Agile Resource Management for 5G

A METIS-II Perspective

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Abstract— **An explosive growth in the demand for higher data rates and capacity along with diverse requirements set by massive and ultra-reliable machine-type communications are the main drivers behind the development on new access technologies as part of the fifth generation (5G) networks. Currently, different air interface (AIF) and/or AIF variants, optimized based on the frequency band of operation and use case, are envisioned for such a network. Developing an agile resource management framework for 5G networks is one of the main goals of the METIS-II project. The METIS-II project builds strongly upon the EU flagship project METIS, which has laid the foundation of 5G. This framework will take into account the multi-link and multi-layer constraints currently envisioned for 5G. In this paper, we provide our first insights into agile resource management and the associated synchronous control functions. We will discuss the essential building blocks in terms of technology enablers and their mapping to 5G services and deployments. The introduced agile resource management framework for 5G is expected to enable enhanced interference management, dynamic traffic steering, fast radio access network (RAN) moderation, efficient context management, and optimized integration with legacy networks.**

Keywords—5G; METIS; RAN Design; Resource Management

I. Introduction

The exponential increase in data traffic is expected to continue during the next decade, as well. This has necessitated the development of fifth generation (5G) technologies that enables the network operators to provide higher data rates, and enhanced quality of service and experience, to a multitude of users. The support for extreme mobile broadband (xMBB) associated with 1000 times higher network capacity and 10-100x higher user data rates in this direction constitutes one dimension of the set of requirements. Furthermore, considering also the other requirements currently defined for 5G, such as support for ultra-reliable machine-type communications (uMTC) with low latency in the order of few milliseconds and massive machine-type communications (mMTC) with 100x more devices to be served than today cannot be satisfied by existing radio access technologies (RATs) [1]. In order to achieve these challenging targets, research on new air interface (AIF) design is currently ongoing. Providing a framework for the design of future wireless and mobile communication networks, along with use cases and requirements, were some of the main targets of the European Union (EU) flagship project Mobile and Wireless Communications Enablers for the Twenty-Twenty Information Society (METIS) to lay the foundation of 5G, which was finalized end of April 2015 [1][2][3][4].

In July 2015, the work related to METIS-II project has been initiated with the commitment of a global consortium, which comprises key global vendors, leading mobile network operators and key research groups as well as small enterprises, mainly targeting the overall 5G radio access network (RAN) design [5][6]. The work done in this project is expected to contribute significantly to the timely and efficient standardization of 5G technologies in 3GPP, anticipated to begin in 2016, where, for example, study on new services and markets technology enablers has already started [7]. Further details regarding the overview of the project, including objectives, structure and expected impact are presented in [5]. The topics discussed in this paper will be targeting the METIS-II innovation pillar on 5G *agile resource management framework*.

5G RANs will introduce new challenges in terms of novel interference constellations, e.g., through ultra-dense networks (UDNs), wide usage of beamforming, uplink/downlink (UL/DL) cross-interference, and device-to-device (D2D) communications, novel modes of communication, e.g., self-backhauling, D2D, and multicast communications, and more diverse and stringent application requirements, e.g., latency-critical applications. It is, thus, required to develop resource management functionality that natively supports the new communication variants and effectively satisfies very different and demanding performance requirements. For instance, interference management in current cellular networks has been extensively studied in literature [8]. Various power control techniques have also been developed to provide enhanced performance within the network. In Long-Term Evolution-Advanced (LTE-Advanced) networks, such mechanisms were mainly studied and standardized from an UL perspective [9]. Nevertheless, in the case of ultra-dense deployments of access nodes in 5G networks, such topics are gaining even more relevance and shall be tailored for the dynamic operation envisioned in such networks [10].

