Design framework and suitability assessment proposal for 5G air interface candidates

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***Abstract*—This paper proposes a unified way of describing 5G air interface (AI) design proposals using a 5G service/frequency map based on work carried out as part of 5G-PPP/H2020 project "METIS-II". It then crucially proposes a design framework and suitability assessment process for 5G AI candidates. The proposed assessment methodology focuses on "harmonization Key Performance Indicators, or KPIs" and how to measure them (qualitatively / quantitatively). The paper proposes that evaluation of 5G AI candidates should, in addition to performance, include the "extent of harmonization", which is defined in this paper. The case is argued that these harmonization KPIs are essential when assessing new 5G AI technologies. Additionally, an initial overview of different User Plane aggregation approaches is provided. We then discuss the types of Application Program Interfaces (APIs) which may need to be offered to higher layers, as well as a broad set of 5G Control Plane features and how AI considerations could take these into account.**

Keywords—5G air interface, User Plane design, RAN architecture, multi-connectivity, 3GPP, METIS-II, 5G-PPP

I. INTRODUCTION

5G will offer support for multiple heterogeneous services, three main types of which are extreme Mobile Broadband (xMBB), ultra-reliable Machine Type Communication (uMTC), and massive Machine Type Communication (mMTC), with their evolved requirements and more ambitious Key Performance Indicators (KPIs) than 4G is able to meet today. The KPIs which will be used for benchmarking novel solutions for the 5G system have been thoroughly documented elsewhere [1].

The 3rd Generation Partnership Project (3GPP) has achieved remarkable data rates through the Long Term Evolution (LTE) and beyond set of standards, making LTE/ LTE-Advanced (LTE-A) and its evolution well suited for MBB, and well placed to meet many of the xMBB requirements. When it comes to other 5G services, there is a large amount of ongoing work in 3GPP to standardize, for example, the support for Vehicle-to-Anything (V2X) and MTC solutions for traffic comprising short data packets and transmitted in quick bursts, such as the Study Item on Narrow-Band Internet-of-Things (NB-IoT) [2].

Despite these achievements and ongoing work to advance them, the METIS-II project [3] envisions that a new radio is needed to fulfil all the performance requirements of the envisioned new use cases including some extreme low latency use cases, ultra-reliable transmission and xMBB requiring additional capacity that is only available in very high frequencies, as well as mMTC with extremely densely distributed sensors and very long battery life requirements. Designing an adaptable and flexible 5G Air Interface (AI), which will tackle these use cases while offering native multi-service support, is one of the key challenges in designing a 5G Radio Access Network (RAN), with far-reaching impact on overall system design. This paper will highlight the challenges of designing an AI to operate in a wide range of spectrum bands and cell sizes, capable of addressing the diverse services with often diverging requirements, and propose a design and suitability assessment framework for 5G AI candidates.

II. 5G AIR INTERFACE: KEY REQUIREMENTS AND DESIGN CHALLENGES

A key question related to the 5G system is how the different AI candidate technologies, including LTE-A evolution, can be integrated into one overall 5G AI, such that this design supports the wide landscape of bands, cell types etc., and such that both the complexity of the standard and that of the implementation are minimized, while the performance of individual technologies is not sacrificed. An adaptable and flexible 5G AI design is therefore required to address these issues while efficiently multiplexing multiple services. An illustration of the required configurability is given in Fig. 1, where it is shown how sub-carrier spacing and Transmission Time Interval (TTI) length can be varied to suit different data services, spectrum bands, network deployment scenarios and user mobility.

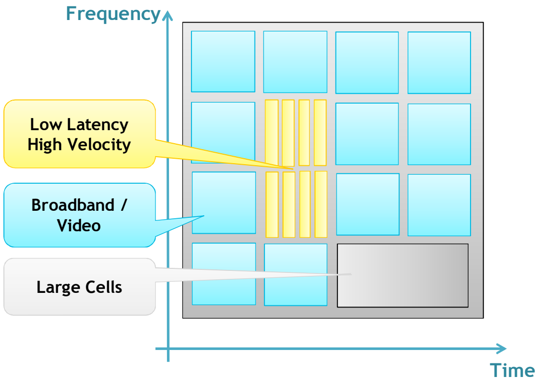

Fig. 1. Example of enhanced AI configurability for multi-service support.

