5G and LTE-A Pro. However, we do not exclude the possibility of interworking of 5G and legacy RATs (e.g., WiFi and WiGig) individually.

Spectrum sharing: Considering the efforts in 3GPP to operate LTE-A on unlicensed bands, the spectrum (both licensed and non-licensed) may be shared among different technologies, either legacy technologies or new ones (e.g., WiGig, LTE-A Pro, new 5G AIVs, and LAA).

TDD and FDD: In current LTE-A systems, both FDD and TDD schemes are defined with the FDD scheme enjoying a much higher emphasis. To support the demanding request in data rate of 5G, high frequency spectrum (above 6 GHz) becomes available. However, high frequency channels suffer from a very large attenuation rate, and beamforming is seen as an important approach for directional transmission to compensate the large path loss. A prerequisite for beamforming is accurate CSI, which is easier to obtain under TDD scheme due to the channel reciprocity. Therefore, TDD (and dynamic TDD) will play a more important role in 5G. Besides this, it is possible that TDD and FDD will coexist in the RAN. For example, FDD is used in LTE-A Pro and TDD is used in a novel 5G AIV. As discussed above, multiple AIVs may be used simultaneously for the same UC and therefore the UE Context should be designed for both TDD and FDD.

<u>Possible Changes in “UE Measurement Context”:</u>

Based on the understanding of the new functionalities required from the UE on 5G RAN architecture investigated in the previous section, the UE context should be properly extended as follows.

Additional mobility configurations: In order to satisfy various mobility requirements in different UCs (e.g. high mobility in “connected cars”, medium mobility in “dense urban information society”, or low mobility in “massive distribution of sensors and actuators”), the network may need to change the measurement configurations to be based on the device speed.

For example, the network can configure the measurement intervals to be related to the device velocity.

Band/time specific configuration for neighbor cell measurements: As illustrated in [MET-II16-D61], in current LTE, neighbor link measurements are currently performed over cell specific reference signal (C-RSs). C-RSs are constantly broadcasted by all the cells and transmitted over the whole bandwidth. In the case of energy efficiency it is obvious that having signals broadcasted all the time and over the whole bandwidth disables the possibility of applying DTX cycles by the network to its power amplifiers, in order to save energy and control the level of interference being generated.

Consequently, although the current LTE C-RS approach gives the device flexibility in time/frequency measurement for neighbor link measurements, it is expected that the network may configure the device to perform the channel signal measurements to be on a specific pair of time and frequency resources.

Space measurement configuration: In high frequencies, the signals are transmitted along a specific direction using the concept of beamforming, so the UE need to detect a beam that may have a narrow coverage, leading to a direction measurement configuration (in addition to time and frequency measurement configuration). Thus, the access node shall configure the UE with the angular space configuration (e.g., antenna directionality) in order to achieve better beam scanning.

Reporting interference across multiple AIVs: In current 3GPP standards, in order to allow users to access various networks and services ubiquitously, a UE may be equipped with multiple radio transceivers. For example, a UE may be equipped with LTE, WiFi, Bluetooth transceivers, and Global Navigation Satellite System (GNSS) receivers. In 5G, several AIVs may coexist and operate simultaneously for different slices as in network slicing. Due to the extreme proximity of multiple radio transceivers within the same UE operating on adjacent frequencies or sub-harmonic frequencies, the interference power coming from a transmitter of the collocated radio may be much higher than the actual received power level of the desired signal for a receiver. This situation causes In-Device Coexistence (IDC) interference and is referred to as IDC problems. As a result, when a UE experiences IDC problems that it cannot solve by itself, a network intervention is required, that is, the UE sends an IDC indication via dedicated RRC signaling to report the IDC problems to the eNB.

However, this IDC interference mitigation scheme may not be efficient in future deployment scenarios. For example, it is not always possible for the access node to switch the device's configured measurement frequency to another frequency which suffers from less interference. In such a case, the access node may need from the UE the report on the measurements of the interference among different active (running) AIVs as an important factor in RM. For example, this can be accomplished by changing the operating resources (time, frequency, and space) assigned for each AIV, or by selecting the best suitable set of AIVs that achieves less interference given the current situation.

Maintaining multiple UE contexts: Due to the multi-connectivity, the UE may need to establish multiple connections with multiple APs at the same time. Consequently, the device may need to maintain multiple UE contexts simultaneously. This may also be the case when several AIVs are activated simultaneously but each AIV may have its own specific template for the UE context (e.g., measurement reporting scheme).

Conceptually, permitting the device to maintain simultaneously multiple UE contexts with different templates may negatively impact both the device complexity and the efficiency of the inter-AIV switch (especially for more frequent inter-AIV switch, when the UE context transfers among the different AIVs). Consequently, a further study may be needed to assess the benefits of having unified UE context across different AIVs.

More accurate and updated location information: In 5G, as introduced in T5.1-TeC9 (RM and Traffic Steering in Heterogeneous Environments, Section 3.2.5), it is expected that the location information (i.e., geometrical position) collected from the device should be known by the network at any time regardless of the device mobility. In addition the accuracy of the measured device location shall be increased.

Based on the above analysis, the indicated directions of changes on the expected UE measurement context are summarized in the following Figure 3-29.

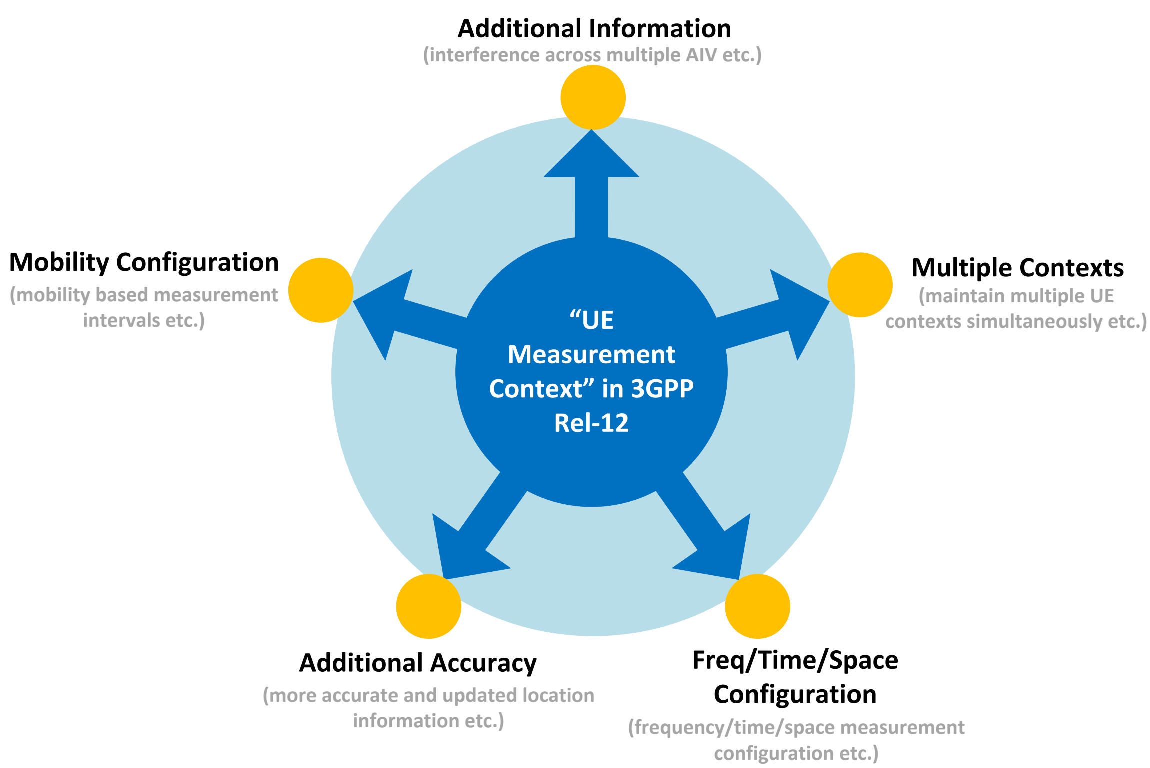


Figure 3-29 Possible changes compared to 3GPP Release 12 "UE Measurement Context".

4 Positioning of Enabling Technologies in 5G Landscape

In the previous sections, an overview of the enabling technologies for the envisioned agile RM framework has been provided on the basis of building blocks and functionality frameworks. In the design of agile RM framework, it is, as well, of paramount importance to highlight the synergies and inter-relations of these technologies and the corresponding building blocks towards functionality frameworks. Further, the RAN design implications of the enabling technologies define the overall impact on the final 5G system. Herein, enabling technologies are positioned in 5G landscape taking into account their roles within agile RM framework. To this end, the 5G landscape is collectively described by 5G services, i.e., xMBB, mMTC, and uMTC, 5G UCs (see Table 4-1 for the summary of the METIS-II 5G UCs [MET-II16-D11]), inter-relation mappings, and the envisioned implications on the final 5G RAN. Furthermore, Table 4-2 summarizes the different target KPIs that are considered for all TeCs and assigns them indices.

Table 4-1. METIS-II 5G Use Cases

UC ID	UC Title	Scope of Services
UC1	Dense Urban Information Society	Broad range of communication services covering needs related to both indoor and outdoor urban daily life (excluding office and factory).
UC2	Virtual Reality Office	Broad range of communication services in the (indoor) office context.
UC3	Broadband Access Everywhere	Full coverage target addressing outdoor/indoor communication needs especially in rural areas.
UC4	Massive Distribution of Sensors and Actuators	Broadest range of IoT services.
UC5	Connected Cars	Strong expectation from the (automotive) industry. Belongs to the first uMTC services expected to be commercialized but also includes xMBB services.

Table 4-2. Target KPIs and KPI indices

KPI index	Target KPI
1	Enhanced user/cell edge user throughput
2	Enhanced reliability

3	Reduced overhead
4	Enhanced energy efficiency
5	Fulfillment of per-slice latency, availability, and throughput SLAs
6	Flexible and simultaneous support of diverse service/QoS requirements
7	Increased architectural and air interface flexibility
8	Coverage extension
9	Reduced latency

4.1 TeC and Building Block Inter-relations

In Table 4-3, we highlight the positioning of the enabling technologies described in Section 3 within the 5G landscape. On this basis, the target 5G services and UCs are shown. The parenthesis around an entry, e.g., (mMTC), implies possible consideration based on the current status of the research activity. Additional columns show the target KPI indices for each TeC within each building block, given the different objectives they aim to solve as well as possible implications on the transport network (TN) and CN.

Table 4-3. Positioning of Enabling Technologies in 5G Landscape

TeC ID	TeC Title	Building Blocks	5G Services	UCs	KPI index	CN or TN Implication
T5.1-TeC3	5G User-centric Interference Management in UDNs	Interference Management	xMBB, (mMTC)	UC1	1,2	
T5.1-TeC8	Flexible Interference Management for 5G AIVs	Interference Management	xMBB	UC1	1	(TN)
T5.1-TeC11	Interference Coordination/Cancellation Strategies	Interference Management	xMBB	UC1	2,3	
T5.1-TeC4	Fast Carrier Aggregation and Coordinated Resource Allocation	Flexible short-term Spectrum Usage	xMBB, (mMTC)	UC1	1,2	
T5.1-TeC6	Multi-cell Coordination for Ultra-Dense Network Employing Dynamic TDD	RAN Moderation	xMBB	UC1, UC2	1,4	

T5.1-TeC10	Dynamic Cell Switch Off	RAN Moderation	xMBB	UC1	4	
T5.1-TeC1 T5.2-TeC1	Multi-dimensional RM for 5G and Legacy AIs	RM for Network Slices	ALL	UC1, UC2, UC3, UC5	5	TN
T5.2-TeC3	AI-agnostic Resource Abstraction Model for Virtualized 5G RAN	RM for Network Slices	ALL	UC1	5	(TN)
T5.2-TeC7	Unified RAN Management	RM for Network Slices	ALL	ALL	6	
T5.1-TeC2 T5.2-TeC2	LTE and 5G Tight Integration and RAN Moderation	Tight Integration with Evolved Legacy	xMBB, (mMTC), (uMTC)	UC3	1,2	TN, (CN)
T5.2-TeC5	Holistic RM Framework for 5G AIVs and Legacy	Holistic RM Framework	ALL	ALL	6	
T5.2-TeC6	Abstraction Model Design for 5G AIVs	Holistic RM Framework	xMBB	UC1, (UC5)	7	(TN)
T5.2-TeC4	RM for 5G D2D	Holistic RM Framework	xMBB, (mMTC), (uMTC)	UC1, UC2, UC4, UC5	8, 9	
T5.2-TeC8	Interface API and RadioMap Towards Inter-Network Collaboration	RM for Inter-Network Collaboration	ALL	UC1, UC3	1	TN, CN
T5.1-TeC7	Multi-AI Traffic Steering and Context Management Framework	Dynamic Traffic Steering	ALL	UC1	1, 4	(CN), (TN)
T5.1-TeC9	RM and Traffic Steering in Heterogeneous Environments	Dynamic Traffic Steering	xMBB	UC1	2, 6	
T5.1-TeC5	User-centric Fast RM & Context Management	Context Management	ALL	ALL	3, 4	(TN)

As the research activities are further investigated, the implications on TN and CN will become clearer. Here, the implications can refer to the requirements imposed on the TN and CN such that the target performance can be achieved on the RAN side. This relation can foster collaborations with other 5G PPP projects focusing on TN and CN.

Further, the building blocks are also indicated in line with the descriptions in previous sections. Throughout the work, the building blocks are expected to be consolidated into larger functionality frameworks that will map onto the overall agile RM framework described in Section 2. These functionality frameworks are seen as key means for developing the 5G RAN design in WP2 [MET-II16-D22].

In line with the above sections, the inter-relation of the TeCs within the building blocks and the positioning of the building blocks inside the envisioned agile RM framework are visualized in Figure 4-1. In the figure, four different elements can be identified defining the agile RM framework: the TeCs, the building blocks, the functionality frameworks, and the interfaces. All inter-building block interfaces have been labeled with a lower case 'i' followed by a subscript containing the numbers of the two building blocks that interface links. In addition, the interface linking the two functionality frameworks is labeled as 'I_x'.

