6G: the Wireless Communications Network for Collaborative and AI Applications

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Abstract—At the dawn of 5G, we take a leap forward and present an original vision of wireless communication beyond its horizon towards 6G: a paradigm-shifting perspective of wireless networks on the cusp of an AI revolution.

I. INTRODUCTION

In recent years, Academia and Industry alike converged to a new radio (NR) specification referred to as fifth generation (5G), whose standard was just released in June 2018 [1]. A freeze of the aforementioned standard will only happen, however, around the second quarter of 2019, with earliest deployments of 5G networks expected for late 2019. It goes without saying that such deployments will not fully implement all features envisioned by the 5G standard, but a mere subset of these. Subsequent releases and updates are expected to follow under what is being referred to (somewhat unimaginatively) as 5G long-term evolution (LTE).

The hype about 5G, not only in Academia and Industry, but also in the Media is well-justified by the promised gains in terms of rate, accessibility and reliability of wireless services, and respectively, the shift in the architecture model of 5G as opposed to its fourth generation (4G) predecessor and legacy systems. Concretely, the improvements of 5G over its 4G predecessor are mainly due to a paradigm shift in the design architecture of wireless systems, which under 5G is ground-up, aimed at solving real business requirements [2].

Amongst such design patterns of 5G is the replacement of the hierarchical layered network architecture of the past into a more flexible format, capable of functional virtualization and network aggregation. Another major deviation from old established ways was the resolution to move beyond the canonical sub-6 Ghz bands of preceding systems towards millimeter waves (mmWaves), leading to a tenfold increase of available bandwidth. From a connectivity density perspective, 5G (in its later versions) will break beyond carrier aggregation, moving decisively towards non-orthogonal concurrent access in both uplink and downlink [3]. These advances are finally coupled with great progress in radio frequency (RF) hardware, going beyond multiple-input multiple-output (MIMO) to add, for the first time in history, wireless full-duplex capabilities.

In the light of all the above, one could ask: “What else could we want? Why even bother with thinking of sixth generation (6G)?” The answer to these rhetorical questions is that, as usual, revolution never comes from within, but is rather imposed by radical changes in exterior conditions. And that radical change, which is now beaming straight towards the wireless communication world ready to cause major disruption, is the raise of artificial intelligence (AI).

II. AI: PARADIGM SHIFT FOR WIRELESS COMMUNICATIONS

One of the most important advances in the history of the man-kind is currently blossoming in the form of AI [4]. Computational intelligence bears the prospects of a trendsetting technology able to unlock solutions to previously difficult and large-scale problems outside of the current cloud-centric paradigm. Intelligent agents trained in the cloud using machine learning algorithms on Big Data will be deployed in the real world in the next decades. Such entities will be tasked to solve multiple optimization problems across a vast set of business verticals, empowering new business models and industries alike and leading to a technological revolution.

But in order to harness the true power of such agents, collaborative AI is the key. And by nature of the mobile society of the 21st century, it is clear that this collaboration can only be achieved via wireless communications.

The proliferation of sensors in modern day appliances, coupled with the aforementioned advances will lead to advanced context-awareness which can be collaboratively leveraged towards common goals. Consider for instance a fleet of autonomous vehicles (the moving base stations of the future) driving collaboratively through a crowded urban canopy, freed of traffic lights / signs. The collaboration of intelligent agents (in this case the autonomous vehicles) will be mostly locally-oriented (connectivity amongst vehicles nearing a given crossing takes precedence), but augmented with outer layers (the planned routes of each vehicle, the prospective proximity of emergency vehicles etc.) that need to be taken into account.

Under the requirements of dynamic applications, designed on the fly by AI nodes sharing a common goal – such as the one illustrated above – collaborative quilt networks will be generated bottom-up. Interactions will therefore be necessary in vast amounts, to solve large distributed problems where massive connectivity, large data volumes and ultra low-latency beyond those to be offered by 5G networks will be essential.

But, the intelligent agents can be deployed to base stations (BSs) as well, where AI technology can be leveraged not only for network optimization tasks, a direction which 5G network slicing and virtualization is aiming to solve, but also to provide business and application intelligence for users.

In light of the above arguments some prospective qualitative requirements of a future 6G standard are:

- functional/situational/positional network self-aggregation
- pervasive enhanced context-awareness
- network / nodes contextual self-reconfiguration
- opportunistic latency, rate and access setup
In summary, we envision that the emergence of AI will be the driver of 6G, which will enable the proliferation of distributed independent autonomous systems and associated common goal-driven massive fog-computing clusters.

III. THE ROLE OF PHY LAYER IN 6G

It is clear from the above list of 6G requirements that the policy-driven network slicing and virtualization at the heart of 5G will not be sufficiently adaptive to address the needs of the future. The AI-central context-aware adaptive device self-reconfiguration and network self-aggregation envisioned at the core of 6G will require thus vast research for its modular development and seamless integration into the canonically rigid communications ecosystem.

