

An Agile Resource Management Framework for 5G

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Abstract—This paper presents the design foundations of an agile resource management (RM) framework for the fifth generation (5G) radio access network (RAN) by describing essential building blocks (BBs). Overall, the presented RM framework provides holistic RM solutions that consider and exploit the novel aspects of 5G systems, such as, diverse service requirements, co-existence of multiple air interface (AI) variants (AIVs) in the overall AI, dynamic radio topologies, and novel communication modes. The proposed framework encompasses the following key BBs: Advanced interference management techniques for dense and dynamic deployments; dynamic traffic steering mechanisms that aim to attain the optimum mapping of 5G services to any available resources when and where needed by considering the peculiarities of different AIVs; tight interworking between novel 5G AIVs and evolved legacy AIVs such as Long-term Evolution (LTE); sharing of a common RAN by multiple network slices; RAN moderation techniques to attain energy efficiency gains; and functional extensions in the device measurement context to enable all the above new functionalities. The BBs are analyzed from the perspectives of key findings and RAN design implications.

Index Terms—5G, energy efficiency, interference management, network slicing, new radio, resource management, METIS-II

I. INTRODUCTION

THE main motivations towards 5G systems are the explosive demand for data rates and capacity as well as the very challenging and diverse service types that have been envisioned in the realms of extreme Mobile Broadband (xMBB), massive Machine Type Communications (mMTC), and ultra-reliable Machine Type Communication (uMTC). In addition, there is consensus that 5G will have to fulfill requirements driven by vertical industries, interested in using radio networks for wireless connectivity and service provisioning. Furthermore, another key aspect of 5G will be the fact that the overall air interface (AI) will comprise different AI variants (AIVs) that are optimized, e.g., for the specific frequency bands of operation (below 6 GHz, millimeter wave, etc.), and for one or more target use cases (UCs) described in [1][2]. Hence, a strong

need for an agile resource management (RM) framework arises to operate both within and across the different AIVs in an overarching manner. This means that, to a certain extent, the functionality framework for RM could remain agnostic to the design of the physical layer design of the involved AIVs.

This agile RM framework should tackle many key issues of the RAN design. Regarding interference, 5G networks would be more challenging due several novel aspects such as the ultra-dense deployment of cells or the dynamic nature of the topology; much wider use of beamforming, flexible uplink/downlink (UL/DL) frame configuration, in-band self-backhauling and device-to-device (D2D) communications. These technology components (TeCs) will jointly contribute to the creation of new interference constellations and patterns. Moreover, the need to support ultra-reliable and latency-critical applications, along with the implementation of network slicing will add a new dimension to the problem of efficient resource allocation within 5G networks. Thus, 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 paper, we present a concise view of agile RM developed by 5G PPP METIS-II project for 5G system encompassing the main components and the key design considerations [3][4]. On this basis, this paper aims at providing the latest considerations and important challenges at an early time point, when the new radio (NR) standardization in 3rd generation partnership project (3GPP) is at its early phase [5]. To this end, we structure our framework into building blocks (BBs), the entities containing the more fine-grained TeCs addressing each of the challenges of a 5G network. In Section II, a vision of the overall framework is provided, recalling the main design RM related principles of 5G and how those are captured. Section III provides a brief description of each of the proposed enabling BBs. Finally, conclusions are drawn in Section IV.

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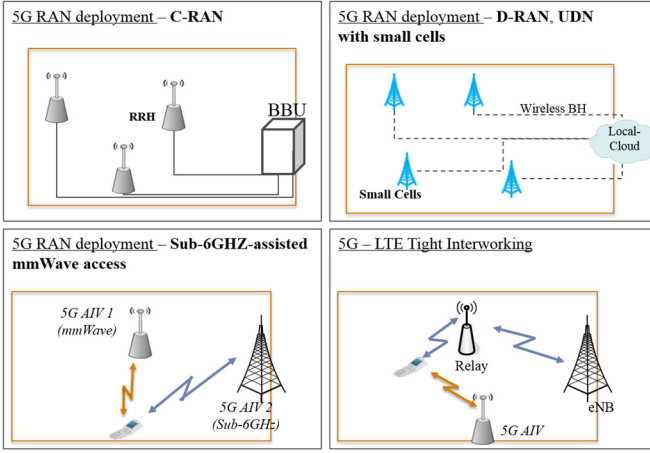


Figure 1. Exemplary multi-AIV RAN deployments.