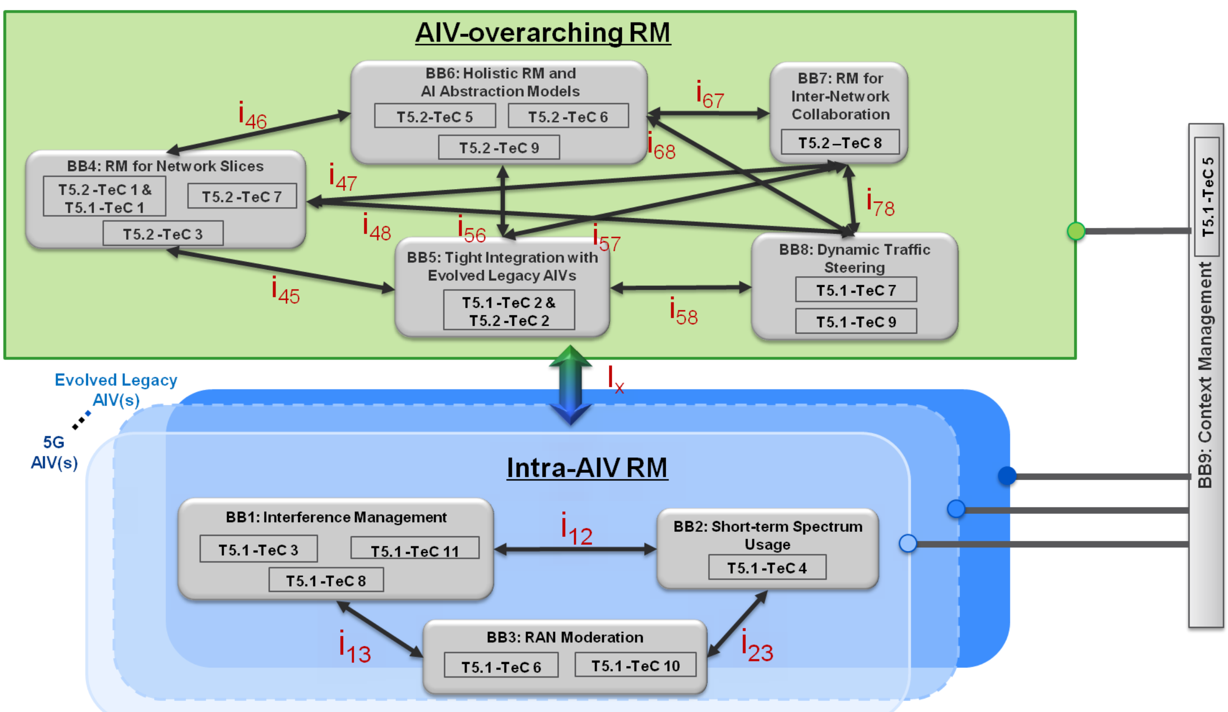


Figure 4-1 The inter-relation map of TeCs and building blocks within the envisioned agile RM framework. Building block is denoted by 'BB' in the figure.

As previously mentioned, the agile RM framework is subdivided into two functionality frameworks: AIV-overarching RM and intra-AIV RMs, each of which captures a different subset of the proposed building blocks and TeCs. Within a building block, the TeCs that are closely related to each other are grouped together, for instance, a TeC being a specific implementation of a more generic TeC (see, e.g., T5.1-TeC1 and the corresponding T5.2-TeC1, in the building block of RM for network slices, or T5.1-TeC2 and the corresponding T5.2-TeC2 in the Tight Integration Building Block*).* One of the main goals of this architecture proposal is to enable future-proofness to our design, i.e., the same framework can be utilized if new TeCs or building blocks are included, or if previous ones are updated. New interfaces might also need to be added for new building blocks or TeCs but the same framework as proposed here may still be used. Inter-building block interactions within intra-AIV and AIV-overarching RM frameworks are characterized through the interfaces depicted in Figure 4-1. Those interfaces exchange bidirectional information between building blocks so that the successful simultaneous operation of the different building blocks is guaranteed. Figure 4-1 represents the interconnection of building blocks as a de-centralized 'mesh network' of logical interfaces where building blocks talk directly to each other. However, depending on the scale and complexity of the system, a centralized controller could be also utilized to manage the interaction among building blocks. Furthermore, an interface between the two functionality frameworks could help bundling AIV-specific metrics for AIV-overarching functionality or vice versa (by breaking down/replicating AIV-overarching metrics to the different AIVs). Examples of such interactions could be the following:

i) BB1 (interference management) could report interference management measurements for the pool of resources in the unlicensed bands managed in BB2 (flexible short-term spectrum usage) via interface i_{12} of Figure 4-1.

ii) BB1 (interference management) could report interference metrics across different AIVs to BB5 (tight integration) using the cross-functionality framework interface I_x to prove the applicability of the tight integration,

iii) BB4 (RM for network slices) could report information about the slice requirements (SLA) and slice status to BB3 (RAN moderation) using I_x so that appropriate slice-relevant base stations are activated

The precise characterization of the inter-building block interfaces in terms of the parameters that need to be exchanged between each pair of building blocks will be carried out during the remainder of this project.

Intra-building block interactions, i.e., the interaction among the different TeCs that constitute one building block, are carried out internally to each building block. To enable the suitable TeCs at each time, the building block internally checks the target KPIs of each TeC and selects the ones needed. TeCs are usually complementary to each other, i.e. can be simultaneously used in the network, even if targeting the same KPIs. However, the building block should be internally aware of any incompatibilities between TeCs if they exist so that they are not activated simultaneously. It shall be also noted that throughout the TeC harmonization work these inter-relations will be further detailed and, thus, can be modified accordingly.

Furthermore, it is expected that there may be also a relationship among the TeCs within different building blocks belonging to different subsets of the agile RM framework, i.e., from the

AIV-specific domain to AIV-overarching and vice versa. This is anticipated because different TeCs may study a similar problem; however, each TeC is investigating a different solution based on a certain perspective. For example, T5.1-TeC9 (RM and Traffic Steering in Heterogeneous Environments) from the building block 'dynamic traffic steering' has as target KPI the reduction of the interference levels in the mmWave band. Hence, this TeC must also be related to the interference management building block.

4.2 RAN Design Implications

Herein, we discuss the potential implications of the various enabling technologies on the overall 5G RAN design. In general, it is assumed that 5G RAN design is expected to go beyond 4G in terms of support for centralizing the higher layer AIV-agnostic RAN functionalities, while distributing the AIV-specific RAN functionalities. It is also foreseen that the AIV-agnostic component within the RAN could support various functionalities such as RAN moderation, dynamic traffic steering, network slicing, etc. In order to support diverse set of UCs and requirements, it is also expected that the QoS framework is made more dynamic, with the enforcement functions moved from CN to RAN. An overview of the various RAN design implications for different building blocks is mentioned below.

<u>Implications due to intra-AIV RM Functionality Framework:</u>

Interference Management:

Within the interference management building block, all the different TeCs require some level of coordination among BSs to apply the corresponding interference management techniques. Hence, the following implications of the building block can be expected in the RAN:

- At the protocol and interface levels, the RAN impact is mostly characterized by the need for signaling and procedures over the wired or wireless backhaul using X2* interfaces to support the exchange of information among BSs. This may include the setup of a BS cluster as well as its operation and management.
- New procedures will also need to be supported to achieve coordinated interference management among BSs that are part of a dynamic topology that is constantly changing. Examples include networks integrating NNs.

Flexible Short-term Spectrum Usage:

This building block focuses on fast CA in dense urban heterogeneous networks, assuming dynamic radio topologies. The coordinated, on-demand resource allocation of unlicensed resources together with different AIVs would require new interfaces and procedures for the coordination between access nodes (e.g., NNs).

- The necessity of modified / new interfaces between NNs and macro / small cells will be studied.
- In order to support scheduling purposes, AIVs should be able to allow UEs and BSs to do frequency-selective channel / interference estimation (also including cross-links between devices or between BSs) also on unlicensed bands.

RAN Moderation:

RAN moderation building block considers both the fully centralized and distributed approaches from an overall RAN design perspective. The following implications are expected from this building block on RAN design:

- New signaling information elements would be required over the X2* interface to indicate the load and interference information on a TTI-level, between BSs operating in TDD mode.
- New information elements would be required in X2* to indicate the type and level of cooperation required between BSs for RAN moderation.
- For energy efficiency, a centralized entity for coordinated scheduling is required. A new discovery signal needs to be defined for UEs to detect the BSs in sleep mode.

Implications due to AIV-overarching RM Functionality Framework:

RM for Network Slicing:

Network slicing will enable the provision of logical networks adapted to different vertical business requirements, in terms of RAN network KPIs as latency, energy consumption, throughput, complexity, scalability, coverage, etc. being able to provide more flexible RM and service-tailored optimization at RAN level. According to the proposed approaches in Section 3.2.1, a RM which is aware of network slices operating on a common physical infrastructure has the following key RAN design implications:

- An AI-agnostic RM is beneficial for network slicing. AI-agnostic RM comes with its own RAN design implications (see implications of building block Holistic RM and AI abstraction models).
- A possible new logical entity (controller) is proposed (e.g., AaSE). It is for further study if and how to integrate it into the overall logical architecture.
- The data flows from/to the CN (e.g., via S1*) need to carry information to which network slices they belong or which SLAs they are associated with.
- There can be a feedback from the AaSE to a core entity (orchestrator/MANO) or to a RAN moderation entity about the SLA status.

Tight Integration with Evolved Legacy AIs:

The current concepts investigated here (see Section 3.2.2) for tight integration between LTE and 5G utilize PDCP as aggregation/split layer. The tight integration concepts described in this document are the fast UP switch and dual connectivity. Both concepts assume a common S1* CN/RAN interface for LTE and 5G. This means that CN signaling can be reduced when e.g. a fast UP switch between LTE and 5G is utilized. Both concepts may benefit from possibly new UE measurements per AIV (LTE and 5G) in order to make a more optimal scheduling decision, preferably on milliseconds basis if the backhaul allows it. Also, metrics to enable the possibility of both load balancing and traffic steering between LTE and 5G can be beneficial but require new measurements over some sort of X2* interface between LTE and 5G. How to do this and how often is left FFS and it may impact the standardization. In short, the RAN design implications are:

- Common LTE and 5G S1* for CN/RAN signaling.
- New signaling for AIV quality metric.
- Adding and deleting a new CP connection to a user, for the proposed tight integration concepts, must be very fast and lightweight in order to support ultra-reliability requirements.

Holistic RM and AI abstraction models:
The holistic RM framework and AI abstraction models for 5G variants will impact different layers of the 5G RAN protocol stack. In the following, a bottom-up approach of requirements and implications is provided.

The physical layer and scheduling functionality should support the following features:

- Variable time (i.e., TTI size) and frequency (continuous and non-continuous) allocation per user and dynamically controlled per scheduling instant, including options for asymmetric link operation, where a user is scheduled with different TTI sizes in the DL and UL (especially relevant for macro-cellular scenarios at lower carrier frequencies).
- Multiplexing of larger number of users per carrier to ensure efficient radio resource usage. This calls for a highly scalable design of radio resources for transmitting scheduling grants to avoid control channel blocking.
- Punctured scheduling support, with implicit and explicit options in terms of signaling details related to the punctured data.
- Native support of D2D and self-backhauling. Design aspects such as frame structures, waveforms, etc. should strive for commonality and reusability with cellular UL/DL and only diverge if gains in terms of performance, complexity, cost, energy efficiency, etc. justify it. The goal is to ensure a seamless integration of these novel communication variants since the beginning of 5G system design.

The MAC, RLC and, in general, synchronous control functions design will be impacted by:

- Level of AIVs harmonization (general 5G RAN design question and not specific to this building block) and split of AIV-agnostic vs. AIV-specific RM/synchronous control functionalities.
- Convergence or abstraction layer definition. The level of abstracted or parameterizable key features of a 5G AIV will determine how the RM functionality interacts with the protocol stack layers.

Interface needs and architectural implications:

- X2* interface messages exchange, especially to manage dynamic topologies with virtual cells. The details will be influenced by the design of a harmonized protocol stack, which is an overall 5G RAN design question.

- Introducing the logical entity of virtual cell will require some modifications at the network management level, both on a distributed architecture (D-RAN) and a centralized architecture (C-RAN).

RM for Inter-Network Collaboration:

At the core of the design of the entire APIs and RadioMap framework, there is the desire to define a fully technology agnostic architecture for intra- and inter-network collaboration. This generates the requirement of separating as much as possible the desired functionalities from the underlying transport layers, normally used as an interface between different network elements. Motivated by these goals, the following changes could be considered:

- Design based on the assumption that a fully IP based environment is available at the exit point of the different AIVs (them being current LTE eNBs or future 5G APs).
- Identification of properties and requirements that are necessary to deploy the framework. IP provides the right level of flexibility to support the requirements defined by the API, through standard IP based protocols (e.g., HTTP based REST Interface).
- As the move to a sole IP based architecture would be drastic and might require incremental deployment, the proposed solution can be adapted to existing protocols and interfaces. Considering as an example the LTE architecture, corresponding APIs could be implemented on top of current interfaces (e.g., S1, for eNB to controller communications).

Dynamic Traffic Steering:

The dynamic traffic steering building block requires fast rerouting of traffic over multiple AIVs in order to achieve the goals of satisfying QoS targets and energy efficiency. The following impacts are currently foreseen on RAN design:

- The functional split between CN and RAN in terms of QoS policy definition and enforcement needs to be redefined with new information elements defined in the S1* interface to exchange this information.
- New measurements would be reported from AN-I layer to the AN-O layer using the 5G xhaul [OPA+15] interface. New information elements for this needs to be defined for e.g., in the X2* interface for this purpose.
- The AN-O layer (or potentially other nodes in the network) needs to keep track of the location of the BSs and UEs in the system. New information elements should be defined for communicating the model of the antenna of each mmW node (e.g., at least the main beam angle and the FBR) to the central entity in the network. This could be done with possible enhancements in the SON function or OAM entity as well.

