Air Interface Challenges and Solutions for future 6G Networks

Jean-Baptiste Doré, Emilio Calvanese Strinati, Benoit Miscopein, Dimitri Kténas, Sergio Barbarossa

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CEA-Leti Minatec, 17 rue des Martyrs, 38054 Grenoble Cedex 9, France
{emilio.calvanese-strinati}{dimitri.ktenas}@cea.fr

***Abstract*—5G networks are expected to be deployed in 2020 and are considered as a global game changer from a technological, economic, societal and environmental perspective with very aggressive performance levels in terms of latency, energy efficiency, wireless broadband capacity, elasticity, etc. Many experts say that the next big step for cellular networks is not 5G but its cloudification that will support the explosion of radically new services and applications ranging from immersive five-sense media to ambient sensing intelligence and a pervasive introduction of artificial intelligence. In our vision, the next generation of wireless systems will transform the 5G service-oriented networks into user and machine ad-hoc dynamic (re)configuration of network slices. This will be enabled by software-defined end-to-end solutions from the core to the radio access network, including the air interface as well as the RF and antenna systems which are envisioned as one of the keys to meet the user/service requirements. Users and machines will be indeed able to dynamically (re)configure network slices thanks to intelligent personal edges. This paper presents our perspective of the 6G air interface and raise the concept of software defined artificial intelligence and air interface (SD-AI^2) as a framework of 6G air interface. This concept is an extension of the one initially proposed for 5G [1]. Instead of a global optimized air interface, we envisage to bring agility and flexibility to air interface with the help of artificial intelligence and learning techniques to improve efficiency. The paper describes the proposed context and highlights the technical challenges at different levels.**

Keywords*—*6G, beyond 5G, Mobile Edge Cloud, Artificial Intelligence, Air interface.

I. Introduction

In 2018, intensive successful testing, proof-of-concepts and trials [2] have supported the launch in 2019 of the fifth generation (5G) services. Today, even though 5G is not in place yet, sixth generation (6G) research has already kicked-off all around the world. Academic, industrial and research communities are working on the identification of relevant key enabling technologies that might define the so called 'beyond 5G' (B5G) [3] or 6G. As an example, the authors of [4] discuss on *what should there be in 6G that is not in 5G or in its long term evolution*. The paper also describes potentials of new communication infrastructures incorporating new distributed architectures, ubiquitous super 3D connectivity, pervasive introduction of distributed artificial intelligence mechanisms. Semantic and machine learning tools at the edge of the network, new human-human and human-machine interaction mechanisms including 5-sense media and interactive communications are also some envisaged concepts for the next generation.

Among several collaborative research activities that are focusing on 6G, on can cite the *Comsenter* project funded by DARPA. This project aims to explore the potential of new spectrum frontiers, in the range of sub-TeraHertz (sub-THz). The objective is to design base stations working in the sub-THz spectrum able to transmit up to 10 gigabits per second (Gbps) per beam with a target of 10 terabits per second (Tbps). The definition of the air interface with adaptive massive spatial multiplexing optimized of sub-THz RF components constraints and combined with cm-precision localization, supplementing GPS, as well as the use of imaging techniques to locate communications partners are the new challenges to address. The *6Genesys* flaghship initiative has also kicked-off research on 6G focusing on several challenging research areas including reliable near-instant unlimited wireless connectivity, distributed computing and intelligence, as well as materials and antennas to be utilized in future circuits and devices. China has also started working on future 6G networks foreseen for commercial services by 2030. Moreover, in July 2018 a new ITU-T Focus Group Technologies for Network 2030 (FG NET-2030) was established by ITU-T Study Group 13. Its goal is to investigate the requirements, use cases, capabilities, and future architecture of the networks for the year 2030 and beyond. In addition to the above mentioned initiatives, other countries and regions are also carrying out 6G conceptual design and R&D work.

From an air-interface perspective, the 3GPP fifth Generation New Radio (5G-NR) standard proposes to adapt the air interface configuration to the provided service and carrier frequency. By doing so, the requirements for each service can be satisfied. However the air interface is usually statically configured after field trials run by operators before commercial deployments. Moreover, it has been demonstrated that the coexistence of different air interface configurations within the same spectrum chunk can be ensured only with a huge compromise in terms of spectral efficiency [5]. On the other hand, the concept of network slicing is expected to play a critical role in 5G networks because of the very wide gamut of expected use cases and new services. Slicing is currently foreseen as a service-level. Extending this concept down to the physical layer remains an open question. To address these challenges, we propose the concept of software defined artificial intelligence and air interface (SD-AI^2) as the framework of the beyond 5G air interface. This concept, mainly inspired by SD-AI [1], provides a scalable and configurable mechanism to customize the air interface design and to support user-centric services based on the potential of latest artificial intelligence (AI) breakthroughs.