II. THE VISION FOR AGILE RM FRAMEWORK: CHALLENGES AND ENABLERS

In 5G RAN, different physical deployments such as centralized/cloud RAN (C-RAN) or distributed RAN (D-RAN), and the awareness of network slices will strongly impact the requirement and the efficiency of RM functionalities. Numerous network slices may share the same RAN resources, so multiple “logical sub-networks” are mapped to limited RAN physical deployments, where also the backhaul technologies and topologies will provide some extra limitations. RM will be very challenging in terms of complexity and signaling. Also tight and diverse 5G key performance indicators (KPIs) per slice will be required to allow for service-tailored optimization within the RAN. In Fig. 1, we observe some exemplary multi-AIV RAN deployments, where the RM framework can be applied and different BBs can be customized to different

scenarios.

The mechanisms within the RM framework shall build upon novel 5G aspects, i.e., diverse service requirements, overall AI comprising multiple AIVs, novel communication modes and dynamic radio topologies. For instance, interference management schemes need to be flexible to adapt to changing radio topologies based on moving access nodes and changing service requirements to enable efficient service provisioning. At the same time, RM schemes should enable mapping of resources to diverse service types with contradicting requirements that exploit specific AIV characteristics such as flexible numerology of the physical layer (PHY). Further, one of the goals should be to enable fast execution of traditionally slow mechanisms in the legacy networks. For example, legacy traffic steering between different radio access technologies (RATs) and access nodes is performed via hard handovers, which results in latency increase. Given the latency-critical services to be enabled by 5G networks, the efficiency of such mechanisms shall be clearly improved to be agile to react sufficiently to service needs. Another important KPI is the overall energy efficiency of the networks particularly given the envisioned ultra-dense networks (UDNs). Accordingly, the number of active access nodes should be optimized, while fulfilling service requirements. RM concepts need to aim at enabling RAN support for multiple network slices. Consequently, the implications of supporting the developed RM schemes on the user equipment (UE) context should be assessed in terms of the functional extensions relative to state-of-the-art, while taking into account the trade-off between device complexity and performance.

A conceptual illustration of the agile RM framework is shown in Fig. 2. In particular, the agile RM framework operates on the 5G landscape consisting of different and novel

