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SMI doctoral school (ED432)
Ph.D. thesis proposal
2023 call

Title: Pre-coding structures for energy efficient Cell-Free massive MIMO networks

Context:

Academic and industrial researchers have been working since few years on the next 6G networks. Indeed, in addition to improving throughput, reliability, latency, and network densification, 6G is seen as a technology that will improve interactions between the human world, the digital world and the physical world of objects and systems, while addressing larger environmental, societal, and economic challenges. These requirements will be broken down into several use cases, among which, one can cite the extended reality, the communications of autonomous cars, the deployment of e-health and the industry 4.0. To address these use cases, multiple key requirements must be mixed to ensure the massively growing traffic and serve the exploding numbers of devices while imposing strict constraints on energy efficiency.

In this context, new wireless technologies are intensively studied to address numerous challenges of 6G wireless communications, among them, the use of Cell-Free massive MIMO (CF-mMIMO) [1]. In CF-mMIMO, the cell boundaries disappear, and a virtual antenna array is built via many access points (APs). This results in a network architecture which uses smaller and lighter radio modules and only few antennas per AP. CF-mMIMO offers many advantages compared to traditional massive MIMO by enabling a good coverage probability, rapid deployment and reduced transmit power levels. A scalable version using a user-centric approach instead of the classical network centric approach has been proposed in [2]. This concept has its roots in the intersection between massive MIMO, Coordinated Multipoint Processing (CoMP) and ultra-dense networks. The main challenge is to achieve the benefits of CF operation with computational complexity and fronthaul requirements that are scalable to enable massively large networks [3][4].

While the concept of CF-mMIMO is promising, it is a recent research topic, and several issues need to be addressed considering realistic assumptions before rolling out it into practice. Among those issues, we can cite the channel estimation in Time Division Multiplex (TDD) and Frequency Division Multiplex (FDD) [5], the design of decentralized/local/scalable digital signal processing algorithms for multi-user (MU) precoding techniques [6][7], the study of the impact and mitigation of hardware imperfections [8]. The contribution of machine learning (ML) tools for the optimization of the CF-mMIMO physical layer to conventional optimization methods is another open question [9].

Objectives and proposed approaches:

This thesis aims to propose model and IA-based solutions for pre-coding and post-coding transmitted and received signal in CF-mMIMO networks in the sub-6GHz frequency bands, where the available spectral resources are scarce. More specifically, the main objective of this thesis is to propose pre-coding and post-coding schemes which will set the roadmap for the necessary transition to greener solutions and infrastructures. Indeed, the ICT sector's power consumption increasing exponentially through the different generations of radio mobile networks, a tenfold increase of the power consumption for the wireless access is expected over the next decade [10]. Thus, power consumption is among the critical key performance indicators (KPIs) to be optimized in CF-mMIMO networks. To this end, this thesis will provide some solutions to satisfy the expected 6G's requirements with ever-increasingly ubiquitous and reliable wireless connectivity while at the same time steadily addressing the crucial reduction of the ecological impact of cellular infrastructures.

To meet the above target, this thesis will focus on dedicated tools whose use is nowadays embraced by the wireless research community. In addition to the classically optimized model-based solutions, it has already been established that autonomous and intelligent communication systems have the potential to improve overall system performance, and AI tools have already led to remarkable and diverse performance improvements of mobile networks [11, 12]. Moreover, Machine learning (ML), and especially deep learning (DL), has proved to be capable to overcome problems related to the high complexity and latency of classical optimization methods. However, the most important factor influencing AI and ML methods is the use of representative training datasets. In case of learning for wireless networks, this suggests that training should use realistic propagation and hardware impairment (HWI) models. Further considering hardware, CF-mMIMO imposes stringent requirements on hardware as well as the need for low power, low-cost hardware which may be characterized by impairments. Based on this, one the approaches envisioned in this thesis is the proposal of key AI-based enabling techniques towards achieving power and spectral efficient massive access in scalable CF-mMIMO for beyond 5G sub-6GHz networks.

The contributions of this thesis are threefold:

1. **Channel estimation and reciprocity**: The first contribution of this thesis will be on the study of existing and the proposal of new channel estimation techniques in the context of scalable CF-mMIMO schemes. To this end, we will focus on the design of limited feedback schemes exploiting partial or full channel reciprocity in FDD/TDD modes.

2. **Imperfect channel estimation and hardware impairments:** The second contribution of this thesis is related to the design of coordinated or locally computed single user (SU) and multi-user (MU) MIMO precoding solutions for CF-mMIMO networks. Efficient SU/MU precoding and detection schemes working with partial channel state information (CSI) obtained from the UE feedbacks will also be proposed. In this context, we will evaluate the impact of possible hardware impairments on the previously proposed solutions. Among these impairments, we will consider those related to power amplifier non-linearities and low-resolution analog to digital converter quantization noise.

3. **Improved energy efficiency and ML:** The third contribution of this thesis is to move toward more energy efficient solutions by enhancing the design of the previously precoding/post-coding schemes by using new efficient cooperative or federated machine learning approaches.

Timeline:

In the following, we summarize the main working steps of this thesis:

1. First step [1 to 3 months]. This step will be dedicated to a bibliographic study phase. During this stage the candidate will study the principles of CF-mMIMO systems and make a synthesis of the main contributions published in the literature and related to the concepts of precoding techniques. During this stage, the candidate must also, if he/she doesn't have a sufficient level in MATLAB and Python programming, follow a learning phase to master these two software tools which will be very important for the rest of the thesis.

2. Second step [~30 months]. This is the useful part of the work which will be dedicated to analytical studies and/or simulations. This step will be punctuated by regular meetings with the supervising team, to develop ideas and discuss contributions that could be published through conference or journal papers.

3. Third step [3 to 6 months]. This stage will be dedicated to the writing of the dissertation and the preparation of the defense.

Ph.D. thesis supervisors:

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Bibliography:

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