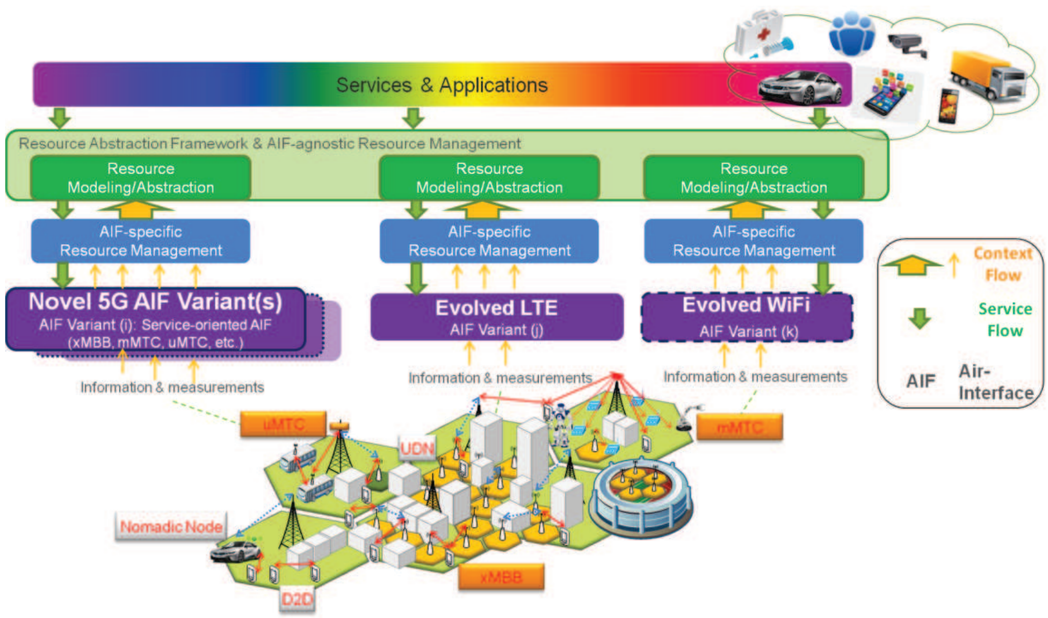

Fig. 1 Conceptual Illustration of Agile Resource Management Framework that will be investigated in METIS-II.

5G networks are also expected to operate in lower (e.g., below 6 GHz) and higher carrier frequencies, such as, cmWave and mmWave frequencies. Such networks are also expected to co-exist with legacy RATs, with possible close inter-working expected between evolved legacy, e.g., LTE-Advanced and Wi-Fi, and novel 5G RATs.. . This integration would require techniques to efficiently steer traffic between several radio access interfaces [11], to which the user equipment (UE)[1] might be simultaneously connected. While higher amount of spectrum is required to achieve the 5G targets, efficient management and utilization of the available spectrum are also important aspects [11], which need to be further studied. The use of context information to efficiently provision services within the network was studied extensively during the METIS project [12]. Such investigations are aimed to continue during METIS-II, as well. With the native support of flexible network design envisioned for 5G, the notion of resource can be extended from traditional time, frequency and power resource grid towards various radio interfaces, network processing elements (e.g., available memory) and network nodes (e.g., access nodes).

The rest of the paper is organized as follows. Section II provides an overview of the agile resource management framework and synchronous control functions for 5G. Section III describes the enabling technologies and possible mapping to 5G services and deployments, and Section IV provides a conclusion of the paper.

[1] UE is herein referred to any kind of mobile terminal that relates to communications for any of the 5G services, namely, xMBB, uMTC and mMTC.

II. Framework of Agile Resource Management and Synchronous Control Functions for 5G

METIS-II will define a new multi-link, multi-layer network ecosystem as part of the 5G landscape. New flavors of control and user plane integration and protocol adaptation in 5G landscape can provide opportunities to re-design or enhance various functions (e.g., interference management, power control, and RAN moderation) so as to meet the wide range of requirements imposed by diverse services and applications. Accordingly, assigning services and applications to the most suitable resources is of paramount importance to fulfill the requirements in an efficient and sustainable way. To this end, METIS-II aims to develop an agile resource management framework. An illustration for the agile resource management framework considering the initial assumptions that are going to be investigated is shown in Fig. 1. By the term "resources", here, we do not only refer to the classical definition of resources as defined in the context of radio resource management (RRM), e.g., available spectrum and resource blocks. We also incorporate 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 soft resources (software capabilities of network nodes and UEs). To improve the utilization of synchronous control functions[2], apart from these resources, additional context information will also be modeled that is required by them (e.g., interference levels and congestion levels). Within the framework of agile resource management, METIS-II will

[2] A synchronous control function is a control function that is coupled with a time frame structure, e.g., power control. For further details on the definition of synchronous control functions, readers are referred to [13].