UE Context Management:

The BS should be able to configure the UE of the new parameters to measure and report, and this could imply the following changes in the RRC layer:

- Modifications in RRC layer are foreseen to enable the UE to acquire new information, such as inter-AIV interference.
- Modifications in RRC layer are foreseen to enable the UE to acquire more accurate information of existing parameters, such as location.
- Modifications in RRC layer are foreseen to adapt to various requirements in mobility.
- Modifications in RRC layer are foreseen to enable the BS to send updated and/or extended measurement configurations to UE.
- The RRC in UE may need to maintain multiple measurement configurations.

5 Conclusions and Outlook

Building upon the foundation laid by METIS, the METIS-II project aims at developing a comprehensive and detailed 5G RAN design to foster timely and efficient standardization. On the basis, in this deliverable, we have provided our first vision of the agile RM framework and the associated synchronous control functions as well as resource abstraction considerations. One key aspect of this framework is the proposed synchronous control functions operating over novel 5G AIVs and legacy AIVs, which take into account diverse service requirements, dynamic radio topologies and novel communication modes. Further key aspects include the assignment of the services to the most suitable resources via dynamic traffic steering and RAN moderation considering the extended notion of a resource, and RM schemes that enable the vision of network slices. The building blocks, which are categorized under the foundations for functionality frameworks, are highlighted to construct the envisioned agile RM framework. The efficient context management framework is seen essential to support the building blocks.

Furthermore, the positioning of the analyzed enabling technologies is provided in the envisioned 5G landscape. To this end, the initial considerations on the inter-relations and RAN design implications are highlighted. The draft framework presented in this deliverable is expected to substantially contribute to the overall RAN design particularly to the CP design. This deliverable is also expected to provide means for pinpointing possible collaborations and joint discussions with other 5G PPP projects.

The future work includes the further development of the enabling technologies and the studies on how these enabling technologies can fulfill the 5G requirements. The building blocks and the associated enabling technologies will be further harmonized on the foundations of functionality frameworks that are presented herein. Accordingly, the functionality frameworks will further be developed, and the overall agile RM framework will be refined. These further analyses, designs, and conceptual descriptions will be provided in the deliverable *D 5.2 "Final synchronous control functions and resource abstraction considerations"* (due in March 2017). The timeline of the work is illustrated in Figure 5-1 along with the various milestones and project deliverables that are the most relevant to D5.1 and D5.2 (see, for example, Section 1.1).

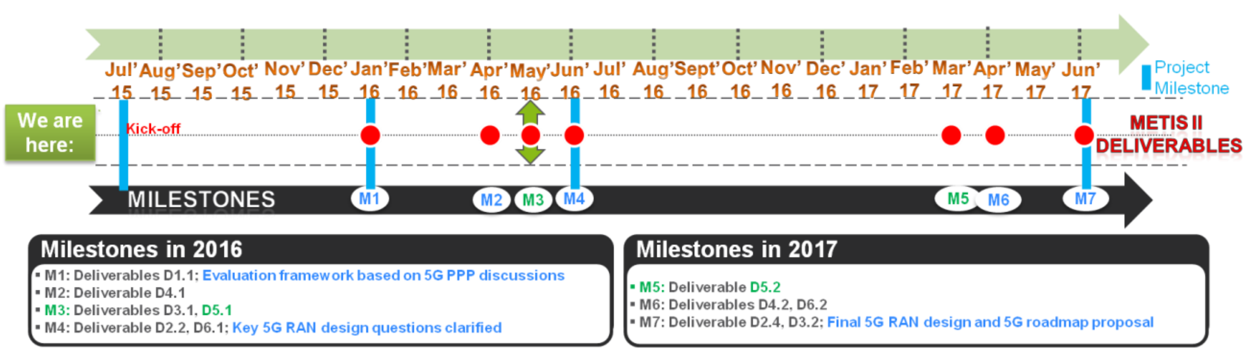


Figure 5-1 Timeline including deliverables and milestones.

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A Annex

A.1 T5.1-TeC11 Interference Coordination / Cancellation Strategy

A.1.1 Evaluation Methodology

Link-level simulations are planned to be conducted for evaluation of this TeC. A Matlab-based link level simulator is under development, incorporating a basic OFDM transmitter-channel-receiver setup corresponding to a given user in a cell who is suffering from interference coming from a neighbor cell, be it within the same coordination cluster, from another cluster, or even an uncoordinated cell not following the proposed precoding scheme:

- Interference from a cell within the same coordination cluster will be modeled by means of a fully constructed OFDM signal carrying random payload bits, in which the effect of the randomizing pattern is analyzed over the error rate performance of the desired link. A signal to interference ratio (S/I) will be defined expressing the average ratio between the received signal power and the interference power coming from a neighbor cell within the cluster. Both the desired and interfering signals will pass through multipath Rayleigh channels characterized by independent power delay profiles. Bit and block error rates versus SNR will be obtained for several S/I operating points.
- Interference from a cell belonging to a different cluster will be modeled by means of a fully constructed OFDM signal carrying random payload bits. The beneficial effect of the scrambling pattern will be analyzed with an S/I ratio defined between the received signal power and the interference power coming from a cell within another cluster. A different Rayleigh channel will also be used for this interference, and bit and block error rates will be obtained for several S/I points.
- Interference from an uncoordinated cell will be modeled by means of a standard OFDM signal carrying random information.

The effects from the three types of interference will be analyzed, first separately (by considering only one type of interference at a time), then jointly (by allowing two or the three effects together). In each case, only one interfering cell representative of each set will be considered, and the complete setup will comprise:

- Desired link + one interfering link (from the same cluster) + one interfering link (from a different cluster) + one interfering link (from an uncoordinated cell).

Given that interference coming from within a cluster has similar effects for all the cells belonging to it, it is reasonable to simplify the evaluations and group together the interference from multiple cells into a single interfering link, as representative of each of the above three types of interference with suitable S/I relations.

A.2 T5.1.TeC-6 RM for Multi-cell Coordination for Ultra-Dense Network Employing Dynamic TDD

A.2.1 Evaluation Methodology

The evaluation scenario is based on the BS deployment and 2D geometric layout of the virtual indoor office scenario described in [MET-II16-D11], accounting for walls but not chairs or tables. Channel modeling therefore assumes the WINNER II A1 indoor path loss model [WINNER08], which includes shadowing between all entities. Operating frequency is set to 2 GHz. For a given snapshot, users are dropped uniformly over the office area constrained on that each small cell serves no more than a single active user. In total, 100 snapshots are generated for the ensemble averaging. While multiple users can be associated with the same BS, only of one of them is assumed to have traffic demand and therefore called active. For active users, queues are infinitely backlogged so that bits are always available for transmission. Thus, system utilization is defined as the ratio between number of active users and number of BSs.

The cell radius of UDNs is typically much shorter than traditional outdoor networks, 10-100 meters, which allows BSs and users to employ similar transmit powers when cell radii are in the lower end of that range. This evaluation is based on the power models in [DDL15] for femtocells with 250 mW transmit power and sleep mode 4 in idle mode, compared to 100 mW transmit power for user devices. Once scheduled, a BS or UE transmits at full power. Single antennas with no beamforming capabilities are assumed for both BSs and UEs to keep hardware costs low.

Relevant KPIs include throughput and energy efficiency. Throughput is calculated using a modified version of Shannon's formula [M+07, Eq. (3)] that takes into account bandwidth (Beff=0.84) and SINR inefficiencies (SNReff=1.25) when the SINR is between -7dB and 30dB. Energy efficiency is calculated for each user as the ratio of throughput with power. Network energy efficiency is therefore the sum of all individual energy efficiencies.

The evaluation employs a greedy search algorithm with the condition that an idle BS is only added if the system performance, either network throughput or network energy efficiency, is also improved. The pseudo-code for the proposed algorithm focuses on worst user performance as those users might gain the most from joint transmission or joint reception:

(1) Sort users based on the worst individual user metric, i.e., either per-user throughput or energy efficiency.

(2) Iterate through all users starting with the worst user first.

(3) If the system objective is satisfied, then add the idle BS and proceed to (1), otherwise check the next user and repeat (3). If all users have been checked, or there are no more idle BSs left to add, then end the algorithm and return the results.

It is noted that in UDN where the cell radius can be small, the notion of cell edge user can be interpreted more loosely.

A.3 T5.1-TeC10 Dynamic cell switch off

A.3.1 Evaluation Methodology

At present two different simulators are available for performance evaluation:

- a simulator developed in MATLAB to study resource allocation issues, where link level performance and effects of higher layers are highly simplified in order to reduce both complexity and simulation time. This was used to evaluate scenarios defined in METIS (a simplified Dense Urban Information Society and the Stadium Test Cases [MET14-D32])
- a simulator developed in C++ for LTE-Advanced simulations where channel effects, link layer and higher layer aspects are modeled with higher detail (implementing classical 3GPP-like scenarios for both homogeneous and heterogeneous networks, see [3GPP10-36814]) .

Both the simulators are semi-static [ART10-D51], meaning that the positions of active users are modeled by a random uniform distribution, are fixed over a simulation run, and multiple simulation runs are carried out in order to collect significant statistics of the behavior of the system. Even if users are not moving during one simulation run, some degree of mobility is included in the system in the form of fast fading on the channel. Full buffer and non-full buffer traffic sources are available in both cases.

A.3.2 Detailed Analyses and Further Results

Models for overall BS power consumption, based on the amount of radio resources used in transmission were firstly proposed in the EARTH project [EARTH]. According to these power models, the overall energy consumption of a macro or micro BS increases in first approximation linearly with the total amount of radio resources that are used for transmission. According to the analysis in [EAR12-D23] this part that changes dynamically with traffic load is mainly due to the power amplifier and base band modules in the BS. The remaining elements in the BS (antenna interface , RF small-signal transceiver, DC-DC power supply, active cooling system, and AC-DC power supply unit) usually shows an almost constant power consumption regardless of the traffic load, representing a static power consumption portion in the overall power consumption of the node. In some BSs a power saving mechanism is available, so that when no transmission is performed, the BS can enter in a sleep-mode that further reduces its consumption. This is shown with a discontinuous point in the Figure A-1 for 0% resource usage.

It is expected that future transmission nodes will be able to scale their consumption, based on the actual amount of traffic that it is served, in a more efficient way than nowadays system does. The 5GREEN project [5GREEN] estimated that an improvement of 8% every year can be achieved in the dynamic part of power models, so that the overall power consumption will scale more significantly with the actual radiated power every year, and also "sleep" mechanism in the nodes will become more and more efficient. Figure A-1 shows the power models for 2010 nodes based on the EARTH project, and compares them with the 2020 power models proposed in 5GREEN.

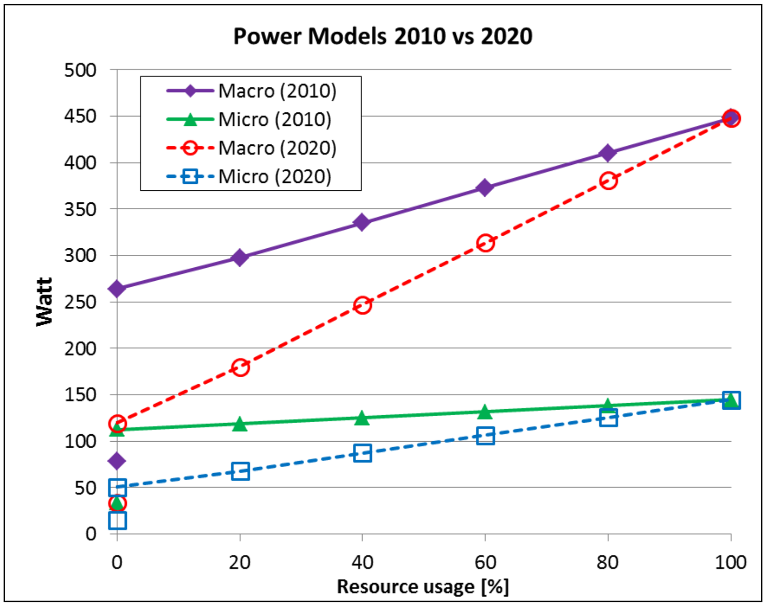

Figure A-1 5GREEN power models for macro and micro BS in 2010 and 2020.

Using these power models, it is possible to evaluate the overall energy consumption of a system when different traffic loads, and consequently different amount of radio resources, are considered. In [MET15-D33] 2010 power models were used to evaluate the improvement in energy consumption that could be achieved using the proposed centralized coordination scheme. Figure A-2 shows the impact of power models suitable for 2020 transmission nodes considering the proposed scheme, comparing them to results that were reported in [MET15-D33] with 2010 power models. Results are obtained under the simplified Madrid Grid scenario described in [MET14-D32]. This scenario comprises 3 macro BS and 9 micro BS, with 10 users connected to each BS. A signal bandwidth of 10 MHz is assumed, and different traffic loads have been evaluated using CBR traffic sources, which generate data at a given rate for each user. As a further reference also the traditional full buffer traffic condition has been simulated. Power consumption when no coordination between nodes (NoCoord) is exploited is compared with results obtained assuming the centralized scheduler that exploits JT and DPS/DPB for Energy Efficiency (EE JT) here discussed.

As shown in the figure, the higher dynamicity of future nodes can be even better exploited by the proposed scheme, which is able to deliver energy savings up to 51%, while only up to 27% savings were achieved with 2010 power models.

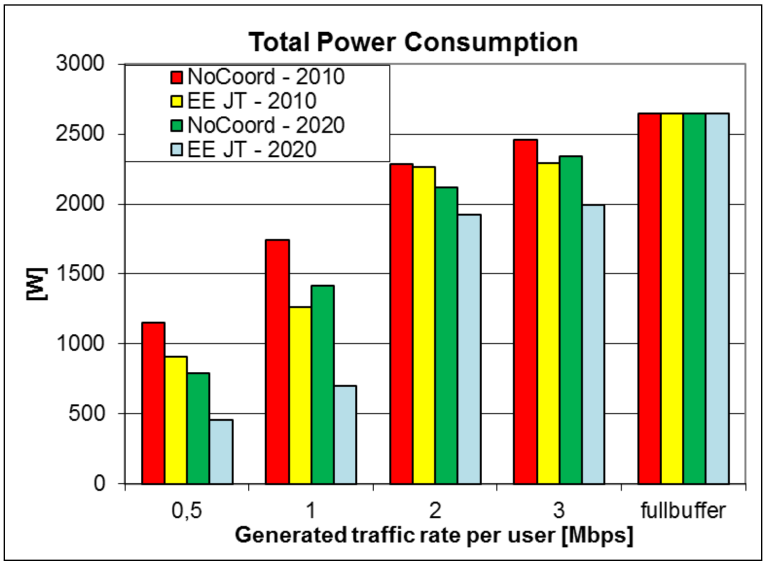

Figure A-2 Comparison of power consumption with and without coordination with 2010 and 2020 5GREEN power models.