Moreover, at millimeter and sub-THz bands, the communication links may become highly unpredictable and potentially inefficient because of blockage events. To cope with the intermittent nature of millimeter and sub-THz spectrum channels, evolved multi-link mechanisms [6] and software defined adaptive air interface will be needed to guarantee an almost deterministic delivery of delay-sensitive applications over such intermittent random channels.

II. AI-based Software-defined air interface

In 3GPP release 15, 5G-NR defines two frequency ranges and a set of waveform configurations. Changing the numerology allows the adaptation of symbol duration and the

SubCarrier Spacing (SCS) to the propagation conditions and the service to be provided. For instance, enlarging the SCS increases the robustness against Doppler shifts occurring in mobility scenarios and strong phase noise of millimeter wave frequencies. In parallel, reducing the symbol duration is beneficial to reduce latency. We can easily assume that the 5G-NR numerology system will be upgraded in the future to support new bandwidth such as sub-THz. One can envisage for the future 6G air interface to define mechanisms to dynamically adapt the numerology of one link to the environment (presence of LOS, Doppler Shift, delay spread of the channel). To this end, multiplexing the numerologies should be performed in an efficient way and with a high spectral efficiency.

The development of software-defined radio techniques offers opportunities for the implementation of smart, flexible and configurable air interface. The main evolution of the proposed concept with respect to SD-AI from [1], is the possibility to dynamically adapt the waveform, the link adaption strategies, channel and bandwidth based on the context of a user (geographical position, motion, services, etc.). Many challenges have to be addressed ; three of them are listed hereafter.

First, the design of an efficient waveform supporting the multiplexing of various waveform types with a limited self-interference generation needs to be considered. It has been demonstrated in [5] that the current 5G-NR waveform, based on OFDM, is not suitable for multiplexing different numerologies (i.e different SCS within the same band) as resources are lost by the required introduction of guard band. The use of filtered waveforms, as proposed in [7][8] could give an efficient way to limited the inter numerology interference. Therefore, one can envisaged to dynamically change the structure of the waveform (SCS, guard interval, pilot distribution) according to the channel conditions. Secondly, the use of the spatial filtering by configurable antenna radiation patterns is also an efficient manner to limit the mixed numerology interference by isolating numerologies in different radiation beams. At high frequency, antenna integration allows efficient multi-user beamforming schemes, but when it comes to sub 6-GHz bands, the design and integration of small and energy efficient antenna systems remains an open challenge. Current works are focusing on hybrid beamforming schemes, i.e mixed digital and analog [9]. Hybrid beamforming transceivers combine high dimensional analog phase shifters and power amplifiers with digital signal processing units. This hybrid beamforming design reduces the cost and power consumption but require complex optimization problem to solve. Second, With the growing interest of artificial intelligence (AI) technologies in image and signal processing, the introduction of AI technologies into wireless communication systems could introduce a new paradigm in the design of modern wireless system. Currently, many researches are focused on the use of neural networks for solving difficult problems, such resource allocation optimization in wireless communication systems. One can envisaged to go forward by implementation neural network to solve hybrid beamformer optimization problems, see [10] as an example. In the framework of our proposed SD-AI^2, it could be considered to collect and analyze channel state information (CSI) as well as localization context (including RSSI, GNNS signal etc.) with a learning network to classify and select the best set of parameters to exchange data, including channel, frequency and spatial resources to be used as well as numerology and modulation and coding scheme. Some preliminary works have been done in the identification and classification of propagation channel condition based on machine learning [11][12]. Third, the virtualization and cloudification of the complete RAN including air interface as well as antenna system will introduce new challenges at different levels. The need of high throughput low latency (possibly wireless) links for the backhauling system and the increase of computation load needed will be a challenge researchers and engineers will have to solve. Distributed computing and caching techniques would probability will play a key role in solving the unprecedented requirements in computation and transmission load.

III. Conclusions

6G research has already started around the world addressing innovative solutions to offer at the horizon of 2030 new services. In this paper we first presented the current vision in the research community on what should be in 6G that is not in 5G from an air interface perspective.

The next generation of wireless systems will transform the 5G service-oriented networks into user and machine ad-hoc dynamic (re)configuration of network slices. This will be enabled by software-defined end-to-end solutions from the core to the radio access network, including the air interface as well as the RF and antenna systems. This paper presents our perspective of the 6G air interface and raise the concept of software defined artificial intelligence and air interface as a framework of the next generation of air interface. We expect to tune the air interface according to each user requirements by taking into account, the expected quality of service, the localization, the propagation environment, the available bandwidth and carrier frequency and so on. It includes the use of new spectrum opportunities such as sub-THz and optical spectrum. We also envisage artificial intelligence (learning scheme), distributed computing and caching techniques to play a central role in 6G.

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