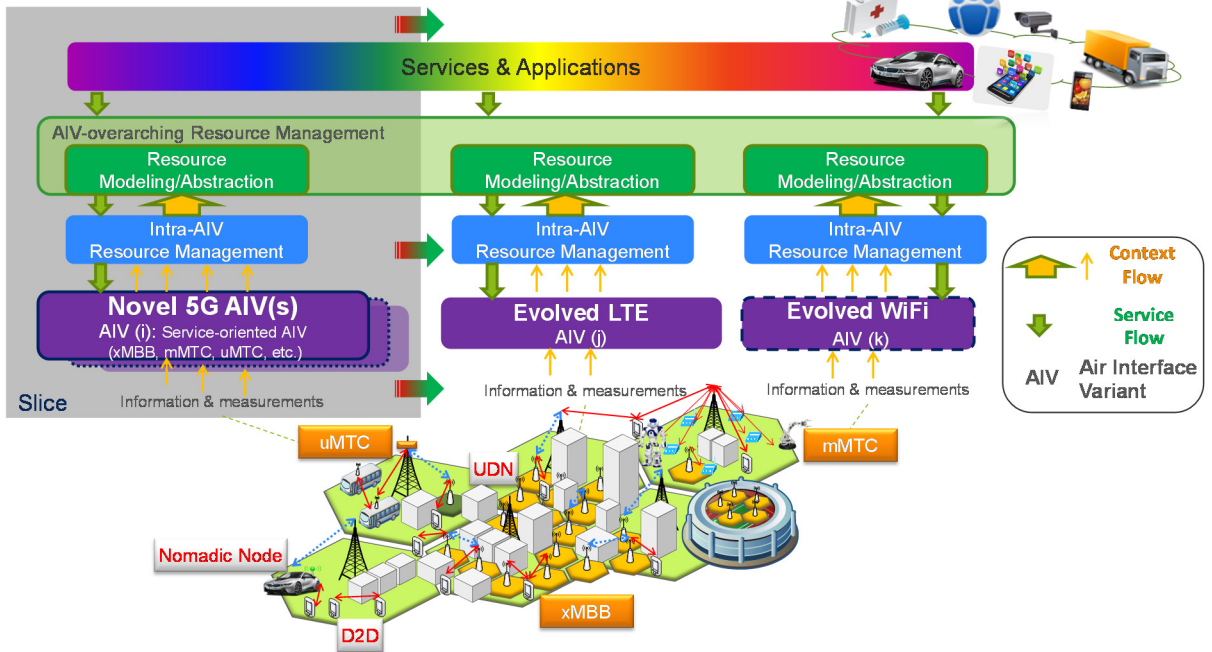


Figure 2. High-level conceptual illustration of Agile RM Framework for 5G, which efficiently maps service flows to available resources considering deployment constraints and diverse service requirements.

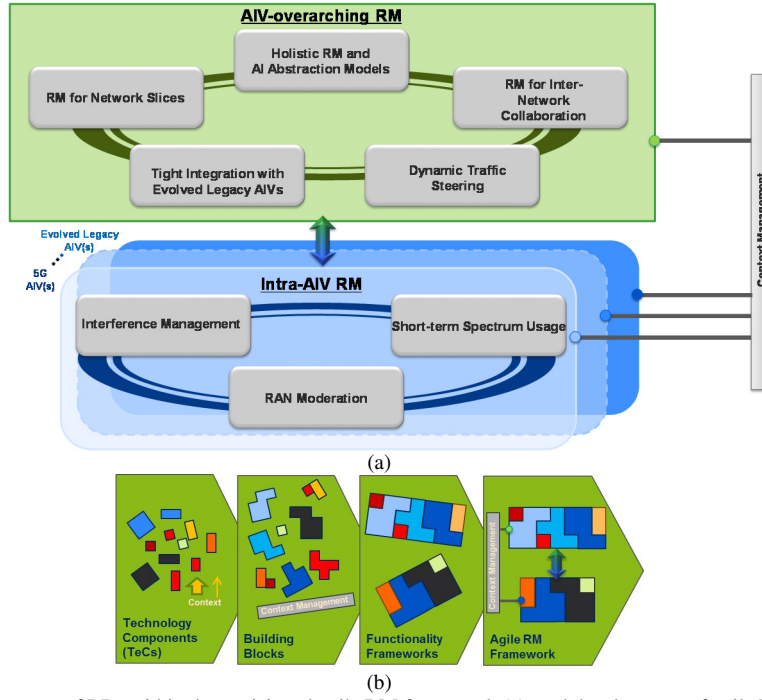


Figure 3. The schematic inter-relation map of BBs within the envisioned agile RM framework (a), and development of agile RM framework (b).

deployment options, e.g., 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 duplexing (TDD) in UDN. Further, it is expected that the wide range of requirements from envisioned diverse services and applications (i.e., as part of uMTC, xMBB, and mMTC) 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, which is a key enabler for new 5G businesses, RM for network slices is also captured within the agile RM framework in an AIV-overarching manner.

Accordingly, we propose an agile RM framework whose functionality is organized based on three abstraction levels: i) The TeC, the basic unit of enabling functionality that solves a problem using one specific approach, ii) the BB, a group of TeCs closely related by functionality that use different approaches to solve the same (or similar) problem, iii) and the functionality framework, a set of BBs characterized by a functionality that is either AIV-specific or AIV-overarching. We devise two functionality frameworks, namely an AIV-overarching framework, and an intra-AIV framework, each of them composed of the set of BBs shown in Fig. 3(a). The complete development process of the RM framework starting from the individual TeCs is depicted in Fig. 3(b).