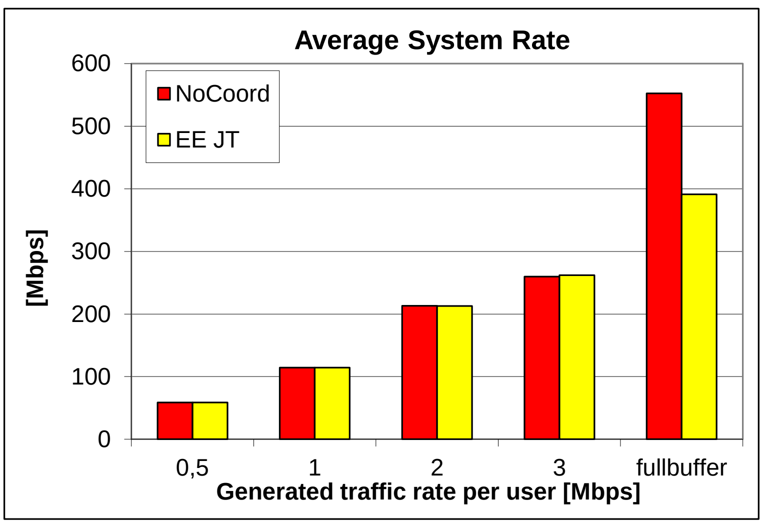

Figure A-3 Average system rate achieved with the proposed solution.

Note that, as shown in Figure A-3, the main focus of the proposed scheme is to reduce energy consumption through the reduction of active nodes, and this could be done with no impact on the achievable rate as long as the amount of traffic is not too large. In full-buffer condition, where all the transmission nodes should be active in order to face the large traffic request, the proposed scheme becomes sub-optimal and should not be used.

METIS-II recently proposed similar power model for 2010 and 2020 equipment [MET-II16-D21] as shown in Figure A-4. According to METIS-II power models, moving from years 2010 to 2020, not only the equipment will have better scalability of the energy consumption as a function of resource usage, and more effective sleep mode states, but the overall energy consumption at full resource usage will also be drastically lower.

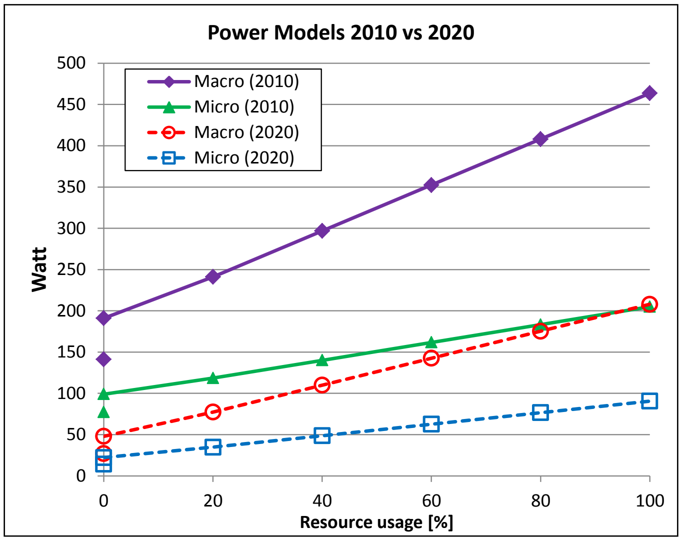

Figure A-4 METIS-II power models for Micro and Macro Base Station in 2010 and 2020.

Simulation results considering METIS-II power models are shown in Figure A-5. As it was expected also in this case the higher energy efficiency of 2020 equipment reflects in a drastic reduction of the power consumption, both with and without the centralized entity for coordination. In this case also the portions of power consumption due to the static consumption part in the power model, and that due to the dynamic part, are shown through different colors in the bar representing the overall power consumption. The higher dynamicity in power consumption that METIS-II power models show can be again better exploited with the proposed solution, so that in 2020 the power consumption reduction that can be achieved using the EE JT scheme can be as high as 51%, whereas in 2010 only savings up to 31% could be achieved.

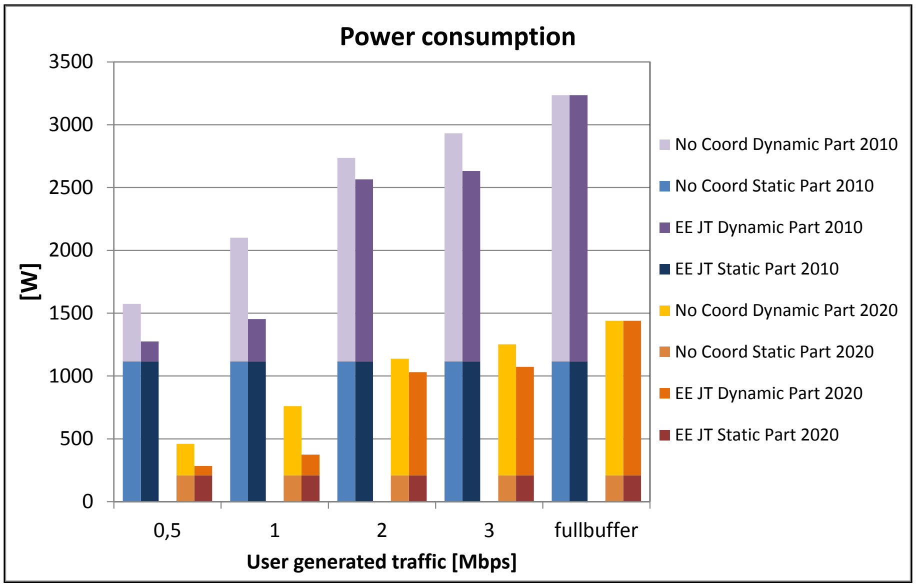

Figure A-5 Comparison of power consumption with and without coordination with 2010 and 2020 METIS-II power models.

A.4 T5.1-TeC2 LTE & 5G Tight Integration and RAN Moderation

The different LTE and 5G tight integration concepts are evaluated using a system simulator.

Table A-1 summarizes the most important parameters used in the simulations. The simulation model for the new 5G AI in this paper is called NX, which utilizes 0.2 ms TTI and 20 subbands (which corresponds to a LTE resource block) per 20 MHz compared to 100 subbands for LTE. The reason the number of subbands decreases is that the symbol length is decreased for the NX AIV. This is done in order to keep the number of symbols per TTI the same for NX and LTE, and due to the inherent properties of OFDM when the symbol length decreases the sub-carrier spacing in frequency domain becomes larger, see [ÖAS+15] for more information. The LTE and 5G nodes are co-sited (see Figure A-6) and the frequency bands investigated are 2 GHz for LTE and 15 GHz for NX. The channel model is the 3GPP Case 1 with typical urban channel model [3GPP05-05] where the attenuation constant is modified based on the carrier frequency. The bandwidth is 20 MHz per radio access.

One of the main characteristics of the novel AI is beamforming, to compensate the propagations effects at higher frequencies. As this is not explicitly modeled in the simulations, in order to compensate for that BF gain, the transmit power for the NX AI has been set to the same values as in the LTE case. Note that all signaling are ideal, i.e., all RRC signaling is always received correctly. This means that there are no handover failures.

Table A-1 Simulation parameters

Parameter	LTE	NX
Carrier Frequency	2 GHz	15 GHz
Bandwidth	20 MHz	20 MHz
TTI	1 ms	0.2 ms
Subbands per 20 MHz	100	20
BS Tx power	40 W	40 W
Deployment	LtE and NX co-sited	
Traffic	FTP download of one 10 MB object per user	
User speed	10 m/s	
Backhaul	Ideal	
RAT selection	RSRP	
Dual connectivity selection	RSRQ	

Figure A-7 shows comparisons of LTE-NX dual connectivity vs. NX stand-alone when NX is using 15 GHz carrier frequency. The difference between LTE-NX dual connectivity (20+20 MHz) vs. NX stand-alone on 40 MHz is relative small on high percentiles. However, for 10%-ile user throughput, LTE-NX dual connectivity (DC, blue solid line) performs much better, almost 300% better user throughput at low load compared to NX stand-alone (yellow line). The difference between hard handover and fast UP switch is small in this scenario even though the hard handover has an interruption delay of 300 ms. The major reason is due to the fact that there are very few hard handovers in this scenario.

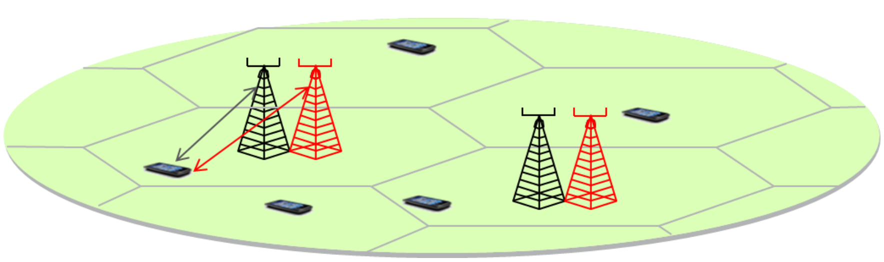

Figure A-6 3GPP case 1 hexagonal cell layout, LTE and 5G are co-sited.

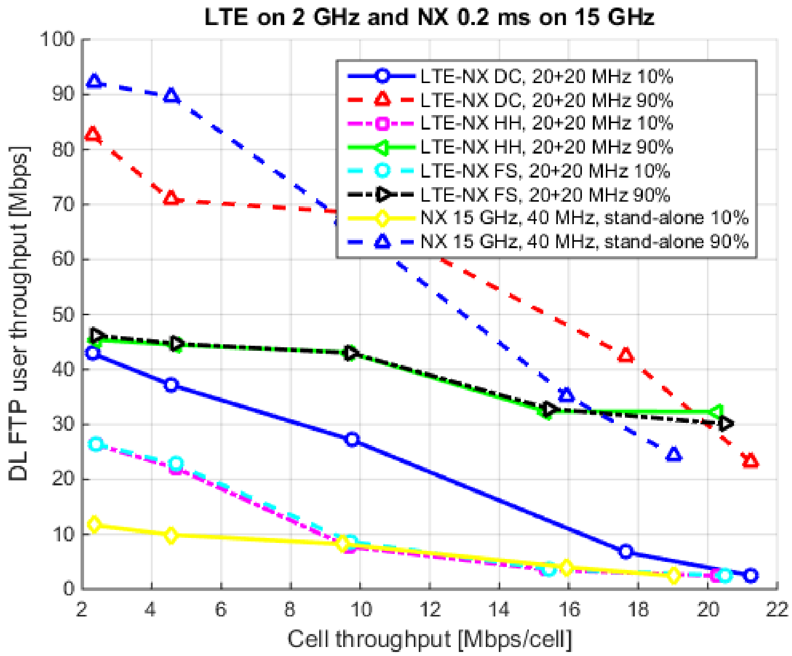

Figure A-7 User throughput vs. cell throughput (load) for different LTE-NX tight integration concepts vs. stand-alone NX. NX stand-alone shows worst performance for the 10%-ile (cell edge users). For the 10%-ile users throughput (cell edge users) the dual connectivity concept (DC, blue solid line) gives 300% higher user throughput than the NX stand-alone (yellow line).

A.5 T5.2-TeC5 Holistic RM Framework

A.5.1 Further Description

As mentioned in Section 3.2.3, it is also the goal of this TeC to study the integration of the different 5G AIVs from a RRM and synchronous control functions perspective, determining what degree of AIV-specific versus AIV-agnostic RRM functionalities is needed and at which level in the protocol stack (Figure A-8). A convergence layer can provide a unified and aggregated view of the various AIVs and available resources at disposal.

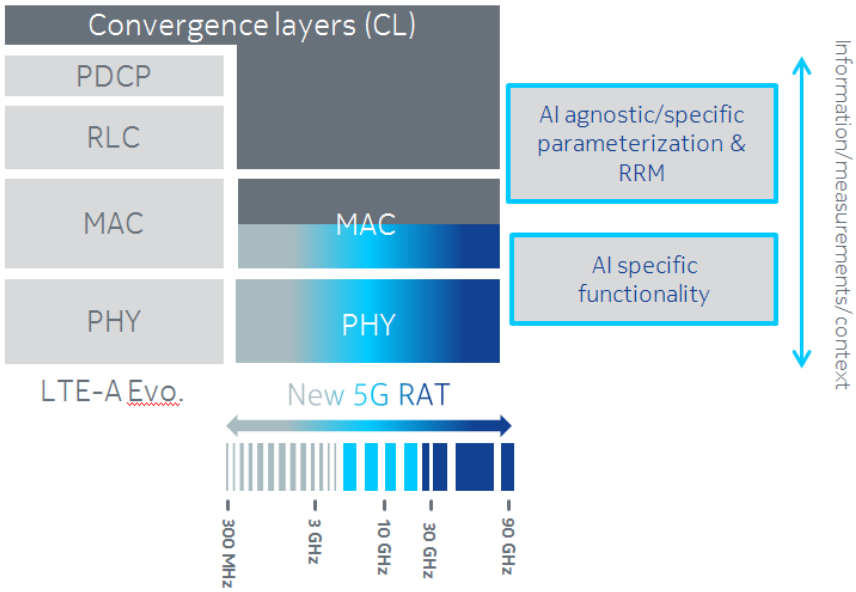

Figure A-8 The differentiation of AIV-agnostic vs. AIV-specific RRM functionalities, their integration and RAN protocol stack implications are aspects to be studied in this TeC.

