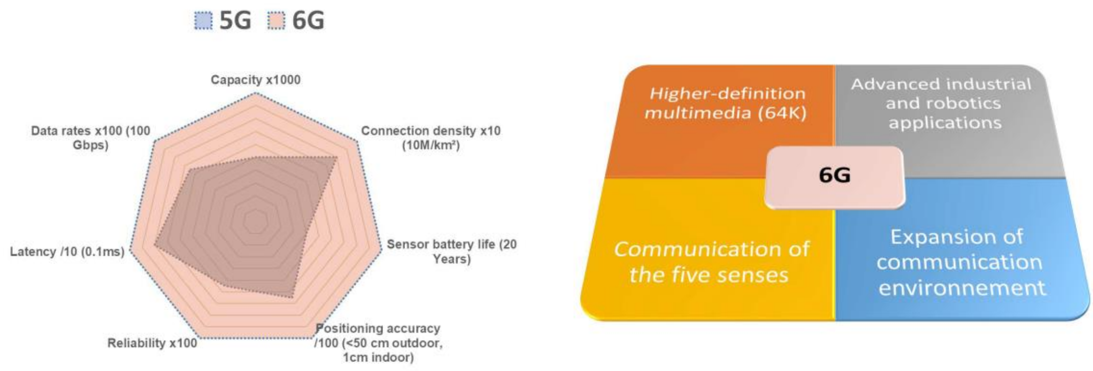
SMI doctoral school (ED432)
Ph.D. thesis proposal
2022 call

# Title: Deep learning techniques for RIS-aided 6G communications in mmWaves and sub-THz bands

## Introduction:

Now that many 3GPP releases on 5G have been published and that the deployment of this technology is progressing almost everywhere in the world, most of the researchers and operators are focused on defining issues, specifications, and scenarios for 6G in the 2030 era. Fig. 1, summarizes some requirements and applications expected from this technology [1, 2, 3, 4].




(a) requirements (b) expected applications

Fig. 1: 6G requirements and expected applications.

To meet these new requirements, new approaches and technologies have been proposed in the literature or are being studied and developed by manufacturers or as part of collaborative research programs. Among these solutions, we can cite:
- The extension of the transmission to millimeter-Waves (mmWaves) and sub-Tera **Hertz** (THz) bands,
- The use of Artificial Intelligence (AI) and Machine Learning (ML) to optimize the performance of some network parts, including the physical layer,
- The control of propagation through Reconfigurable Intelligent Surfaces (RIS).

The work proposed within the framework of this thesis is at the intersection of these three topics. The main purpose of this Ph.D. is to propose ML-based beamforming solutions for controlling the propagation of 6G millimeter-Waves (mmWaves) and sub-Tera Hertz (THz) signals by using RIS technology.

## Context:

The rapid increase of connected mobile terminals in the 4G era pushed data rate requirements of 5G systems to new levels [5]. From one side, as the sub-6 GHz spectrum is congested, moving towards other ranges, such as mmWaves for 5G and Beyond systems [6] as well as Sub-THz bands [7] for 6G systems, are and will be the main solutions for achieving these requirements.
From another side, meeting the challenging 6G requirements identified in Fig. 1. requires an hyper-flexible network with configurable radios. In most of the prospective studies for 6G [1, 2, 3, 4], it is proposed that AI and ML will be used in concert with radio sensing and positioning to learn about the static and dynamic components of the radio environment. This will be used to predict link loss events at high frequencies, to proactively decide on optimal handover instances in dense city networks and to determine optimal radio resource allocations for base stations and users. An important question is whether AI

could be used to design optimal air interfaces on the fly for a given environment and set of specific requirements. This suggests AI inspired air interfaces. However, their true performance in terms of energy efficiency in real use cases is an open research problem. Indeed, existing communication systems exhibit inherent limitations in translating theory to practice when handling the complexity of optimization for emerging wireless applications with high degrees of freedom. Deep learning has a strong potential to overcome this challenge via data-driven solutions and it can improve the performance of wireless systems.

It has been widely established [8], that Multiple Input – Multiple Output (MIMO) transmission systems, is a very attractive solution to increase the range and reliability of wireless communication systems. These systems can achieve antenna gains in transmission and in reception by using beamforming techniques. To support data rates, increase and networks densification, 5G networks are integrating MIMO systems equipped with a very large number of base station antennas (a few tens to a few hundred). This leads to massive MIMO systems [9], which when combined to beamforming architectures for mmWaves is introduced as a key technology for 5G [10]. On the other hand, Reconfigurable Intelligent Surfaces (RIS) using reflect and transmit arrays are envisioned as low energy consumption architectures to meet future high speed communication systems, with exceptional beamforming capabilities [11]. This concept allows to concentrate energy in certain directions of space, to achieve very high data rates with better energy efficiency. Compared to conventional planar antenna arrays, the radiation pattern is adjusted by activating the meta-surface diode grid, as depicted by Fig. 2.