This paper is structured around BBs as they represent a reasonable level of abstraction to provide the desired depth of technical details. As mentioned before, the main goal of this paper is shedding light onto the main design considerations and challenges toward RM in 5G rather than providing a complete analysis for each design consideration. For various detailed

conceptual descriptions and analyses, interested readers are referred to [3] and [4]. In the following section, we present the BBs designed within the proposed agile RM framework.

III. BUILDING BLOCKS OF AGILE RM FRAMEWORK

Herein, we highlight the BBs of the agile RM framework, where we provide a summary of the key aspects, findings and the RAN design implications in Table I in the appendix.

A. Highlights of the Building Blocks

The overview of the BBs are presented in the following.

- **Interference Management:** The schemes 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 interface (see X2* interface in [6]) 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. 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. 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.
- **RM for Network Slices:** Considering the envisioned AI consisting of multiple AIVs, services and the vision of network slicing [6][7], RM techniques for inter-slice and intra-slice resources are captured in this BB.
- **Tight Integration with Evolved Legacy AIVs:** This BB analyzes the interworking between novel 5G AIV(s) and evolved LTE avoiding inter-RAT handovers. The envisioned BB aims at efficient interworking. Various interworking approaches including possible integration at radio protocol stack are taken into account.
- **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 BB 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 BB 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 BB. 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.

B. Context Management as the Enabler

The identification of the context information required from different sources (e.g., UE) is of key importance to support new 5G features required for efficient RM and for the realization of the aforementioned BBs.

Context awareness is defined as delivering context information in real-time on the network, devices, applications, the user and his environment to application and network layers in the context of IMT-2020 [8]. The context data are gathered by UE and base station (BS), and then they are sent to specific databases in the network and exploited by extended and new radio management algorithms.

While designing the UE context in 5G networks, the amount of data to be gathered and the complexity of RM algorithms need to be tracked carefully between the network performance

enhancements they make available and the load they impose on both the BS and the UE in terms of data gathering, signaling, processing and storage. For example, since multiple UCs possibly with contradicting KPIs are identified in 5G, different AIVs may be used in different UCs. Consequently, more frequent inter-AIV switches (i.e., the switch from a certain AIV to another AIV) are foreseen. For example, inter-AIV switch can occur due to a change in running applications and the related AIVs, or due to the switching between bands and related AIVs. So, to enable the efficient switching from one AIV to another, the UE may need to perform separate measurements for each AIV.

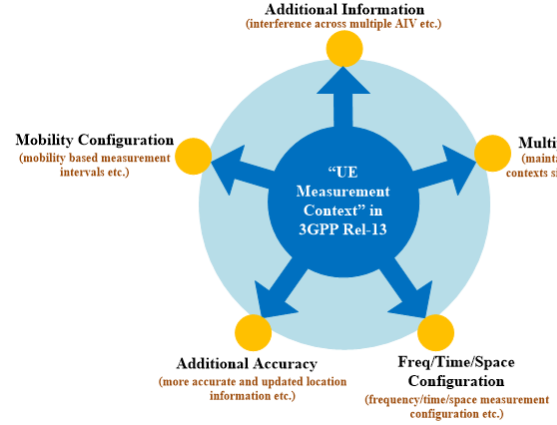


Figure 4. Possible changes on "UE Measurement Context".

To address the above challenges, the UE measurement context should be adapted to assist in reporting existing information (such as location) with a more accurate estimate (as required by "dynamic traffic steering" BB), and reporting new information such as the inter-AIV interference (as required by "interference management" BB). Moreover, the exploitation of high frequencies is based on directional transmission schemes via beam-forming, which may imply updating the measurement context to support such new configurations (e.g., space tailored configurations as required by "interference management" BB).

In addition, in order to satisfy various mobility requirements in different 5G UCs, measurement configurations should be adapted to support mobility based configurations (such as a mobility based measurement intervals). Furthermore, the UE could be able to maintain multiple measurement contexts, such as multiple configurations for multiple AIVs (as required by "tight integration with evolved legacy AIVs" BB). The indicated functional extensions and changes on the UE measurement context are included in Fig. 4.