Unified MAC

5G systems will require a radio layer framework flexible enough to stretch across the different AIVs envisioned to operate in different frequency ranges. A unified MAC can be considered to integrate these AIVs, with the term unified indicating that the logical framework for the radio layer should remain common across different instantiations of the AI. It is evident that different AIVs will impose different constraints on the radio layer functionalities.

So the ideal unified framework should allow to integrate these diverse AIVs in order to:

1. The logical structure of radio layer remains standard across AIVs
2. Allow the flexibility to optimize specific AIVs towards specific use cases
3. Facilitate a simpler common implementation
4. Enable cross-operation/interaction among AIVs to enhance the system performance

On the other hand, the unified MAC design presents the following challenges: differences in the physical layer attributes of different AIVs; restriction in terms of flexibility in comparison to individually optimized MAC functionality for each AIV; and the careful evaluation of the associated trade-offs and compromises to reach a satisfactory unified solution.

AIV-agnostic vs. AIV-specific RM and synchronous control functions

Some MAC or synchronous control functions are expected to be AIV-agnostic, like for instance: logical channel prioritization, (de-)multiplexing of logical channels, queue management, feedback control to higher layers, AIV-specific configuration control function, adaptation layer towards higher layers (e.g. to reduce dependencies of RLC parameters on radio). The scheduler can be designed with different degrees of AIV-agnostic versus AIV-specific functionalities. Two examples are described in the following:

<u>Example 1 of AI-agnostic RRM: Integrated MAC layer for multiple AIVs</u>

- In this option, a single MAC entity would handle different AIVs with specific MAC layer functions or sublayers which can handle the radio-aware part of each.
- The common or AI-agnostic layer of the MAC performs the controlling role of configuring different radio specific entities.
- The scheduler in this view is a common across all radio interfaces and configures parameters across all of them.
- MAC-H (High) as a common layer is envisioned to encapsulate the interface with higher layers and the common control/coordination functions.
- MAC-H + MAC-L (Low) constitute the unified MAC previously described.

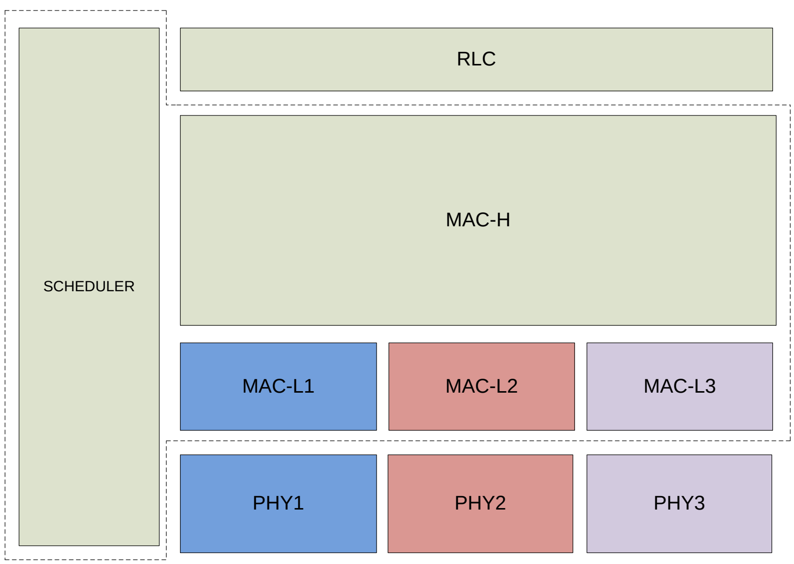

Figure A-9 Example of AI-agnostic RRM: Integrated MAC layer for multiple AIVs.

<u>Example 2 of AI-agnostic RRM: coordinated MAC instances for multiple AIVs</u>

- In this logical view, separate instances of radio agnostic MAC are instantiated for each AIV.
- There are separate radio schedulers for each of the AIVs coordinated by a central scheduler entity.

- This view allows flexibility to have independent optimized scheduling algorithms for individual AIVs or use cases. Each radio scheduler could be handling a separate AIV or a specific traffic type.
- Individual MAC instances would coordinate together to provide a unified framework, with individual schedulers coordinating or under a joint overall scheduler/coordinator.
- MAC-H + MAC-L constitute each of the unified MAC instances defined in this option.

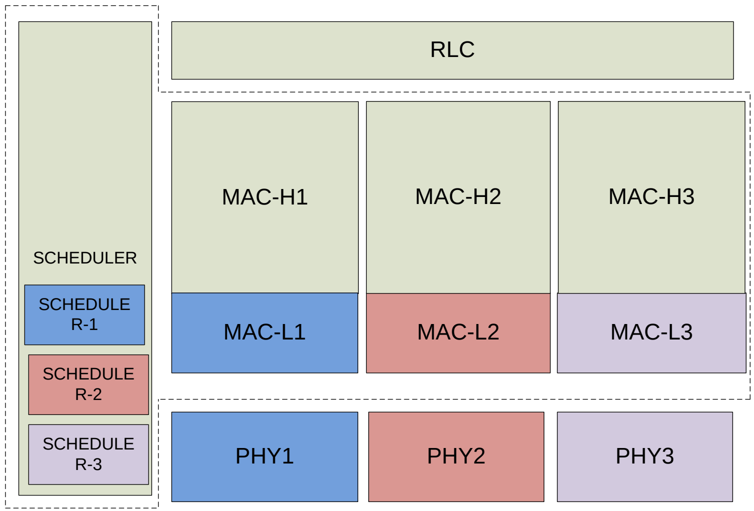

Figure A-10 Example of AI-agnostic RRM: Coordinated MAC instances for multiple AIVs.

A.5.2 Evaluation Methodology

System-level performance evaluations will be provided for the scheduling framework. Conceptual analysis and requirements in terms of functional enablers, signaling and protocol stack implications will be provided for the AIV-agnostic/convergence layer for RM and synchronous control functions.

A.6 T5.2-TeC4 RM for 5G D2D

For LTE, D2D communication is supported in UL spectrum resources, i.e., in the UL band or UL subframes in the case of an FDD or TDD network, respectively. The reasons for this decision are related to both regulatory and implementation aspects.

However, 5G networks should be designed to flexibly manage UL/DL resources and utilize different types of spectrum bands and therefore, in 5G D2D should be designed to be able to operate flexibly in UL as well as DL resources. Also, D2D should be able to operate both in licensed and unlicensed spectrum bands depending on the scenario, UE capabilities, coverage situation and other factors. For 5G, the expectation is that in higher frequency bands (>6 GHz), the network will typically operate in TDD mode, whereas in lower frequency bands both FDD and TDD operations can be assumed. We expect that in FDD networks, the 5G D2D link will still advantageously use UL frequency resources, whereas in TDD networks, D2D operation will be configured by the NW in line with the flexible duplex and dynamic TDD principles.

In 5G, the D2D sidelink can evolve such that the UL, DL, sidelink and backhaul links become similar in terms of PHY layer capabilities, including duplexing schemes. For proximity communication, that is when two devices are close to one another, bidirectional full duplex can also be a viable duplexing scheme [HRL+14].

Operating in unlicensed and licensed bands may require that the sidelink must flexibly support scheduled and carrier sense type of MAC protocols. The consequences of such solutions on CP and performance are proposed for future studies. The proposed D2D concept uses clusters to support the broad diversity of in-coverage, out-of-coverage and partial coverage use cases, see Figure A-11.

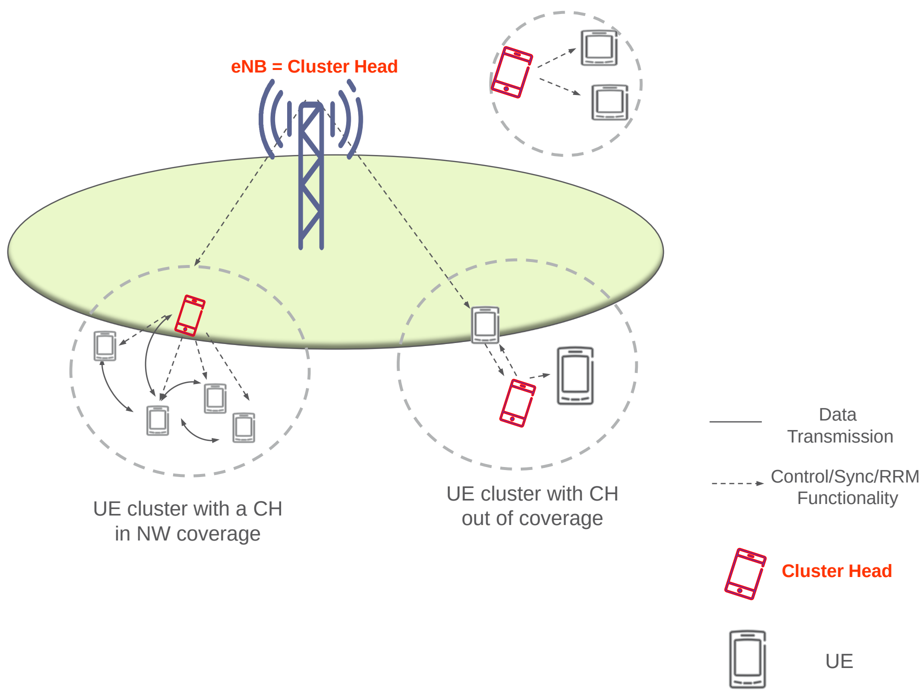

Figure A-11 D2D communications supported by the clustering concept. The cluster head (CH) node can be in NW coverage or out of NW coverage. A UE in coverage can act as a source for synchronization signals or provide RRM information to a CH which is outside NW coverage.

The basic idea of the clustering is to extend the cellular concept to out of coverage situations by nominating a UE (handheld, truck mounted or provisionally deployed) to act as a resource owner and control node, similarly to a regular eNB. The cluster head (CH) node is thus very similar to an eNB, although differences in capabilities in terms of output power, number of UEs that it can support or mounted antennas can vary.

The CH, when outside NW coverage can get synchronization information or RRM information from a non-CH UE that is inside coverage and capable of relaying such information from an eNB.

An inherent part of the cluster concept is the dynamic CH selection process [FPS+14].The clustering concept is a hybrid of distributed (CH selection) and centralized (CH itself acting as a central node within the cluster) elements. In short, the CH selection process is distributed, and uses discovery beacon signals transmitted from all devices, including meaningful information about its status to be able to be selected as a CH.

As illustrated in Figure A-12 and Figure A-13, when a 5G network is co-deployed or when 5G AIV and LTE are deployed at different sites, UEs with different AI capabilities may be in the proximity of one another such that D2D communication can be a viable alternative provided that these UEs use compatible AI.

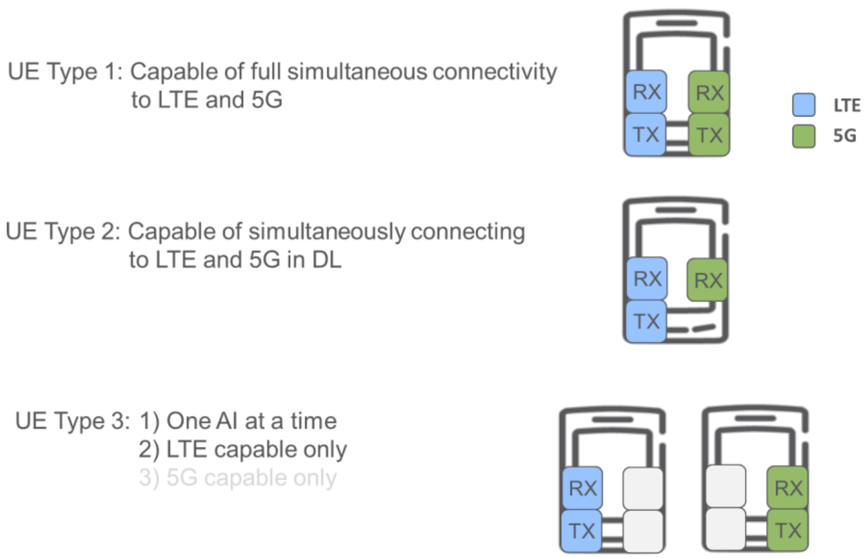

Figure A-12 UE types in terms of LTE and 5G D2D capabilities.

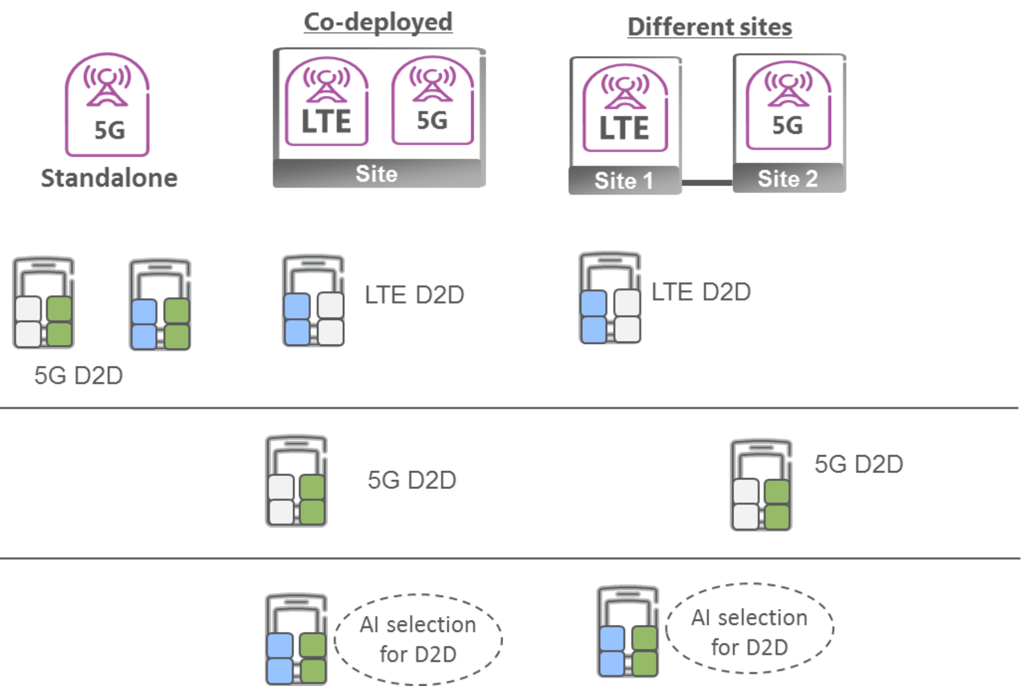

Figure A-13 Some combinations of UE capabilities and deployment scenarios. In the METIS standalone case (left), the UE must support METIS/5G (green), whereas in the co-deployed (middle) and multi-site (right) cases, there may be a need for RAT selection for D2D.