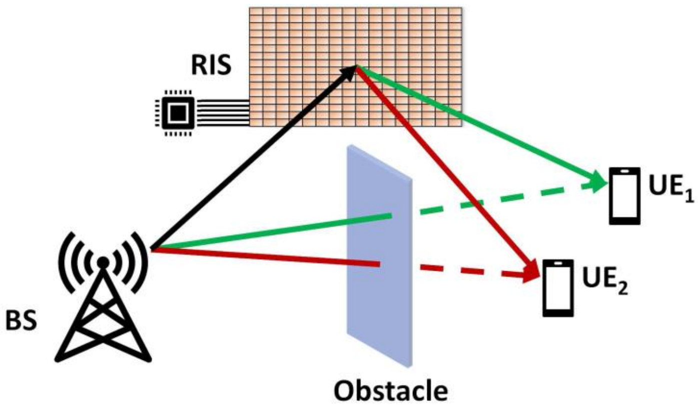



Fig. 2: Typical RIS based communication scenario.

Driven by a revolution in electromagnetically tunable surfaces (e.g., based on metamaterials), 6G technology plan to control signal reflections and refractions by using RIS. Open research problems range from the optimized deployment of passive reflectors and metamaterial coated smart surfaces to AI-powered operation of reconfigurable RIS [12]. ML-driven smart surfaces in mobile environments may require continuous retraining, in which the access to sufficient training data, high computational capabilities, and guaranteed low training convergence are needed. Holographic radio could be made possible with 6G by using RIS and similar structures [2]. Holographic RF allows the control of the entire physical space and the full closed loop of the electromagnetic field through spatial spectral holography and spatial wave field synthesis.

In the national context, many collaborative projects have been launched on 6G and related technologies. Among these projects, we can cite the MESANGES (for Meta-surface based Electronically Steerable Antenna arrays for Next Generation EHF Systems.) ANR project [13], which started in February 2021, involving: CNAM, Orange, CEA-Leti, IEMN and INSA-IETR.

In the international context, several consortia, collaborative projects, and scientific events have emerged since 2018, to imagine and harmonize the societal and technical expectations of 6G [14-25]. Specifically, for RIS-focused projects, we can cite the RISE-6G EU funded project [12], which started in January 2021.

## Objectives and proposed approaches:

As stated previously RIS have been proposed to dynamically manipulate electromagnetic waves in temporal and spatial dimensions. This is achieved by adding active components into elements of the meta-surface, such as positive-intrinsic-negative (PIN) diodes, varactors, etc. Independently switching the state of these components can adjust the phase of reflected wave from each element on the meta-surface and form complex spatial waveforms. This provides an additional degree of freedom to control wave propagation in real time. The element reflection phase can be quantized into binary codes. For example, the 1-bit code "0/1" represents the element can have two different reflection coefficients, and the 2-bit code "00/01/10/11" indicates four different states in the element reflection coefficients.

By defining beams parameters (directions, 3dB width, side lobes), we can compute the optimal phases to be applied to the unit cells by using nonlinear optim²ization algorithms, such as, genetic algorithm (GA) [27], particle swarm optimization (PSO) [28], or simulated annealing (SA) [29]. However, the high computational complexity of these algorithms makes it particularly challenging to compute the unit cells' phases in real time. In the literature ML-based contributions have been proposed to overcome the shortcomings of classical optimization approaches [30, 31].

The objective of this thesis is threefold:

1. **Optimization of the grid phases in a static context**: As a first step, we will dump the propagation channel effects and focus on the design of single and/or multi-user beams. The idea will be to focus more on DL/ML-based approaches to design single and multi-beams respecting different constraints such as beams widths, side lobes level etc.… The optimization problem can be extended to the case where more than one spatial stream per user is allocated or when multiple single spatial stream users are allocated simultaneously.
2. **Channel state estimation:** The optimal control of the RIS requires perfect channel state information (CSI) of the individual channels that link the base station (BS) and the mobile station (MS) to each other via the RIS. Thereby super-resolution channel (parameter) estimation needs to be efficiently conducted at the BS or MS with CSI feedback to the RIS controller.
3. **Energy efficiency:** RIS allow energy efficient communications as they do not require additional RF chains. However, to our knowledge, few or no studies have been made to compare the energy efficiency of this solution to that of classical Massive-MIMO based one. A third objective of this thesis will be to carry a fair comparison of the above-mentioned solutions for a fixed spectral efficiency.

## 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 RIS systems and make a synthesis of the main contributions published in the literature and related to the concepts of beam management and beam steering. 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 exchanges through contributions that can be enhanced by publications and/or patents.
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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