Due to the illustrated possible various extensions on the UE measurement context, it is expected that UE measurement configurations shall be increased significantly. Which may increase both the signaling overhead required for configuring the UE measurements, as well as the time required to configure the UE measurements. So, it is desired to have a measurement configuration mechanism which enables the BS to adjust the UE measurement configurations without increasing the required signaling overhead or the measurement configuration time. The measurement configuration mechanism should also provide a quick method to change the UE measurement

configuration whenever needed (e.g., when the UE mobility state is changed, when the BS load state is changed, etc.). Thus, a framework between the UE and the BS is introduced which allows the UE and the BS to adapt the UE measurement configurations dynamically as shown in Fig. 5.

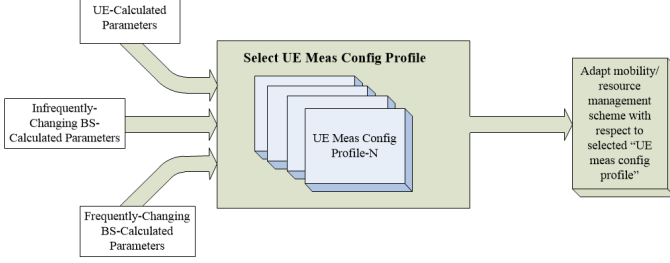


Figure 5. Framework for adaptive UE measurement configuration process

The introduced framework defines a set of measurement configuration profiles (MCPs). Each MCP contains a predefined set of UE measurement configurations (e.g., UE measurement intervals, measurement sampling rate, maximum number of measured cells, etc.). The framework allows the UE and the BS to select the best suitable MCP according to variety of parameters. Those parameters can be categorized into different groups as following:

UE-Calculated Parameters: This group contains all the parameters calculated by the UE (e.g., UE mobility state, UE power state, UE capability, etc.) and then reported to the BS.

Infrequently-Changing BS-Calculated Parameters: This group contains all the infrequently changing parameters calculated by the BS (e.g., number of neighbor cells, BS served cell size, BS capabilities, etc.), and then sent to the UE (either through dedicated or broadcasted signaling).

Frequently-Changing BS-Calculated Parameters: This group contains all the frequently changing parameters calculated by the BS (e.g., current active radio bearers, load of neighbor BSs, etc.).

The algorithm used in this framework consists of 3 main steps: **STEP-1: UE selects the best suitable MCP** according to the “UE-Calculated Parameters” and the “Infrequently-Changing BS-Calculated Parameters”. Subsequently, the UE shall adopt to the RRM scheme indicated by the selected UE-MCP (e.g., adjust measurement intervals according to the selected profile). **STEP-2: BS reselects (fine-tunes) the “active UE-MCP”.** When UE establishes a connection with BS, it shall transmit to the BS the “UE-Calculated Parameters”. Therefore, the BS may reselect the UE-MCP taking into consideration the “UE-Calculated Parameters”, “Infrequently-Changing BS-Calculated Parameters”, as well as the “Frequently-Changing BS-Calculated Parameters”. As a result of this reselection (fine-tuning) of the suitable UE-MCP, the BS may command the UE to adjust the current active UE-MCP.

STEP-3: UE and BS both update each other with latest calculated parameters. Whenever the UE detects that the “UE-Calculated Parameters” are different from the values transmitted to the BS, it shall inform the BS with the updated parameter set. Similarly, the BS shall inform the UE when the BS detects that the values in the last calculated parameters set differ from the ones which have been provided by the BS to the UE. Consequently, the best suitable UE-MCP shall be reselected accordingly.

The introduced framework should provide BS with flexibility to extend the defined MCPs by adding new MCPs. The BS shall send the new MCPs to the UE (either through dedicated or broadcasted signaling).