To facilitate D2D communications in such scenarios, AI selection for D2D may be a necessary function to fully exploit the proximity of various devices.

This TeC will further refine the design principles and suggested improvements in coming deliverables.

A.7 T5.2.TeC-8 RM for Inter-Network Coordination

A.7.1 Evaluation Methodology

Evaluation will be carried out using software prototypes deployed on the ORBIT wireless testbed [ORB] which enables realistic evaluation using software-defined radios and spectrum measurement infrastructure (the testbed was recently used to support the “DARPA Spectrum Challenge” conducted in 2013-14 which provided a competitive evaluation of peer-to-peer spectrum cooperation and dominance techniques). The prototype architecture is depicted in Figure A-14.

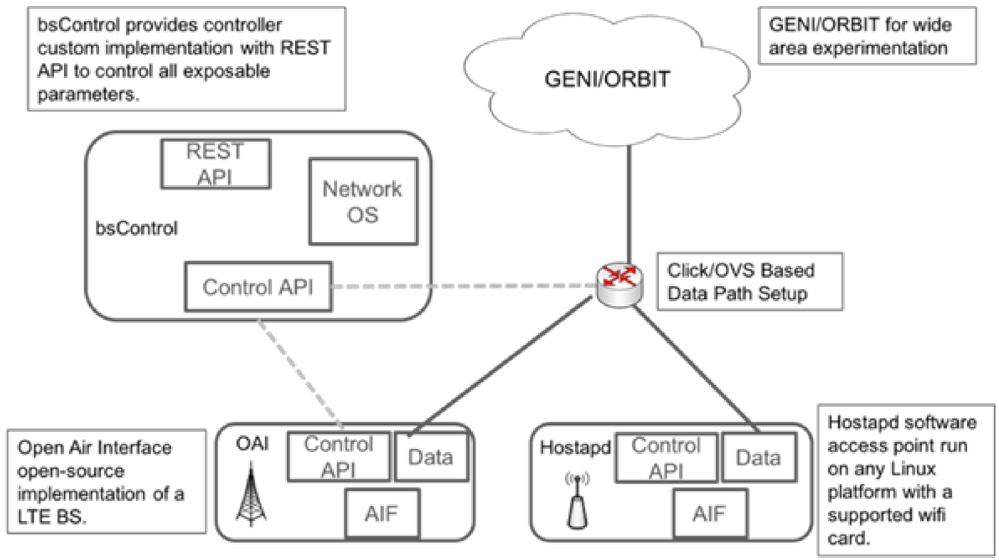

Figure A-14 Prototype architecture.

Previous simulation based work showcases benefits of spectrum coordination across different wireless networks. The prototype based deployment will be exploited to both corroborate the results obtained in simulation, both to further push the introduction of new coordination algorithms. First, we will demonstrate previously published results, with particular focus to WiFi spectrum coordination [BSS+12] and to WiFi/LTE coordination [SBS+15]. Second, based on a set of use cases we will evaluate the potential of the proposed API framework.

The prototype consists of the following components extended to support external control APIs:

- Open AirInterface: Open-source implementation of a LTE BS and UE. In the ORBIT testbed, USRP B210 [USRP] are used for LTE BS and UEs and Android devices as commercial grade UEs.
- Hostapd: Software access point run on any Linux platform with a supported WiFi card.
- Bscontrol: A custom controller implementing southbound control interfaces using hardware specific protocols (e.g. OpenFlow, SNMP, etc.) and that exposes a northbound REST API to control all exposable parameters of such hardware.

Use cases such as interference management and datapath management across multiple technologies will be deployed on the presented prototype to evaluate the proposed design.

A.8 T5.1-TeC7 Multi-AI Dynamic Traffic Steering Framework

A.8.1 Further Description

In this section, we describe the evaluation methodology used in terms of simulation details, models used, etc., and provide some further simulation results and related analyses.

A.8.2 Evaluation Methodology

The basic scenario used is as shown in Figure A-15, with a 5G-UE engaged in multi-connectivity with multiple AIVs. Here we consider the case where the UE has simultaneous multi-connectivity with LTE and mmW carriers with center frequencies at 30 GHz and 60 GHz. Each UE is connected to the best link from each of the AIV after considering the pathloss and shadow fading. The scenario used is similar to the Madrid scenario considered in [PLV+15], with only outdoor deployment assumptions. 1000 UEs are dropped randomly in the scenario with 200 small cell nodes positioned uniformly at random within the simulation scenario. The pathloss models for the mmW frequency bands are similar to the NYU model used in [STR+15], with a shadow fading mean value of 3 dB assumed for all the carriers. The approximation is based on the values presented in [STR+15] for UEs that are located in the close vicinity of the BSs. We assume that each small cell node supports all the three AIVs. Throughput calculations were done similar to the methodology adopted in [PLV+15], with packet delay distribution calculated based on the time taken to deliver one packet to the 5G-UE. Here we assume two different packet sizes, normal burst of 1 MB per packet and short burst of 0.5 MB per packet. The two packet sizes were used to show the potential impact of packet size on the dynamic traffic steering mechanism.

We use the non-line-of-sight (NLOS) model similar to the NYU model used in [STR+15], and assume that the NLOS would lead to a RLF over the mmW carriers, which would require dynamic traffic steering. The traffic steering is assumed to be done by the AN-O layer, which is considered to be a logical entity located at the traffic aggregation layer. In case of RLF, there would be an additional delay of 200 ms for the baseline LTE case due to the need for RLF recovery and traffic forwarding over the X2* interface. Due to the use of GBR bearers to deliver the high priority traffic, it is also assumed that in the event of a RLF, there is resource reservation in the AIVs even if the link is actually broken.

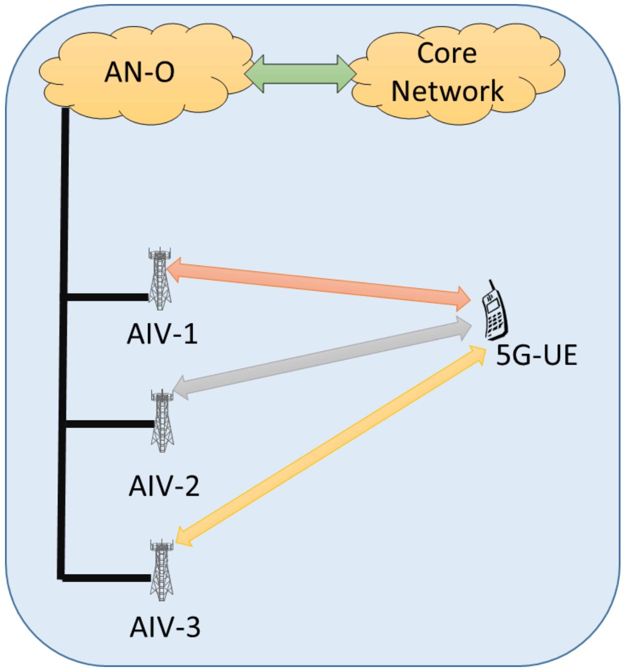

Figure A-15 Scenario Overview.

A.8.3 Detailed Analyses and Further Results

The LTE E2E bearer architecture based on [3GPP14-23203] and the envisioned 5G QoS architecture is as shown in Figure A-16. The 5G dynamic QoS architecture is assumed to be inherently linked to the system architecture considered here in Figure 3-23, which would also enable a dynamic traffic steering over the multiple AIVs. Here the main change is expected to be in moving some of the CN functionalities related to QoS from the CN to the RAN, in order to enable better QoS enforcement and radio resource utilization in the access interface. Some of the key requirements due to the dynamic QoS, especially on the MAC layer could be summarized as [PME+16]:

- The QoS policies received from the CN can be enforced in the RAN with a higher level of granularity, as compared to LTE. This could be done by moving from an EPS / radio bearer-centric approach to application-centric architecture, which takes the E2E application requirements into consideration.
- The QoS characteristics could be adapted dynamically, depending on the varying application requirements and on the real-time radio link conditions.
- The QoS characteristics could also be adapted based on the aggregated feedback received from different AIVs to the higher layer functionalities in order to achieve optimizations based on the global view of the RAN, as compared to enforcing and achieving individual targets.

Thus, compared to legacy technologies, the dynamic 5G architecture is expected to have close inter-working with the requirements derived from the diverse set of applications and use cases that are expected to be supported by the system. Here S*/P*-GW are the 5G versions of the Serving-Gateway (S-GW) and P-GW present in the LTE EPC. Here the radio-core transport is expected to have a limited set of QoS policies that are defined by the P*-GW, which is then enforced at the access network.

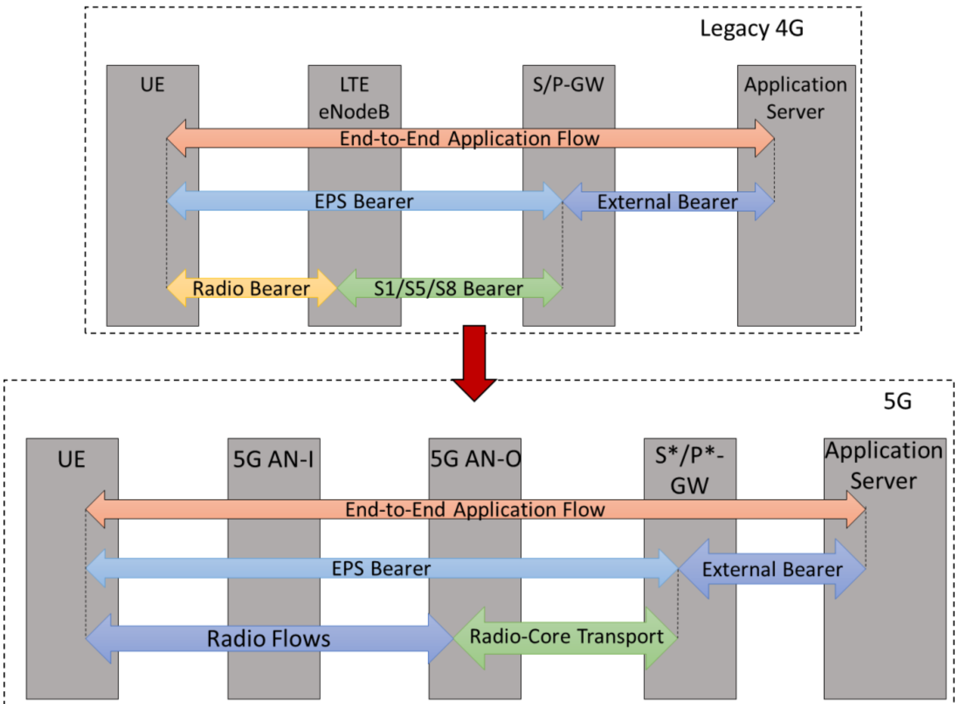

Figure A-16 LTE bearer architecture and evolution towards 5G service flow architecture [PME+16].

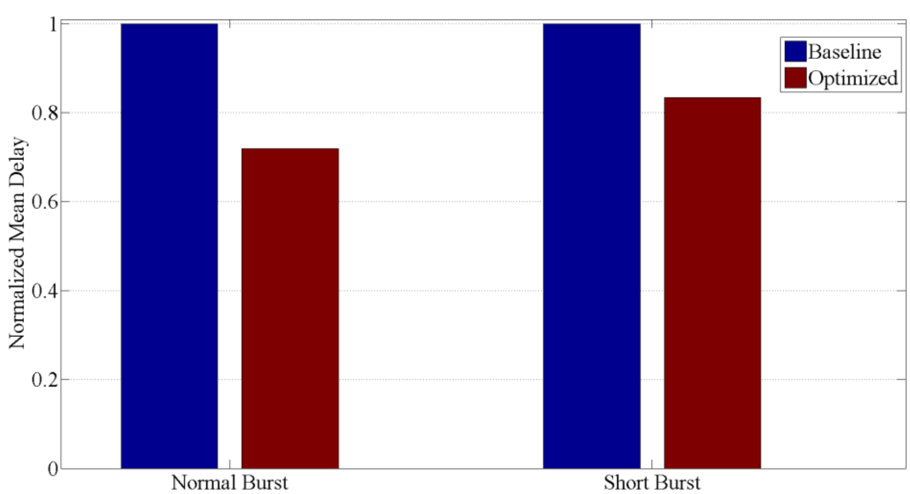

Figure A-17 Normalized mean packet delivery delay.

The mean delay values normalized to the baseline mechanism is as shown in Figure A-17, based on the distribution shown in Figure 3-25. The figure gives an indication of the relative reduction in the packet delivery times for the 5G optimized mechanism, as compared to the legacy LTE baseline mechanism. There is approximately 28 % reduction for normal burst and 17 % reduction for the short burst for the optimized mechanism relative to the baseline case. The significant reductions are due to the dynamic traffic steering and QoS mechanism adopted in 5G with the flexible functional splits between the AN-I and AN-O.

The potential options for a flexible protocol split between the 5G radio access point (RAP) and Cloud RAN is as shown in Figure A-18, based on [3GPP16-RP160043] with an open 5G xhaul assumed to be present between the RAP (local AN-I layer) and the C-RAN (assumed to be the local AN-O layer). Option-A is similar to the LTE dual connectivity feature and Option-D would be the fully centralized option where the xHaul* would be similar to the fronthaul in LTE-A networks today. From the dynamic traffic steering framework perspective, if the split is done at the MAC layer or lower (options C-D), then there are potentially no new impacts perceived on the xHaul* for dynamic traffic steering. But if the split is done at a higher layer (option A-B), with fast traffic re-routing done over the multiple AIVs, then new RAN measurement information elements should be defined to be transported over the xHaul*, in order to enable the traffic steering mechanism. The feedback in this case should be optimized to avoid any significant additional signaling load over the xhaul interface. Here we assume an open fronthaul / xhaul interface, similar to the considerations in [3GPP16-RP160043].

