IMT Atlantique
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PhD topic: Waveform innovation for 6G: addressing synchronization, efficiency and integration challenges with filtered multi-carrier modulations

Place: MEE department of IMT Atlantique (Brest campus), Lab-STICC laboratory
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A. Context and motivations of the research topic

The applications and services envisioned for the 6G wireless communication systems are foreseen to provide ubiquitous connectivity and seamless service delivery in all circumstances. The important expected number of devices and the coexistence of human-centric and machine-type applications will lead to a large diversity of communication scenarios with stringent requirements on the system design. These requirements do not only concern increasing data throughput and achieving extremely reliable connections, with an availability of 99.999% [1-2]. The latency also becomes a crucial constraint for emerging applications such as tactile Internet or factory automation with an aim of 0.01*ms* end-to-end latency [1-2]. Furthermore, efficiency in terms of resources utilization, such as energy and radio spectrum, is becoming more and more critical.

Addressing these challenges requires investigation on new techniques from the application layer to the physical layer. For the latter, the current Orthogonal Frequency-Division Multiplexing (OFDM) waveform used in 5G suffers from a list of drawbacks that question its ability to support all these demanding constraints. In fact, OFDM was an attractive solution in 4G/5G due to its high robustness against multipath channel thanks to its Cyclic Prefix (CP), its orthogonality in both the time and frequency plane, its straightforward implementation with a Fast Fourier Transform (FFT), and the simple per-subcarrier equalizer.

However, the high Out-Of-Band Power Leakage (OOBPL) of OFDM compromises the coexistence of multiple services in the same carrier as foreseen in 5G. In addition, it requires strict synchronization with the base-station in time and frequency for each user, which adds important signaling overhead. Consequently, the latency and the energy consumption are highly impacted. In fact, with the emergence of efficient resource allocation techniques for grant-free multiple-access, the support by the physical layer of relaxed synchronization becomes of paramount importance. The waveform plays the central role in this regard.

Filtered multi-carrier waveforms, such as FBMC/OQAM, provide viable alternatives to OFDM. They exhibit better spectrum shape, resilience to imperfect synchronization (e.g. in dense networks with D2D and machine type asynchronous communications) robustness to high mobility (e.g. in vehicular communications) and enable the coexistence of multiple diverse services.

During the last years, our research team has developed and patented several innovative contributions at the transmitter and receiver sides related to FBMC [3-11]. The conducted work has triggered several new ideas to address a few remaining challenges that we aim to investigate in this PhD topic.

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B. Research objectives and work plan

In the context described above, our research team has recently proposed a novel transmission technique, namely Modulation Code Overlapping (MCO), based on intentionally overlapping the subcarriers of adjacent users to improve spectral efficiency of multicarrier systems. MCO was originally designed for SISO transmissions. However, since spectral efficiency (SE) is a crucial element of cellular communication networks, added to the continuous growth in mobile data traffic in wireless networks, there is a regain of interest in further enhancing SE for massive MIMO (mMIMO) systems. In mMIMO, the users' channels are supposed to be asymptotically orthogonal if the number of antennas at the receiver side is much greater than the number of users. Following this constraint, one cannot increase unbounded the number of users in a subband for improving the SE indefinitely. Indeed, there is a compromise between system performance and SE, as increasing the number of users will lead to a degradation in system performance. To address this challenge, the MCO technique can be employed to potentially enhance the SE while maintaining optimal performance. The key idea is to overlap the subcarriers of adjacent subbands, with each subband accommodating different users. Essentially, the concept is to carefully manage the allocation of subcarriers and users across multiple subbands, leveraging the advantages of mMIMO while considering the limitations imposed by channel orthogonality and system performance. By exploring the potential of the MCO scheme in the context of mMIMO, we aim to strike a balance between achieving high SE and ensuring satisfactory overall system performance.

The second main objective of this thesis work concerns the investigation of algorithm simplification and complexity reduction techniques for the recently proposed contributions in our research team on waveform design at transmitter and receiver side. Efficient and optimized application-aware hardware/software architectures should be proposed and integrated into a demonstration platform as a proof-of-concept. For the demonstration platform, several options could be considered such as extending our available FPGA-based platform for wireless communications or adopting existing similar platforms from our academic and industrial partners.

C. Research group

Since the invention of turbo codes in IMT Atlantique by Prof. Claude Berrou (recipient of the Hamming Medal in 2003 and the Marconi Prize in 2005), the know-how of the MEE department has been extended and recognized in a wide range of cutting-edge communication techniques including diverse channel codes, modulation schemes, interleaving, MIMO systems, and generalized iterative processing targeting high-throughput, flexible-, energy- and cost-efficient air interface. A main strength corresponds to the real algorithm/architecture interaction approach enabled by the recognized available skills at our department in both related fields.

The research group, proposing this PhD offer, has established a complete development framework with all required expertise, tools, and platforms for (a) algorithm definition, simplification and optimization, (b) architecture exploration, (c) hardware implementation, and (d) on-board validation and demonstration. Available design experiences can be classified in two main classes: proposal of highly optimized architectures for a specific application and exploring new architectural models and design methodologies to meet the emerging flexibility challenge. In this context, the ultimate target is to unify flexibility-oriented and optimization-oriented approaches in the design of flexible terminals for next generation communications systems. Different application requirements and key-performance indicators (KPI) in terms of throughput, latency, cost, energy consumption, error rate performance, and flexibility degree are considered in our research implementation activities.

D. Expected skills of the candidate

The candidate must have a Master's degree or equivalent (engineer Bac+5) in telecommunications or electronics. Expected skills include:

- Solid skills in digital communications, in particular OFDM and channel coding.
- Mastery of simulation tools (MATLAB/Simulink) and programming (Python/C++).
- Practical experience with embedded systems, processor architectures and FPGAs.
- Ability to collaborate in a multidisciplinary environment.
- Communication and scientific writing skills in English.
- Ability to work in autonomy, develop innovative solutions and integrate them into practical applications.

E. Application

To apply, please send an email to Charbel Abdel Nour (charbel.abdelnour@imt-atlantique.fr) and Amer Baghdadi (amer.baghdadi@imt-atlantique.fr) with the following documents:

- CV
- Cover letter
- Academic transcript
- Other related documents, if available (e.g., letters of recommendation)

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