But one would be mistaken to think that 6G will focus on network aspects, and that the PHY layer in 6G will have a secondary role. In fact, the research community was at a similar cross-roads at the dawn of 4G, when it asked itself if “the PHY layer was dead” [5]. The concern then was that physical layer (PHY) research would slowly fade and limit to satisfying short-term and derivative needs of the Industry. Those concerns were short-lived, as proven by the powerful revival propelled by groundbreaking innovations such as non-orthogonal multiple access (NOMA), full-duplex (FD) radio and hybrid mmWave RF technologies.

Learning from this recent history, we believe that PHY research will not become extinct but will transform and solve future challenges along the road, as discussed in the prequel. Concretely, we believe that PHY will be separated in two components: the Low-PHY and the High-PHY.

The first will focus on solving signal processing problems close to hardware, including the handling of waveforms, beamforming & interference management, all taking into account the hardware impairments imposed by the compacting of massive MIMO antennas, full-duplex operation and mmWave RF, as well as the imperfections of channel state information (CSI), caused by all the dynamics of 6G architectures. This “Low-PHY” will also develop strongly towards enabling software-defined radios (SDRs), a dream many times attempted before, but which never really blossomed.

In turn, the “High-PHY” will move towards becoming the software oriented driver of the Low-PHY. Research on High-PHY will therefore focus on the interface with the AI core, developing the code-domain technologies required to control and interact with the Low-PHY.

To cite an example, take the last requirement (opportunism) cited at the end of Section II. Although 5G aims to deliver low-latency and high connectivity density, it will still employ the traditional model of grant-based access [1]. In contrast, a truly opportunistic system, requires the implementation of a grant-free access scheme, such as the one proposed in massively concurrent NOMA (MC-NOMA) [6], in which non-orthogonal massively concurrent access is enabled both at downlink and uplink thanks to the exploitation of properties of Frame Theory [7]. MC-NOMA can seamlessly multiplex $K$ active users onto $M < K$ available orthogonal resources, e.g. time slots, frequency tones, spatial streams, spreading the symbols of active users onto all available resources.

As an example, the MC-NOMA scheme transmission over a group of OFDM sub-carriers leads to the following received signal model corresponding to a $k$-th user

$$y_k = H_{k,DL} F \cdot s + n_k,$$

where the frame $F \in \mathbb{C}^{M \times K}$ forms an overcomplete virtual signature waveform dictionary that carefully spreads all the active users’ symbols $s \in \mathbb{C}^K$ upon the available pool of $M$ subtones transmitted over the downlink fading channel modeled by the diagonal matrix $H_{k,DL}$.

From the above, it is easy to foresee how MC-NOMA can be expanded also to include duty-cycles (periods of activity and inactivity), such that the method can be a basis to completely eliminate the need for network discovery procedures.

To be complete, an MC-NOMA scheme must include not only the optimum design of $F$, but also a practical multi-user detection (MUD) at the receiver. These problems are solved using randomized incoherent tight frames, coupled with efficient low-complexity stochastic generalized sphere decoders (GSDs) at the receiver, leading to optimum maximum likelihood (ML) detection [8], as illustrated in Fig. 1.

**Fig. 1.** BER performance over Rayleigh fading at 200% overloading.

**REFERENCES**

[1] ETSI EN, Technical Specification (TS) 123 502 V15.2.0: 5G: Procedures for the 5G System (5GPP TS 23.502 Version 15.2.0 Release 15), Std., June 2018.

[2] ETSI, “5th Generation (5G):” 2018, retrieved Jan. 2019. [Online]. Available: https://www.etsi.org/technologies-clusters/technologies/5g

[3] Z. Wu, K. Lu, C. Jiang, and X. Shao, “Comprehensive Study and Comparison on 5G NOMA Schemes,” IEEE Access, vol. 6, pp. 18511–18519, Mar. 2018.

[4] S. J. Russell and P. Norvig, Artificial Intelligence: A Modern Approach, 3rd ed. Upper Saddle River, NJ: Pearson Education Limited, 2016.

[5] M. Dohler, R. W. Heath, A. Lozano, C. B. Papadias, and R. A. Valenzuela, “Is the PHY Layer Dead?” IEEE Communications Magazine, vol. 49, no. 4, pp. 159–165, Apr. 2011.

[6] R.-A. Stoica and G. T. F. de Abreu, “Massively Concurrent NOMA: A Frame-Theoretic Design for Non-Orthogonal Multiple Access,” in 2018 IEEE 52nd Annual Asilomar Conference on Signals, Systems, and Computers, Oct. 2018, pp. accepted, to appear.

[7] P. G. Casazza and G. Kutyniok, Finite Frames: Theory and Applications, 1st ed. Birkhäuser Basel, 2012.

[8] R.-A. Stoica, G. T. F. de Abreu, T. Haru, and K. Ishibashi, “Frame-theoretic Massively Concurrent NOMA for 5G and Beyond: Capacity, Transmitter and Receiver Design,” (in preparation), 2019.