METIS-II envisions that the overall 5G AI should ideally be characterized by a large extent of protocol harmonization across the technologies used for different bands, services and cell types. A harmonized physical layer (or PHY), as an example, could mean the choice of the same waveform (WF) family or reference frame structure for different bands, such that different PHY variants for different bands and services can be derived from the same framework. This type of harmonization can be achieved simply through parameterization (e.g., through adjusting the PHY numerology) or through (de-)activation, addition or removal of certain functionalities, such as an additional Discrete Fourier Transform (DFT) in the processing chain for some PHY variant. Another example of a harmonized PHY involves harmonization of technologies that are potentially based on different WF families (e.g., Orthogonal Frequency Division Multiplexing (OFDM) and Filter Bank Multi-Carrier (FBMC) based solutions), by enabling a physical or logical implementation that supports easy switching between different variants, and even their multiplexing in time, frequency and/or space. An alternative approach to harmonization when different WF families are used at the PHY layer, or a single WF family with very different frame numerologies employed for different services/use-cases, is Medium Access Control (MAC) layer (or higher) harmonization towards a single specification and is elaborated in more detail later on in this paper.

Note that, while a large extent of lower-layer harmonization among novel 5G PHY technologies may already be considered in their design phase, the lower-layer harmonization of novel protocols with evolved legacy technology (LTE and beyond) may be challenging or not even desirable; here, the benefits of harmonization have to be weighed against the potential legacy constraints imposed towards the novel 5G AI technology.

III. BRIEF OVERVIEW OF ONGOING STANDARDIZATION AND REGULATORY WORK AND GAP ANALYSIS

The Vision of the International Telecommunication Union (ITU) for International Mobile Telecommunication system 2020 (IMT-2020), was finalized in September 2015 [4]. In parallel with the Vision, a report was produced on IMT focusing on the bands above 6 GHz [5], giving a positive assessment of the underlying technical feasibility. And crucially, World Radiocommunication Conference (WRC'15) agreed on the input to the agenda for WRC'19, where it is expected that the main agreements on above-6GHz bands for cellular use will be reached.

3GPP Radio Access Network (3GPP RAN) held a 5G Workshop in September 2015. This Workshop was followed by the opening of a RAN1 Study Item on channel model for frequency spectrum above 6 GHz [6], as well as a RAN Study Item on Scenarios and Requirements for Next Generation Access Technologies [7]. This work is likely to extend over Rel-14 and Rel-15 and will run in parallel with the ITU work, summarized above. Additionally, a new RAN1 Study Item has recently been opened, with a view to developing a new Radio Access Technology (RAT) [8], so as to meet a broad range of use cases including xMBB, mMTC and uMTC and consider frequency ranges up to 100 GHz.

The 3GPP activities detailed in the previous paragraph are quite comprehensive and well-aligned with ITU timelines. However, the initial 3GPP studies are understandably limited to a subset of use cases and they focus (in Phase I) on OFDM-based WFs. Additionally, they are constrained by the requirement of tight interworking between the new RAT and LTE from the outset, whereas there exists consensus in METIS-II that the newly designed 5G AI should not be constrained to be backwards compatible with LTE-A[1]. METIS-II also additionally envisions that future proofness needs to be guaranteed [9]. Therefore, it should be clear that the 5G AI framework reported in this paper takes into account and expands the current considerations in 3GPP; while current 3GPP study and work items focus on specific aspects such as numerology details, in this paper we already explore a comprehensive integrated system. Additionally, assessment methodologies put forward in this paper are of broader scope than those developed within standardization activities, such as the ones in 3GPP. In what follows, the views of METIS-II on the 5G AI design principles are explained in detail.

IV. METIS-II AI DESIGN PRINCIPLES

A. *High-level design principles*

In this section we outline key METIS-II design principles, whose goal is to produce 5G AI proposals suitable for providing the required flexibility, in addition to achieving 5G KPIs which LTE and its evolution cannot fulfil in their entirety.

1. Flexibility by design: 5G AI needs to be adaptable and flexible in order to provide the required flexibility for multi-service support and non-traditional applications. A single but sufficiently widely harmonized AI would allow this flexibility. More specifically, the extent of harmonization is an important METIS-II 5G AI design KPI to achieve this flexibility by design, and will be elaborated upon in great detail later in Section IV-B.

2. 5G AI should be forward-compatible: This is needed to ensure future-proofness for upcoming variants of existing 5G services as well as potential new services not necessarily in the xMBB, uMTC or mMTC categories. Such a future-proof design needs to allow the introduction of new physical channels.