a) investigate a resource abstraction model that can be used to provide the means for the integration of the 5G synchronous control functions among the novel 5G air interface (AIF) variants (likely enabling more possibilities due to clean-slate approach) and the legacy ones (e.g., those of evolved LTE and Wi-Fi) and b) improve the operation and the performance of typical synchronous control functions (e.g., interference, short-term spectrum management and RAN moderation). It is to be studied to which extent AIF-specific and AIF-agnostic resource management functionalities are beneficial for the overall system design. Although there have been some related activities, the extensions in METIS-II beyond the state-of-art include a) the support for holistic control and user plane framework that will be developed within METIS-II, b) the support of new spectrum opportunities, c) the support of mixed combination of multi-link/multi-layer 5G networks taking into account evolution of legacy networks, and d) studying the synchronous control functions in a holistic way and further advancing their capabilities (e.g., new scheduling paradigms to minimize the delay). It is important to emphasize that the developed resource management framework is aimed to efficiently support the novel modes of communication envisioned in 5G systems (e.g., D2D, self-backhauling, and multicast). At the same time, the varied set of applications and use cases with very different and demanding performance requirements (e.g., regarding xMBB, uMTC, and mMTC) shall be supported.

Furthermore, it is expected that there are constraints caused by the strong relationship to the different timings of the AIF variants, different deployments and the imposed limitations of the legacy networks. One of the goals of the METIS-II work is then to give insights into control functions and the necessary modifications with respect to the system layout and deployments.

III. Enabling Technologies and Mapping to 5G Services and Deployments

Herein, the building blocks of the agile resource management framework are briefly described.

A. *Interference Management*

To cope with the increasing demand for capacity driven by xMBB-type of services, a more intensive reuse of existing spectrum bands through an ultra-dense deployment of small cells is envisioned. This level of densification implies low average network utilization and closer proximity between the BS and users. UDNs are considered a key enabler in addressing the traffic demands for 2020 and beyond [2]. Indoor UDNs (see the virtual indoor office scenario in [3]) are especially promising deployment scenarios for dynamic TDD thanks to high probability of line-of-sight, similar transmit powers for BSs and users, and shielding effects of the inner and outer building walls [14][15].

In systems employing dynamic time-division duplex (TDD), a flexible switching point is used to adapt the time resource allocation to varying traffic conditions. This type of duplexing lends itself to more efficient resource allocation over a short (fast) time scale caused by the burstiness of mobile broadband data. On the downside, dynamic TDD can

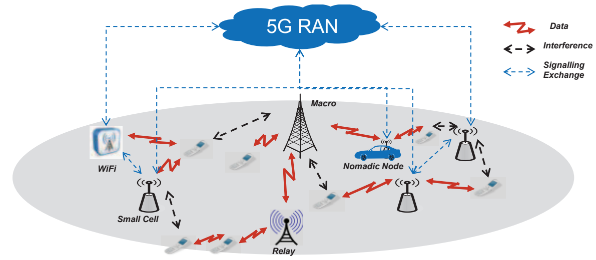

Fig. 2 Inter-cell interference in exemplary 5G RAN deployment.

induce so called same-entity, i.e., base station to base station (BS-to-BS) and user-to-user interferences which occur when DL and UL transmissions take place in the same time resource. The user-to-user interference can have an especially negative impact on the performance of some cell-edge users when receiver and interferer are in close proximity of each other. Interference management is therefore an essential part of dynamic TDD.

Dynamic TDD has recently seen increased attention also in the context of D2D communications, game-theoretical distributed networks, and energy efficiency. However, the feasibility, scalability, and performance bounds of dynamic TDD in certain dense deployments vis-à-vis network and user utilities remain unexplored. Impact of multi-layered network design and evolved protocol stacks may also demand a more detailed study. Answers to these questions can be exploited for future algorithm design.