IV. CONCLUSION

This paper has presented the highlights of the envisioned agile RM framework, which provides holistic RM solutions that consider and exploit the novel 5G aspects of diverse service requirements, overall AI comprising multiple AIVs, dynamic radio topology and novel communication modes. In particular, RM mechanisms shall

- adapt to peculiarities of multiple AIVs that constitute overall AI, such as, multi-service support,
- take into account dynamic radio topology with new types of access nodes, such as NNs,
- be able to operate over extended notion of a resource, such as unlicensed band,
- enable tight interworking with evolved legacy networks to avoid hard handover,
- enable end-to-end slicing considering novel 5G aspects,
- enable energy-efficient network operation while fulfilling service requirements, and
- operate on a faster time scale, e.g., by dynamic traffic steering without the need of hard handovers as in legacy networks.

Further, the UE context shall be extended to support the novel RM mechanisms. Consequently, the proposed agile RM framework is seen as an enabler for multi-AIV, multi-service, and multi-slice 5G system.

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TABLE I
OVERVIEW OF ENABLING BBS WITHIN THE AGILE RM FRAMEWORK

Title	Highlights	Key Findings	RAN Design Implication
<i>Interference Management</i>	Functionality can be implemented as flexible interference mitigation for dynamic topologies, interference avoidance techniques, interference-resistive design, etc.	Flexibility in interference mitigation techniques is crucial, particularly for dynamic and dense deployments characteristic of 5G.	Some level of coordination among BSs needed to apply the corresponding interference management techniques; mostly involve the use of X2* interface over wired or wireless backhaul; this requirement should be also met in dynamic topologies with e.g., NNs.
<i>Flexible Short-term Spectrum usage</i>	Coordinated Resource Allocation for unplanned and dynamic LAA deployments.	Throughput increase by the coordinated use of unlicensed bands and spectrum utilization efficiency.	For the effective and efficient utilization of the unlicensed spectrum AIVs should allow interference estimation also on the unlicensed bands.
<i>RAN Moderation</i>	Determine optimum number of active access nodes.	Multi-cell coordination schemes to fulfill service requirements while clearly improving energy efficiency of the network.	A centralized entity for coordinated scheduling is required. A new discovery signal needs to be defined for UEs to detect the access nodes in the sleep mode.
<i>Tight Integration with Evolved Legacy AIVs</i>	LTE and 5G dual connectivity solution for more reliable mobility and better coverage.	Substantial gains for the cell-edge users with a solution similar to dual connectivity compared to legacy inter-RAT handover.	Common LTE and 5G S1* for core network (CN)/RAN signaling. Possibly new signaling for AIV quality metric. Adding and deleting a new control plane connection to a user, for the proposed tight integration concepts, must be very fast and lightweight in order to support ultra-reliability requirements.
<i>Holistic RM & AI Abstraction Models</i>	Enable multi-service/multi-AIV resource mapping and native D2D support.	Optimum transmission time interval (TTI) configurations in multi-service scheduling to achieve low-latency communications and D2D landscape in 5G.	Flexible frame structure with variable TTI sizes for different services. Native support for D2D and self-backhauling.
<i>RM for Inter-Network Collaboration</i>	Implementation of future-proof power control framework covering wide range of UCs.	Radio Map coordination mechanisms among different networks result in clear throughput gains demonstrated by prototype-based evaluation.	Minimal impact; establishing only base interface properties and requirements.
<i>Dynamic Traffic Steering</i>	Fast service data flow routing among different AIVs to fulfill QoS requirements avoiding hard handovers.	Significant latency reductions and energy savings.	New information elements to be defined between the open interface between the higher and lower layer RAN functions. Moving the QoS enforcing capability to RAN requires new functionalities defined in the aggregation layer for enforcing these functions within the RAN.
<i>RM for Network Slicing</i>	Flexible adoption of new services and businesses.	Resource sharing between network slices and service level agreement (SLA) monitoring is required.	Signaling and potential new network element for SLA monitoring and enforcement required.
<i>Context Management</i>	Functional extensions and changes in the UE measurement context.	Proposed efficient mechanism for UE measurement configuration. Trade-off between performance and signaling overhead and energy inefficiency.	New information and configurations in the UE measurement context. Proposed framework to adapt the UE measurement configurations dynamically.