3. 5G AI should offer easy interworking with evolution of LTE: It is assumed in METIS-II that the 5G RAN should allow to integrate LTE-A evolution and novel 5G AI. The exact mechanics of this interworking are under study in METIS-II.

4. Design of 5G AI should be lean, minimizing signaling overhead and unnecessary transmissions. As one example of a system design under study, one could strive to avoid transmitting reference signals over the entire bandwidth, but instead use self-contained transmissions.

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[1] Nevertheless, some benefits exist in harmonizing at least some 5G AI aspects with the LTE design and this is discussed in more detail in the remainder of this paper.

5. 5G AI design should take into account the latest information on bands available (or to be made available shortly) to mobile: 5G systems will operate across a wide range of mm-wave and cm-wave frequencies. The 5G AI design should, therefore, consider a beam-centric approach, i.e., Control Plane (CP) and User Plane (UP) signaling should be designed having in mind that these will often be transmitted in beams.

6. 5G AI design should take into account terminal complexity. The extent of harmonization again plays an important role here, since the implementation of one widely harmonized AI is expected to decrease terminal complexity compared to the implementation of its AI components in a non-harmonized way.

7. 5G AI design should enable Application Program Interfaces (APIs) to higher layers, so as to facilitate the implementation of network slicing. Beyond harmonization, METIS-II investigates to which extent UP instances related to different bands can be logically aggregated on certain layers, and beyond which layer there would be a single CP instance. Different AI designs may offer different support of CP features, which needs to be considered. This will be further discussed in Section VI.

B. *Spotlight on harmonization*

Different proposals for the overall 5G AI design are being developed within METIS-II [10], but also within other 5G Infrastructure Public Private Partnership (5G-PPP) projects, standardization bodies, and elsewhere. These different proposals contain different levels of harmonization. Some alternatives rely on the harmonization of the lower layers, while other solutions rely on the harmonization of the higher layer protocols (with a greater differentiation at lower layers). Each METIS-II proposal currently under study is a single framework comprised of multiple AI components selected to jointly fulfill the performance of the different main service types and frequency bands as depicted in Fig. 2. Each of these harmonization alternatives could have several (potentially different) benefits. In general, benefits of harmonization include better utilization of available resources due to the flexibility even in short time scales, reduced complexity in the access nodes and the end devices, lower delay in case of switching between AI variants, less standardization and implementation effort and simpler upgrading of an existing system by implementing additional AI variants. In order to evaluate the degree of these benefits contained in different proposals, harmonization KPIs have been defined so that not only performance, but also other, equally important aspects (e.g., cost and complexity as well as switching delay) are taken into account when assessing the relative suitability of different proposals as 5G AI candidates. These harmonization KPIs are described next.

1) Ability to dynamically utilize radio resources

This KPI assesses in which time scale the proposed AI can utilize the frequency bands in a given location. The highest level is achieved when multiple services, possibly relying on the same numerology (e.g., frame structure) can be scheduled in the fastest possible time scale (i.e., on a TTI-basis), in order to capture the dynamics of the traffic demands on these services and maximize the resource utilization. The lowest level is when a dedicated portion of the spectrum must be allocated in a large time scale (higher than minutes / hours) so that no other service can utilize that due to design reasons. In the case of multiple numerologies, one should assess the ability to schedule multiple shorter Transmission Time Intervals (TTIs) within longer TTI periods.

2) Support of UP aggregation

This KPI assesses the degree of ability to aggregate multiple AI components on different layers of the protocol stack to support UP aggregation. Aggregation on a certain protocol stack layer means that on and above that layer there is only one single logical protocol stack instance, and hence the higher layers are agnostic to the existence of multiple protocol stack instances at the lower layers.

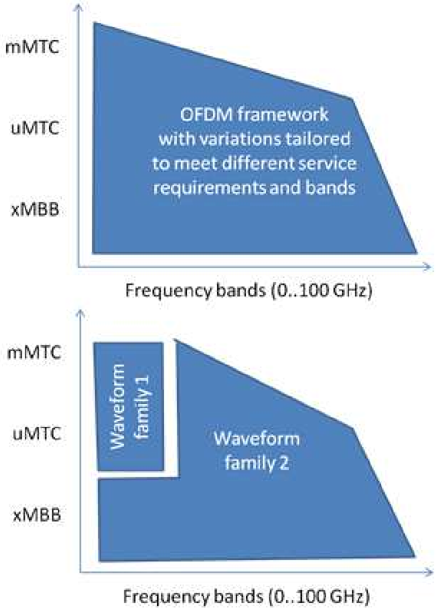

Fig. 2. Examples of potential overall 5G AI landscapes.