The widespread usage of beamforming and/or full-dimension MIMO (FD-MIMO) will be an important technique for interference management as well as providing coverage by compensating the challenging propagation conditions especially in high frequency bands. In case of frequency-division duplex (FDD) systems, other new challenges emerge such as pilot overhead, channel state information (CSI) estimation complexity, CSI quantization and feedback overheads, which can become particularly complex as high-order multiple-input multiple-output (MIMO) and multi-user MIMO (MU-MIMO) are deployed [16]. Any 5G interference management framework, thus, ought to take into account these issues, with cell-edge performance being one of the essential key performance indicators (KPIs). One promising solution is already introduced FD-MIMO cellular communication system, which places a large number of active antenna elements in a two dimensional grid at the BS. In order to achieve the promising gain of FD-MIMO in practice, in addition to already identified challenges, we need accurate beam steering and tracking in three dimensions (3D) [16].

5G RAN is expected to provide fast, seamless and uniform connectivity to the user, while supporting multiple services with challenging requirements. To cope with the huge capacity and coverage demands, a multi-layer and multi-RAT access network is one of the key building blocks. To this end, the pooling of resources in a centralized-RAN deployment (which can be implemented as a cloud-RAN), along with flexible centralization of RRM functionalities is a possible solution so as to substantially enhance RAN performance [17]. As exemplified in Fig. 2, inter-cell interference is a key challenge in 5G RAN, where numerous and diverse sources of interference in co-channel deployments can significantly degrade users' performance [10]. In this context, the employment of nomadic access nodes, D2D and ad-hoc small cells under the centralized-RAN umbrella poses some challenges regarding the effectiveness of interference management mechanisms due to the backhaul state /availability and the dynamicity of the environment.

Additionally, on the topic of small-cell deployment, small cell discovery in mmWave is a potential challenge due to high-gain directional access. Improving cell search procedure and minimizing scanning delay may be some of the topics that need to be addressed. Additional complications arise when control plane / user plane split is implemented, e.g., when control plane is operated at a 4G/5G macro BS.

Moreover, different KPIs and requirements from different use cases might give different flavor to the way that performance improvement is interpreted in UDNs. In other words, there might be cases where a certain level of interference should be allowed, whereas in other use cases the interference isolation or high spectral efficiency is critical. To this end, the flexible operation of resource management with low signaling and low complexity is critical to meet the 5G requirements in a centralized 5G RAN deployment, assuming variable backhaul, heterogeneous access technologies with multiple KPIs.

This flexible and co-operative resource management will need to be mindful of an additional level of scheduling complexity, particularly in the mmWave bands and possibly in cmWave bands – those same bands may be shared between access, backhaul and fronthaul. At mmWave frequencies, in-band backhaul is a real possibility thanks to high directivity of links; however, mobility will introduce additional complications into spectrum sharing. Access links and backhaul normally have very different requirements when it comes to variability of frequencies in space and over time.

B. RAN Moderation and Traffic Steering

While the high densification of the network will be essential in order to meet the increasing traffic demand in future systems, it is also important to ensure that the overall energy consumption in these hyper-dense scenarios will be kept under control. Energy consumption in mobile networks have been widely studied [18][19], 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 systems do. Mechanisms that enable fast on/off switching of nodes already exist, allowing to significantly reduce the energy consumption of a node that is not transmitting, exploiting a "sleep mode" or "lock" state [18]. In [20], it was shown that when a highly dense network is deployed and traffic is below its peak value, it is possible to exploit traditional coordinated multi point (CoMP) schemes such as non-coherent joint transmission and dynamic point selection/dynamic point blanking to reduce the number of active transmission nodes necessary to serve the existing amount of traffic. The mechanism, which uses the three abovementioned CoMP schemes, assumes that a centralized entity is able to control the transmission of a cluster of cells, and designs the scheduling of transmissions from the cells of such cluster in order to reduce the overall power consumption of the system. This is achieved by dynamically selecting during the scheduling process the transmission nodes that should be kept in sleep mode and those that should be kept active, and by allowing this subset of active nodes to coordinate their transmission, in order to improve the efficiency of the transmission and reduce the overall number of active nodes necessary to satisfy the requested amount of traffic.

The scheduling approach proposed in [20] could be enhanced to include features that will be potentially available in 5G networks: As an example, 3D beam-forming could be used as an additional booster to concentrate the transmission to the receiver while reducing interferences towards other nodes providing further energy efficiency; moreover, new power models that are able to include enhanced on/off switching features that fit 5G transmission nodes (e.g., discontinuous transmission, DTX) should also be considered. The impact of these enhancements on the proposed scheme will be assessed within the research activity of METIS-II.