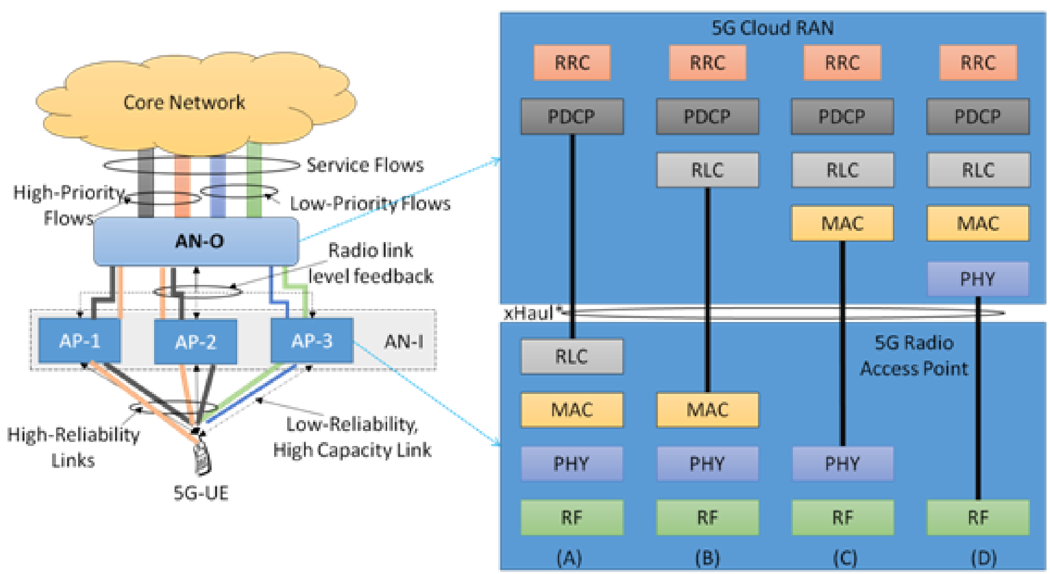

Figure A-18 Application of potential 5G protocol split options [3GPP16-RP160043] to AN-O and AN-I for C-RAN deployments.

A.9 T5.1-TeC9 RM and Traffic Steering in Heterogeneous Environments

A.9.1 Detailed description of the solution

The following definitions are used in the proposed solution description.

- A network node is defined by its coordinates and its mobility type. The mobility type defines the mobility characteristic of the network node by three categories, from the highest to the lowest mobility: *Mobile*, *Nomadic* and *Fixed*[8].
- A transmission link is defined by its transmitting node and its receiving node and by the type of used transmission band. The transmission link may be of three types: a *Downlink*, an *Uplink* or a *Common* (specifically, *Downlink* or *Uplink* bands are used if a FDD technique is adopted while the *Common* band is used if a TDD technique is adopted)[9].
- A collision is defined as the situation occurring when, the establishment of a new transmission link between a transmitting and a receiving node or the modification of an existing transmission link, creates an extra interference toward neighbor receiving nodes in such a way that at the receiver of a neighbor node $(C/I) < T_{C/I}$, having defined C/I as the ratio between the useful signal power and the interference power associated to the transmission links affected by the extra interference and $T_{C/I}$ as the minimum allowed C/I threshold (e.g 12 dB as specified in [PGR09]).
- A Resource Sharing Cluster (RSC) is defined as the set of transmission links that need to be coordinated (e.g. by a suitable Time-Division Multiplexing mechanism) in order to avoid potential collisions between each other's. Each RSC may be defined by the set of potentially colliding transmission links, the transmission band, the center of gravity (defined, as an example, by the average values of the coordinates of all the transmitting/receiving network nodes involved in the transmission links of the cluster) and the mobility category of a RSC corresponding to the mobility category of the most mobile network node among all the transmitting and receiving network nodes of the transmission links of the RSC[10]. The data associated to the RSCs need to be updated by taking into account that:

[8] As an example, by adopting a Cartesian reference system, a fixed network node A, can be described by a couple $A_{3D}=[(x_A,y_A,z_A),$ *Fixed*] or $A_{2D}=[(x_A,y_A),$ *Fixed*] if respectively a 3D or a 2D geometrical analysis is adopted.

[9] For example a transmission link L_1 can be described by a triplet L_1=[A, B, *Downlink*] where the network node A is the transmitting node (TxNode(L_1)=A), the network node B is the receiving node (RxNode(L_1)=B) and the transmission band is of the downlink type.

[10] As an example, a Resource Sharing Cluster RSC_1 can be defined by a quadruple RSC_1=[{L_1,L_2,L_3,…},*Downlink*,(x_{CG},y_{CG}),*Nomadic*] where the set of transmission links that form the cluster is {L_1, L_2, L_3, …}, all the

- a RSC containing a transmission link L should be updated at the end of the transmitting period of the transmission link by the deletion of the link from the RSC;
- RSCs having a mobility category corresponding to *Nomadic* needs periodically updates of the transmission links involving all the transmitting and/or receiving nodes of the *Nomadic* type.
- RSCs having a mobility category corresponding to *Mobile* need of constant updates of the transmission links involving all the transmitting/receiving network nodes of the *Mobile* type as soon as the location information of at least one of said nodes change and it is delivered to or known to the system.

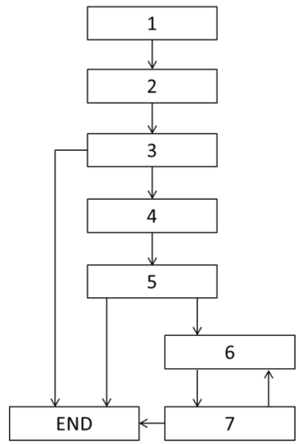

Figure A-19 Steps of the solution

The method for avoiding transmission collisions prior to a new mmW transmission in a cellular network by means of a geometrical analysis is described by the following steps (see Figure A-19).

1. The process starts when a new transmission link needs to be activated[11].
2. The second step of the method provides for the discovery of a list of candidate RSCs to be considered for performing the geometrical analysis in the activation of the new transmission link. The criteria for the inclusion in the list depends on the transmission band category and possibly on the distance between the center of gravity of the candidate RSCs and the transmitting network node of the new transmission link (i.e.

transmission links of the cluster are of the downlink type, the center of gravity (CG) of the cluster has coordinates (x_{CG},y_{CG}) (in a 2D) and at least one network node among all the transmitting and receiving network nodes connected by the communication links of the cluster has a mobility category defined as *Nomadic* (all the other network nodes are classified either *Nomadic* or *Fixed* and none network node of *Mobile* category is present).

[11] L_{NEW}=[N_1,N_2,Band_Cat] is defined by the band category Band_Cat (that can be *Downlink*, *Uplink* or *Common*), by the transmitting network node N_1 = [(x_{N1},y_{N1}), Mobility_Cat$_{N1}$] and the receiving network node N_2=[(x_{N2},y_{N2}), Mobility_Cat$_{N2}$] with Mobility_Cat$_{N1}$ and Mobility_Cat$_{N2}$ that can be *Mobile*, *Nomadic* or *Fixed*.

since transmission links are limited by a maximum range, for example, a two times maximum range could be considered). The list of candidate RSCs involved in the activation of the new transmission link is named CAND_RSC_LIST

3. If no RSC is found and the CAND_RSC_LIST is empty, a new RSC containing the new transmission link is created, and the method ends[12]. Otherwise, if the CAND_RSC_LIST is not empty, a geometrical interference analysis for identifying possible collisions between the new transmission link and all the candidate RSCs belonging to the CAND_RSC_LIST is performed in the following step 4.

4. For each RSC in the CAND_RSC_LIST the set of transmission links of the RSC is considered and each incumbent transmission link of the set is geometrically compared (by an algorithm described below) with the new transmission link to determine if a possible transmission of the new transmission link could interfere or be interfered by the incumbent transmission link. If at least one collision is found, the search in the current RSC terminates and the RSC is inserted in a list, named 2MOD_RSC_LIST of RSCs to be modified[13].

5. If no RSCs containing a colliding link are found (i.e. the 2MOD_RSC_LIST is empty) a new RSC containing the new transmission link is created and the method ends. Otherwise, the following step 6 is performed.

6. Prior to the insertion of the new transmission link in at least one of the RSCs listed in the 2MOD_RSC_LIST, an evaluation procedure (specified below) can be performed in order to assess whether the considered RSC will have enough resources to include the new transmission link, without having an unacceptable degradation of the performances of the new transmission link or of one or all of the incumbent transmission links.

7. If an unacceptable degradation is foreseen, a number of different actions (described below) could be performed and the process ends. Otherwise, the new transmission link is added to the considered RSC (that is deleted from 2MOD_RSC_LIST) and resources will be re-usable e.g. in time and/or frequency domain within the RSC. The steps of the evaluation procedure are then repeated (going back to step 6) for all the others RSCs listed in the 2MOD_RSC_LIST (in the event of a multiple insertion in different RSCs a coordination between the resource sharing mechanisms of the different RSCs will be

[12] For example, by considering the new transmission link L_{NEW} defined above, a new RSC would be RSC_{NEW}=[{L_{NEW}},Band_Cat,(x_{CG},y_{CG}),$Mobility\_Cat_{NEW}$] where $x_{CG}=x_{N1}+x_{N2}/2$, $y_{CG}=y_{N1}+y_{N2}/2$ and $Mobility\_Cat_{NEW}$ would be the most mobile category between $Mobility\_Cat_{N1}$ and $Mobility\_Cat_{N2}$.

[13] For example if a RSC_k=[{L_1,L_2,L_3,…L_n}, Band_Cat,(x_{CG},y_{CG}),Mobility_Cat] is the RSC considered against the new transmission link L_{NEW}=[N_1,N_2,Band_Cat] , each L_i of the RSC_k is tested in two ways for determining a potential collision between L_i and the new transmission link: whether the transmitting node N_1 of L_{NEW} may possibly interfere the receiving node RxNode(L_i) of L_i and whether the transmitting node TxNode(L_i) of L_i may possibly interfere the receiving node N_2 of L_{NEW}. If, after having performed this test, a potential collision is found, (e.g. with L_3) the search in RSC_k is stopped (links L_4 through L_n are not tested) and RSC_k is inserted in the 2MOD_RSC_LIST.

needed e.g., by simply merging the two RSCs) until the list is empty and the process ends.

A.9.2 Detailed description of step 4

The geometrical-based interference analysis of step 4 is here described with reference to Figure A-20.

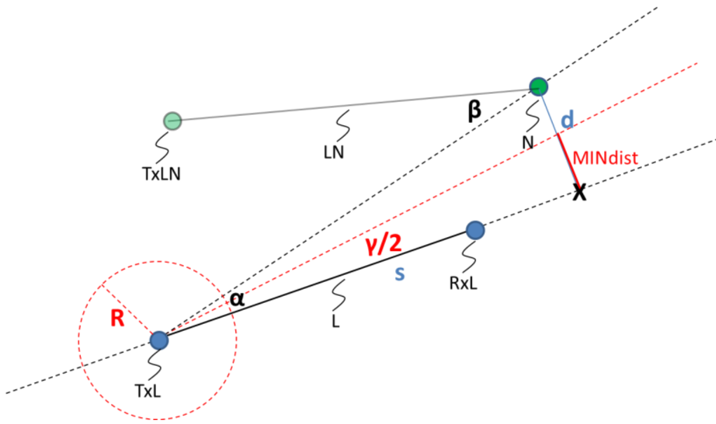

Figure A-20 Geometrical-based interference analysis on whether link L interferes the receiving node N.

The approach, described in a 2D, can be extended to a 3D analysis. The aim is to check whether a transmission link L can interfere a receiving network node N of a transmission link LN. In Figure A-20, the transmitting network node (TxNode(L)) of the transmission link L is designated with TxL and the receiving network node (RxNode(L)) of the transmission link L is designated with RxL while the second transmitting network node of the transmission link LN is designated with TxLN. The geometrical-based interference analysis comprises the following three main steps:

I. computing the distance d between the straight line connecting the nodes TxL, RxL and the node N; the angle α between the straight line connecting the nodes TxL, RxL and the straight line connecting the node TxL and the node N; the distance s between the node TxL and a projection x of the node N on the straight line connecting the nodes TxL, RxL. As an example, according to an embodiment of the present invention, given the coordinates (x_{TX},y_{TX}) of the node TxL, (x_{RX},y_{RX}) of the node RxL and (x_N,y_N) of the node N,

- the slope of the straight line connecting the nodes TxL, RxL can be computed as: $m_L=(y_{RX}- y_{TX})/(x_{RX}- x_{TX})$;
- the distance d can be computed as: $d = |y_N-(m_L(x_N- x_{TX})+ y_{TX})|/\sqrt{(1+m_L^2)}$;

- the slope of the straight line connecting the node TxL and the node N can be computed as: $m_N = (y_N- y_{TX})/(x_N- x_{TX})$;
- the angle α can be computed as: $\alpha = \arctan(|(m_L-m_N)/(1+ m_L m_N)|)$;
- the distance s can be computed (using the cotangent function) as: $s = d \cot(\alpha)$;

II. determining the minimum distance MINdist within which an interference between the two transmission links L, LN is possible, according to the following considerations:

- the distance s;
- the location of the projection x with respect to nodes TxL and RxL that is whether the projection x is or not on the same half–line of the node RxL (i.e. α is larger than 90°);
- whether the antenna of the node TxL is directive (i.e. conveying the main part of the radiated energy in a specific direction) or not (in such a case, angle α is essential for determining if the node N is within the main beam of transmission of the antenna of the node TxL);
- whether the antenna of node N is directive or not (in such a case, angle β between the straight line connecting the nodes TxLN, N and the straight line connecting the node TxL and the node N, that can be computed in a similar way as angle α, is essential for determining if the receiving antenna of the node N is within the main beam of transmission of the antenna of the node TxL);
- the transmission power, and other specific radio parameters (e.g. radiation pattern, sensitivity, etc.) of nodes TxL and N;
- safety margins driven by concerns about technology constraints (e.g., non ideal radiation pattern), type of environment (open range against canyon, free Line-Of-Sight against a lot of obstacles), etc.