3) Ability to reuse software (SW) and hardware (HW) components among components of new AI

This KPI assesses the ability to reuse SW and HW components by the different AI components / instantiations, for both the UE and the network equipment.

For networks with a heterogeneous set of AI components supported by the UEs and the network there will be variations in the number of devices using a particular component. This is caused by fluctuations in the number of users in the network, as well as a requirement to use AI components that are simultaneously supported by the network and the UE. Reusing components is good because it avoids implementation of multiple radio chains where only one is used at a time.

4) Standardization effort and product development of AI proposals (time-to-market)

This KPI assesses the amount of work needed to standardize and develop the different AI proposals. This effort translates into additional standardisation time and thus increase the time-to-market for a new feature, a new scenario or a new service. The amount of effort can be measured approximated by the number of features / protocol layers that can be reused by the multiple AIVs.

5) Ability to integrate new AI proposals with LTE-A

This KPI assesses the ability a proposal has to integrate with LTE-A, using the KPIs explained above. There is a METIS-II consensus that the new 5G AI should not be constrained to be backwards compatible with LTE-A. However, some benefits exist in harmonizing at least some 5G AI aspects with the LTE design, such as the possibility to reuse HW and SW components and perform HW load balancing (see previous subsection), as well as a potential reduction in the standardization effort. Within METIS-II there is a consensus that LTE and 5G radio would likely be integrated on PDCP (Packet Data Convergence Protocol) / RRC (Radio Resource Control) level.

6) Forward compatibility

This KPI assesses the ability of efficiently introducing new features and services (as defined in Section IV-A) in the future without the need for re-designing the AI. Beyond harmonization, METIS-II will also investigate to which extent UP instances related to different bands can be logically aggregated and on which layer(s), and beyond which layer there would be a single CP instance. Different AI design proposals may offer different support of CP features, which needs to be considered.

V. IMPACT ON UP DESIGN AND OVERALL RAN ARCHITECTURE

As explained in Section II, one approach to harmonization is MAC layer or higher (e.g. PDCP) layer harmonization towards a single specification at that layer and above. For standalone NR, MAC layer aggregation has the potential to enable tighter integration features than PDCP aggregation like cross-carrier scheduling, but may be challenging in the context of e.g. PHY layers with very different frame numerology. Also, UP aggregation on MAC or Radio Link Control (RLC) layer would typically be better suited in co-located deployments and/or deployments with good backhaul quality. PDCP-level aggregation can enable several features similar to MAC-level aggregation (not necessarily with the same gains) except cross-carrier scheduling, with the benefits of being likely more suitable for distributed deployments with non-ideal backhaul and not requiring the harmonization of the AI lower layers.

We will use here the case of MAC-layer harmonization as an example, to show the impact of a harmonized design on physical implementation and overall UP design. Assuming the harmonized design aims to cater for both uMTC and xMBB requirements, which may differ e.g. in the way Hybrid Automatic Repeat Request (HARQ) is applied, it could still be supported by a single MAC design, captured in a single set of standards documents and supporting different parameter settings. It should further be noted that even in this case where a single MAC design can be used for two AI components (targeting e.g., two different types of services as in the example above), for implementation purposes and complexity analysis we may need to distinguish between the same MAC functionality, and the same MAC instance. Different AI components may use the same multiple access scheme (i.e., use the same MAC functionality) as illustrated by Fig. 3, but they may support physically separate traffic flows, which can in turn be scheduled separately, but possibly using the same MAC mechanisms. Hence we may need to distinguish between aggregation on a logical (functionality) level (where separate harmonized MAC instances run independently) and on the physical/implementation level (where there is only one aggregated MAC instance serving more than one PHY variants jointly).

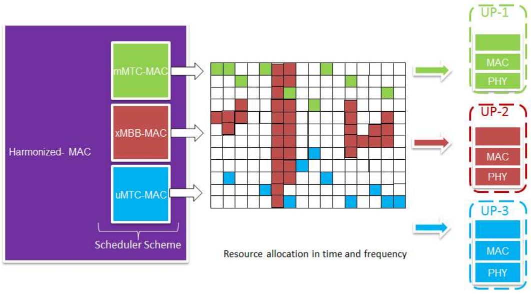

Fig. 3. Harmonized MAC: each service-specific MAC behavior is a subset of wider, harmonized MAC scheme.