Each of the applications foreseen for 5G networks (e.g., car-to-X communication, broadband wireless access, and smart metering targeting 5G services) may require a different set of network functions such as mobility management, cyphering and authentication. The 5G White Paper of the Next Generation Mobile Networks (NGMN) Alliance [21] introduces the concept of network slicing that can be used together with flexible network functions virtualization (NFV) and software defined networking (SDN) based architecture. Here, the physical network resources are utilized by multiple virtual networks, the so-called network slices. A network slice can then be tailored to the demands of a specific application (business-driven approach).

With respect to the RAN, network slices can make use of multiple AIF variants simultaneously, see Fig. 1. In addition, different network slices can access the same AIF variant. The task of the RAN moderation in this context is to efficiently manage the available radio resources of multiple AIF variants in combinations with the requirements originating from multiple networks slices.

In line with earlier discussions, 5G is expected to operate in a heterogeneous environment, with access nodes, which are of different capability classes, e.g., massive MIMO [20] support, operating on different frequencies and possibly with AIFs optimized or configured for different services. Thus, it may be more efficient to steer some specific service through the access nodes that support the service best even though the access node is not the closest or has the best connection to the UE. In addition to the aforementioned energy-efficiency savings, traffic steering may also be efficient for load balancing reasons between the different access nodes. Further, traffic steering should also be possible between 5G and evolved LTE, i.e., it shall not only be limited to operate within 5G RAN (see Section III.D). Thus, there is a need to investigate the potential of traffic steering within METIS-II.

With regards to multiple AIF variants foreseen in 5G networks as depicted in Fig. 1, METIS-II will try to answer the question of how many AIF variants are likely to be supported, and how tightly these AIF variants are expected to be integrated. METIS-II will then further support different deployments and grades of integration of the radio variants through developing mechanisms related to resource management, by observing the frame/slot/sub-frame structure of potentially multiple AIF variants. METIS-II will further look at impact on device complexity and whether a device should be able to serve multiple AIFs simultaneously, as well as whether a device should be able to conduct a transmission to the infrastructure and to another device simultaneously and what the required enablers are. Additionally, METIS-II work on AIFs will involve indicating applicable bands, and it may be expected that this will provide indications as to how this spectrum is used / shared, answering some of the newly posed resource management questions.

C. *Context Management*

The term "context awareness" was first explicitly introduced in the research area of pervasive computing as stated in [22] and refers, in general, to the ability of computing systems to acquire and reason about the context information and adapt the corresponding applications accordingly. For the advanced synchronous mechanisms to operate efficiently in the demanding 5G environment, the necessary context management schemes need to be in place since these mechanisms can benefit from context awareness. In particular, context-awareness in a multi-layer 5G RAN is of key importance so as to minimize the complexity and signaling required for fast resource management functions (e.g., interference management and cross-carrier scheduling) by predicting the user's behavior and mobility patterns.

Furthermore, international telecommunication union-radio communication sector (ITU-R) working party 5D (WP 5D), [23] 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 as device level (e.g., battery state and processing load), user (e.g., quality of experience preferences, activities, location, and mobility status), environment (e.g., devices in neighborhood, topology, background activities, and weather) and network (e.g., load, throughputs, reliability, supported radio technologies, interference and spectrum availability). Whereas 3GPP Release 13 [24] already provides context data as information elements, for instance, UE power preference indicator (PPI) enabling the BSs to configure properly discontinuous reception (DRX) values and reference signal received power (RSRP)/ reference signal received quality (RSRQ) measurements of serving and neighboring cells, there are still many challenges in particular in the exploitation of user data for radio resource allocation in heterogeneous 5G networks deploying dense and widespread small cells.

Context data will be gathered by UE and network BS and access points (AP), sensing locally data to be sent to specific databases in the network and to be exploited by extended and new resource management algorithms. The amount of data to be gathered and the complexity of resource management algorithms need to be traded very carefully between the network performance enhancements they will make available and the load they will on both the BS/AP and the UE in terms of data gathering, signaling, processing and storage.

Therefore, METIS-II will look at means to support effectively and efficiently a fast resource management, for example, for small cell network deployments. It will elaborate on mechanisms how to derive UE data for context-aware resource and interference managements in dense multi-layer networks natively incorporating self-backhauling and D2D communications.