For example, given the C/I threshold $T_{C/I}$, a simple way to determine MINdist could take into account the distance s, the main lobe (or beam) angle of the antenna of the node TxL, the transmission range r_L of the transmission link L i.e. the distance between the nodes TxL and RxL. Under the assumption that the antenna at the receiving node is omnidirectional and that at each receiving node the received signal power it's always of the optimal magnitude, the delta power level reached by the transmission link L in the projection x compared to the power level in the node RxL can be calculated by the following formula that determines a dB increase/decrease of the transmission power level of the transmission link L: $10 \log(r_L^2/(s/\cos(\alpha))^2)$. Moreover, defined γ as the angle of the main lobe (or beam) of the antenna of the node TxL, the projected distance d_{MAIN} "under" the main lobe can be calculated as $d_{MAIN}=s \tan (\gamma/2)$. Defined a Front to Back

Ratio (FBR) as the delta in dB between the transmission gain of the main lobe of the antenna of the node TxL and its side lobe, and a circle whose radius R is determined by the C /I threshold such that – (10 log(r_L^2/R^2) – FBR) = $T_{C/I}$, we can then define:

- MINdist=0 for all distances s such that s>Rcos(γ/2) and -10 log(r_L^2/(s/cos(α))^2) >$T_{C/I}$;
- MINdist=d_{MAIN} for all distances s such that s>Rcos(γ/2) and -10 log(r_L^2/(s/cos(α))^2) ≤$T_{C/I}$;
- MINdist= R sin(α) for all distances s such that –R ≤ s ≤ Rcos(γ/2);
- MINdist=0 for all distances s < -R (in the opposite half–line of the node RxL);

III. Determining by the comparison between d and MINdist whether the transmission link L eventually interferes with the node N. The collision check is negative if and only if the distance d is higher than MINdist, otherwise it is positive. For example, the collision check shown in Figure XX is negative and no interference is foreseen by the transmission of link L toward the receiving node N.

The geometrical comparison between the new link L_{NEW} and L_i (one of the links of the considered RSC) in step 4 is therefore performed in both ways:

1. L= L_{NEW} and N is the receiving node of L_i to check if the new link interferes
2. L=L_i and N is the receiving node of new link L_{NEW} to check if the new link is interfered

A.9.3 Detailed description of step 6

Step 6 can also be further detailed. In particular, the evaluation procedure, prior to the insertion of the new transmission link in a RSC to assess if the RSC has enough resources to include the new transmission link, without having an unacceptable degradation of the performances of the new transmission link or of one or all of the incumbent transmission links, can take into account the following aspects.

A. limits on the available resources per RSC; for example, a simple evaluation could consists in a comparison between the number of incumbent transmission links of a considered RSC and a fixed threshold MAX_RSC_Link_No (maximum number of transmission links per RSC): if RSC_k=[{L_1,L_2,L_3,…L_n}, Band_Cat,(x_{CG},y_{CG}),Mobility_Cat] is the RSC considered, the check would be n < MAX_RSC_Link_No;

B. service level agreements and operator QoS policies for the new transmission link or one or all of the incumbent transmission links in the considered RSC, possibly in conjunction with the type of transmission (or type of service that is the cause of the transmission) of the new transmission link or of one or all of the incumbent transmission links; for example, a gateway/backhauling purpose of the new transmission link or of one of the incumbent transmission links has in itself a sort of priority over other transmissions;

These aspects can be clarified with an information exchange with the lower and upper RRM/SON layers (see Figure 3-27). Specifically, for the information of type A an exchange with the lower layer (scheduler) is expected, while for information regarding type B aspects an interaction with upper RRM/SON layer can be predicted.

A.9.4 Detailed description of step 7

In step 7, if indeed an unacceptable degradation is found, a number of possible actions available to the network could be performed with the help of upper and lower layers of Figure 3-27. For examples, the followings actions can be performed:

- an alternative transmission link on a lower frequency can be set up for the new transmission link or for one or some of the incumbent links (in this case, the upper layer with a its traffic steering mechanisms is involved in the solution);
- in case all of the transmitting/receiving nodes involved in the activation of the new transmission link are mobile nodes a random postponement of the transmission can be applied, looking forward to more favorable new conditions of the cellular network due to new positions of the mobile nodes (in this event the lower layer with its scheduling functionality is involved); a similar action could be adopted by one or more of the incumbent transmission links, provided that the same mobility condition of their respective nodes applies;
- in case the new transmission link has gateway/backhauling purposes for a group of network nodes (for example, in vehicular and NN services) an alternative network node within the group can be chosen. In such a case the foreseen transmission will not take place and a new analysis will be performed on another transmission link involving the alternative network node (in such solution, upper layers of the RRM/SON are involved)

A.9.5 Evaluation Methodology

The preliminary simulation is performed under the following assumptions:

- 1 km^2 flat area with no obstacles
- Random positioning of transmitting and receiving nodes
- Maximum range of mmW links: 200 m
- C/I threshold: 12 dB
- Receiving nodes antennae are omni-directional
- Transmitting nodes antenna: angle of the main lobe (or beam) is 4 degree

- Transmitting nodes antenna: Front-Back-Ratio (FBR): 30 dB
- “Monte Carlo” simulation: 10000 runs for every studied point
- Number of concurrent mmW links varies from 10 to 200 (with a 10 links step)
- An ideal power control mechanism is active: at each receiving node the received signal power is always the optimal magnitude

In simulations without PGIA, after the random deployment of nodes in the area (maximum range withstanding), the receiving nodes with a C/I below the C/I threshold are counted regardless of their source of interference (main or secondary lobe, one or several interferer).

In simulations with PGIA, initially every random link is a member of its own cluster (RSC). A geometrical analysis is then performed to determine collisions by the main or secondary lobes: a collision (with the C/I of the receiving node below the C/I threshold) of at least one of a RSC members with a member of a different RSC causes the merging of the two RSCs. At the end of the process the receiving nodes with a C/I below the C/I threshold are counted. In such a scenario, the remaining interfered nodes will be the ones interfered by several transmitting links belonging to different RSCs from their own (each interferer producing a C/I above the threshold if considered standalone and therefore undetected by the PGIA analysis). The contribution of each interferer is divided by the size of its cluster under the hypothesis of a (time) sharing of the resources.

A.9.6 Further results

In Figure A-21 the performance of the RSC clustering mechanism as the number of links increases is depicted.

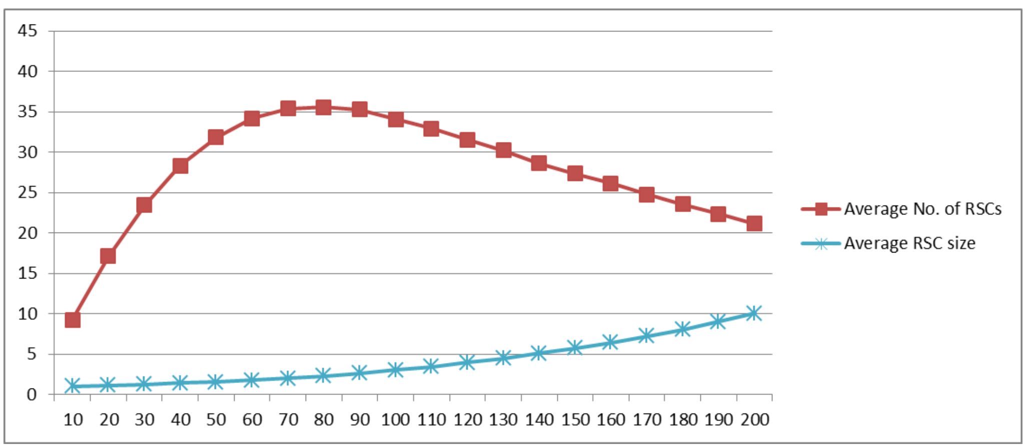

Figure A-21 Average No. of RSCs and RSC size as functions of the number of concurrent links in 1 square km

It can be noted that the average number of clusters in the scenario increases to around 35 RSCs and then decreases as the average number of links per cluster (RSC size) increases. This can be explained by the fact that with more links there is a raise in the probability of collisions and subsequently more merges of clusters occurs diminishing the average number of clusters and increasing their average size.

A.10 T5.1-TeC 5 UE Measurement Context

Inter-AIV switch and multi-connectivity: This functional extension is envisioned in the following examples:

- Several AIVs/numerologies are used simultaneously for the same application to provide a better reliability and/or an increased throughput. Following are some examples:
    - The device may use 2 different AIVs/numerologies, each of which has its own physical layer characteristics (e.g., out-of-band (OOB) emissions, side lobes and others). Typically, each AIV shall be better in certain aspects (e.g., AIV-1 has much lower OOB emissions, while AIV-2 has negligible side lobes). Therefore, the device shall send the same data through the 2 AIVs concurrently in order to achieve a better reliability which is needed, for example, in uMTC (e.g., the “connected cars” use case).
    - Dual/multi-connectivity: the device may use a certain AIV for carrying CP packets, while using another AIV for transferring UP packets. The AIV-1 is able to achieve a wide cell coverage to transfer the CP packets (i.e., using AIV-1 for the link with the macrocell), while the AIV-2 is able to achieve a better data rate to transfer the UP packets (i.e., via using AIV-2 for the link with the micro cell.). This shall be needed for xMBB use cases (e.g. the “dense urban information society” use case).
- The running application is changed to another with a different service type at UE and the underlying AIV/numerology must be switched.
- The device may activate/run several applications supported by different AIVs at the same time. Following are some examples:
    - If a mobile device is running both a conversational video (live streaming) application and a real time gaming application (online gaming) in parallel. Then each application shall need its performance characteristics (e.g., data rate, latency, reliability, and availability) to deliver the best QoS to the user.
    - If a mobile device is running a conversational voice application and a remote tactile interaction application (e.g., the remote augmented reality), then each application shall need its specific QoS attributes.

To summarize, different from the inter-AIV handover in current LTE, which occurs only when the cell of the UE is changed, the inter-AIV handover is expected to occur much more frequently. It is thus necessary that the UE Context is accordingly designed to assist in a fast switch.

Interworking with legacy RATs: In current 3GPP activities, the LTE-A is being enhanced and some enhancements are given as follows:

- LTE-A WLAN Aggregation (LWA): this enhancement enables the data offloading from licensed LTE-A networks to unlicensed spectrum. The standardization of LWA has recently been finished in Release 13 [3GPP15-36300].
- Enhanced LWA: LWA will be further enhanced by supporting, e.g., WiGig operating at higher frequencies, namely, 60 GHz. This is already a Work Item in Release 14 and will be an important feature of LTE-A Pro [3GPP16-RP160600].
- LAA: LAA enables LTE-A to be operated on unlicensed bands and it is being extensively discussed in 3GPP.

A.11 T5.1-TeC1 Multi-dimensional RM for 5G & Legacy AIs

Figure A-22 shows AaSE in combination with an AIV-agnostic RM. Step 0 now informs AaSE about the radio resource availability in the system. Based on this, step 3a3Aa can be executed more precisely compared to the operations without an AIV-agnostic RM as AaSE can now take into account the exact situation in order to monitor the SLA status and to execute AC and/or ARP. The steps 3B and 3C are no longer required, as they are part of the AIV-agnostic RM (Step 5). Step 4A can now contain abstracted QoS information, independent from an AIV. The steps 4B, 3B and 2B remain unchanged.

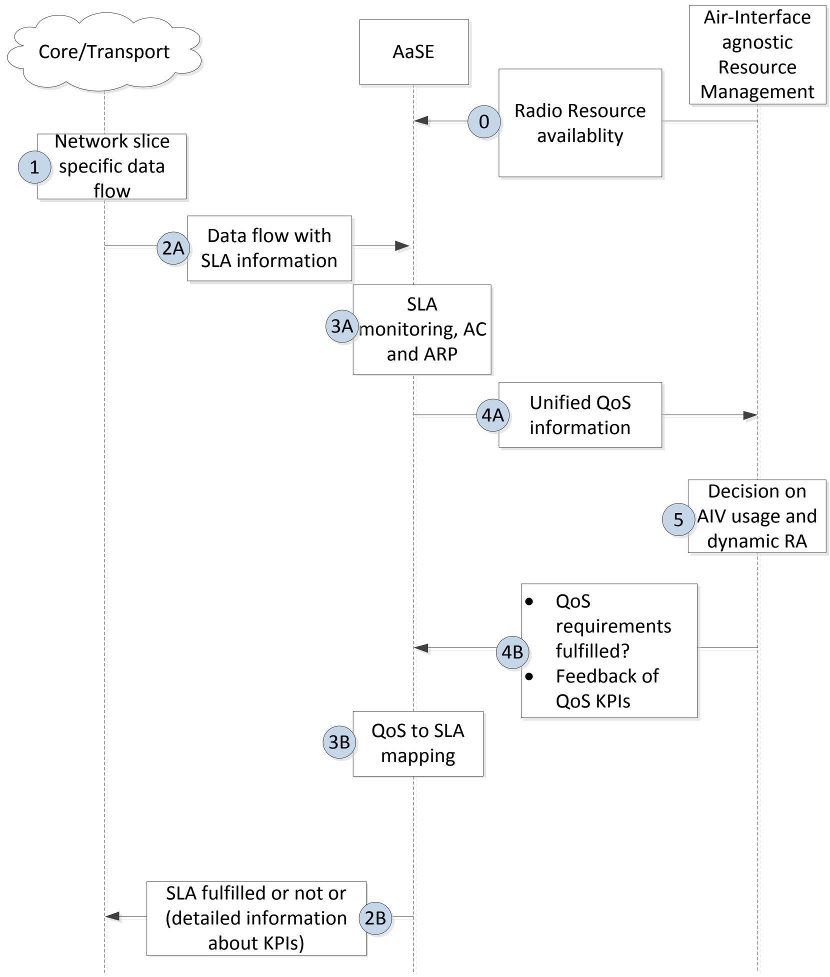

Figure A-22 AIV-agnostic Slice Enabler with Air-Interface-agnostic RM.