The identified difference in terms of implementation between a single, integrated MAC instance, and two “separate” harmonized MAC instances[2] will now be further elaborated. Unlike in the case of the PHY layer, where many functions are implemented in HW and this question is easier to answer, for the case of MAC (and above), the physical, tangible interpretation of two separate protocol instances is less straightforward to define. Some options include:

- Two different SW/HW modules;
- A single SW/HW module, but serving different traffic flows independently;
- A single SW/HW module handling certain PHY functionalities differently (in a way unable to be captured as part of a single set of specifications) – say, for different frequency bands and/or different services;
- A single SW/HW module with two separate logical instances.

From previous sections, it should be clear that what is ultimately crucial to examine is how various extents of harmonization translate into the mechanics of Service Data Units / Protocol Data Units (SDUs/PDUs) transport, headers addition and overhead, SW/HW implementation (such as examples given above), and so on. These implementation details will enable us to agree on a suitable level of aggregation. Once this suitable level of aggregation is reached, the following questions on the impact on higher layers remain:

- We need to understand how the specific AI design can accommodate multi-service support; in other words, what sort of APIs need to be offered to higher layers.

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[2] By separate MAC we mean here either different MACs or two copies of the same MAC.

    - Examples include: the extent of resource granularity (variable TTI size configuration, continuous and non-continuous allocation in the frequency domain, switching between uplink (UL) and downlink (DL) at a certain prescribed granularity), suitability for interference mitigation (including cross-link interference considerations) as well as minimizing energy consumption.

- Continuing in the same vein, will aggregation mean that above the aggregation layer the functionalities are agnostic to which AI component the data flow came from, or is it necessary to keep this information as part of the APIs offered to higher layers?

- Implementation of Radio Resource Management (RRM) schemes will very likely be a super-set of algorithms required for individual AI components / technologies; it will be an aggregated set of L2/L3 functionalities. Two key issues need to be addressed:
    - Minimizing this set of algorithms while maintaining performance
    - Measurement signalling for RRM support

VI. HANDLING CP REQUIREMENTS

Under certain link conditions / deployment scenarios / traffic assumptions, certain of the AI proposals may allow for better support of certain CP features. In this section, we list potential requirements posed by CP aspects on the AI design, as additional criteria that can be used in the context of the 5G AI assessment. Numerous other projects and research and standardization activities have evaluated different WFs from the perspective of KPIs such as spectral efficiency, robustness towards imperfect synchronization in time and frequency and others. In the context of the design of an overall RAN, it is now important to also check whether or not the considered WF and PHY constructs are suitable for the various CP (and higher layer in general) aspects we are considering for 5G.

At this stage, it is impossible to produce a comprehensive list of stringent CP requirements, since no single 5G design is emerging as the dominant one. Therefore, at this stage we propose a ‘soft indication’ is made of whether an AI proposal supports a certain of the below CP features (under what conditions, to what extent, based on what assumptions, at what cost, and so on). A list of possible CP features that a 5G system design may need to support currently include:

- Self-contained transmissions;
- Synchronization signals with orthogonal properties possibly encoding information such as beam / cell ID;
- Multicast Broadcast Single Frequency Network (MBSFN) transmission of CP information e.g., system information blocks or equivalent;
- Beam-based measurements for mobility and initial access, especially important for high frequencies;
- Flexible standalone operation in narrowband channels;
- Ultra-lean schemes for mobility e.g., signals for measurements confined in time and frequency;
- Fast switching between low and high frequencies;
- A HARQ round trip time in the order of 1ms.

VII. CONCLUSIONS AND FUTURE WORK

Numerous AI proposals are being introduced in the 5G context; we have detailed here the key 5G AI design principles as recently proposed by METIS-II, while expounding upon the AI evaluation criteria. Key focus of the proposed evaluation framework is on the extent of harmonization across underpinning components in overall AI considerations, which was defined in this paper as a combination of features such as utilization of radio resources, implementation complexity, standardization effort, forward compatibility, and interaction with legacy systems. Additional criteria include UP-related design principles, and requirements posed from CP considerations. It is expected that the elaborated evaluation criteria, resulting from wide consensus reached within METIS-II, and aligned with 3GPP whilst offering a long-term, integrated system view, will impact researchers and standards bodies in the technical and economic trade-offs they take into account when assessing new AI technologies.

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