Context management is seen as an important input for the RAN moderation, as well. Especially the selection of a suitable AIF for different data flows can be improved by taking into account context information. Specifying context management information to be exchanged is predicated on deciding on the type of resources to be abstracted. Additionally, identifying all the required flows of information exchange (between nodes, layers etc.) will prove crucial for successful context management.

D. *Integration with Evolved Legacy Networks*

As mentioned in Section II, evolutions of legacy network AIFs should be an integrated part of the 5G RAN, allowing a fast link switching and/or efficient multi-link handling within the 5G AIF family. In addition, also the interworking of 5G AIFs with former generations of legacy air interface technologies should be investigated.

In parallel with the 5G research activities, 3GPP is continuously adding new features to LTE-Advanced, and it is likely that at the time 5G reaches the market, evolved LTE would be capable of addressing various future requirements envisioned today. In addition, LTE is also expected to be heavily deployed and, the fact that it operates in frequency bands with better propagation properties, can make the integration of the LTE evolution and at least the new 5G AIF variants operating in higher frequency bands appealing. A possible solution relying on common control- and user-plane protocols (common radio resource control, RRC, / packet data convergence protocol, PDCP) at the RAN level has been proposed in [25]. A common RRC / PDCP can make it possible to support seamless user-plane switching or even dual connectivity between LTE and 5G AIFs or frequency/cell layers instead of relying on slower inter-RAT handovers. This topic will also be investigated in METIS-II.

Figure 3 shows the logical architecture proposed in [25] for the RAN which is aimed to enable agile multi-RAT resource management features (synchronous packet transfer, control plane diversity / switching, etc.) compared to the current interworking solutions that rely on hard handovers via core network signaling. Further evaluations for this logical architecture are planned to be provided in METIS-II, such as, a) the potential usage of common 5G core network functions and b) the usage of an access-agnostic core network/RAN interface (e.g., evolution of S1-C/S1-U in the case of the tight integration of the new 5G AIFs and LTE).

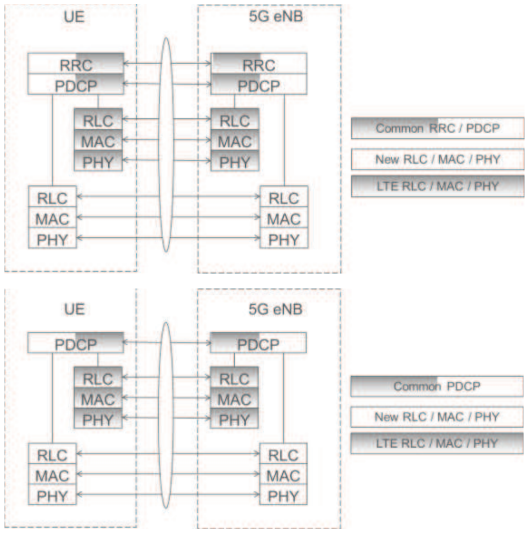

Fig. 3 One possible solution for control-plane (above) and user-plane (below) protocol stacks that will be investigated in METIS-II.

In 5G RAN, the co-existence of multiple AIF variants and legacy networks raises some challenges regarding the efficient utilization of resources and the imposed complexity of both synchronous and asynchronous control functions. Therefore, a resource abstraction framework as illustrated in Fig. 1, which will be investigated when defining the interface between the synchronous and asynchronous control functions, will be applied to different AIF variants (other alternatives will also be evaluated in the final design). This resource abstraction framework will be used for the integration of the synchronous control functions among the 5G AIF variants and with the corresponding legacy ones, and also to investigate how some of today's asynchronous functions can be executed more efficiently (e.g., faster) in certain 5G deployments.

IV. Conclusion

The METIS project has been a leap forward for the establishment of global consensus for 5G. 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. In this paper, we have touched upon our first vision of agile resource management framework which will be developed during the project. Key aspects of this framework can be stated as the easy integration of 5G AIF variants and their optimized integration with evolved legacy networks efficient synchronous control functions, and assigning the services and applications to the most suitable resources considering the extended notion of a network resource. Enhanced interference management, dynamic traffic steering, and RAN moderation, are all seen as our main design goals. Efficient context management framework is, as well, seen essential to meet these goals.

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