AIMM

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Antenna Arrays and Reconfigurable Intelligent Surfaces

Executive Summary

AIMM is a two-year European collaborative research and innovation project targeting radical performance improvements and efficiency dividends for beyond-5G/6G Radio Access Network (RAN), through novel multiple-input multiple-output (MIMO) enhancements and technologies, powered through and managed by the latest advancements in Artificial Intelligence (AI)/Machine Learning (ML).

This document provides an outline of the transmission technologies and architectures towards future wireless systems that are currently being developed within the AIMM project Work-Package 3 (WP3). The technologies of focus include Antenna Arrays, Reconfigurable Intelligent Surfaces (RIS), and Power Amplifier Enhancements, with AI/ML serving as a key tool for systems operation and optimisation.

AIMM in MIMO Evolution

MIMO is a key air-interface technology underpinning nearly all modern wireless systems. In 5G New Radio (NR), MIMO plays an ever-present role, both in terms of improving performance in congested sub-6 GHz bands as well as serving as a key enabler in facilitating operation in higher frequencies. Despite the great success of MIMO to date, there still exists a significant gap between the performance of MIMO systems in practice versus the information-theoretical capacity bounds.

A key reason behind this trend relates to the challenge of dealing with the cost and complexity of large-scale antenna systems which has resulted in the use of lower-order MIMO with sub-optimal signal processing schemes. Novel solutions and enhancements are needed to bridge the MIMO performance gap and to facilitate the operation of extremely large antenna arrays for future wireless systems. This is the motivation behind AIMM, a two-year collaborative European research and innovation project defined in the area of end-to-end RAN delivery chain with six tightly coupled work-packages, as shown in Figure 1.

The AIMM project WP3, titled “Antenna Arrays and Reconfigurable Intelligent Surfaces”, focuses on the benefits and practical realisation of extremely large antenna arrays, the use of RIS as a new type of network node for turning the wireless channel into a service, and power amplifier enhancements, with tools from AI/ML used for systems operation and optimisation against legacy approaches. The remainder of the document provides additional details over the scope and progress to date of the technical solutions being developed within AIMM WP3.

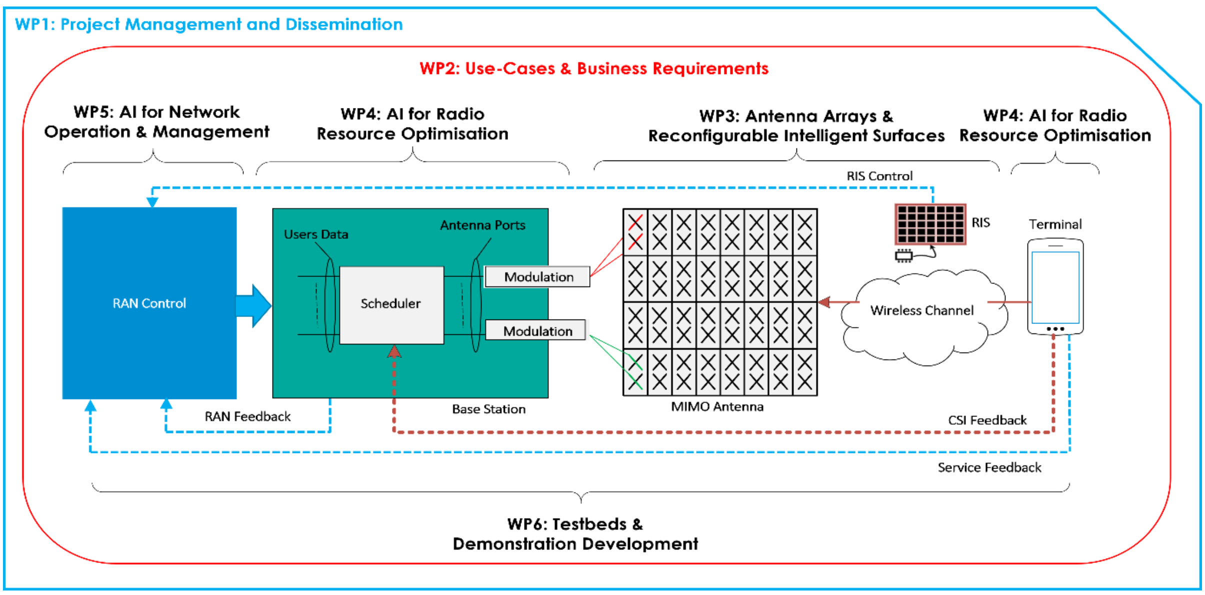

Figure 1. AIMM project structure.

Antenna Array Geometries

Massive MIMO is in the state of being deployed in the first commercialized 5G NR products, and is already considered to be one of the major technologies to cover the required increase of area capacity. During the last few years, it has been shown that the antenna geometry is crucial for separating closely spaced users. As most of these practical implementations and investigations work with a limited number of antennas (64) the question remains whether a very large number of antennas (>1024) is more advantageously deployed in a concentrated or distributed fashion. Moreover, the best antenna geometry for different types of cellular systems is yet to be found, with cell sizes ranging from femto to macrocell.

A large number of antennas results in a huge amount of data, and hardware cost is increased significantly. Therefore, advanced techniques for transceiver design as well as channel state information (CSI) data acquisition, need to be studied and improved, to further reduce the amount of hardware costs per chain, while keeping all the advantages of Massive MIMO. Moreover, fast and accurate electromagnetic simulation of antenna arrays with a large number of antennas is a challenging, but crucial task within the search for cost-effective optimal antenna design that satisfies given specifications. Within AIMM WP3, novel antenna technologies are being investigated to overcome practical challenges concerned with the deployment of high-order MIMO. This includes looking at the applications of extremely large antenna arrays, considering novel antenna technologies and architectures.

One approach under consideration for realising high-order MIMO is the use of large building structures to create 3D (holographic) distributed arrays, thus providing additional beamforming and spatial multiplexing gains. The main challenges are in connecting several large antenna arrays to a concentrated processing unit, without losing receiver sensitivity. The potential high processing delay required, as well as the complexity of essential channel estimation and aggregation, suggests the characteristics of the propagation environment including coherence interval in time and frequency must be carefully studied.

To study the propagation environment under different antenna designs (including linear, holographic, and along buildings) and architectures (including centralised and cell-less, as shown in Figure 2), over-the-air channel sounding activities have been ongoing within the AIMM consortium. The measured CSI datasets are then being used to study the performance benefits of different deployment solutions, with the use of tools from AI/ML as a key enabler for systems operation and optimisation. At the same time, efforts are ongoing within the AIMM consortium around the development of electromagnetic (EM) simulation tools for accurate analysis of such high-order MIMO systems.

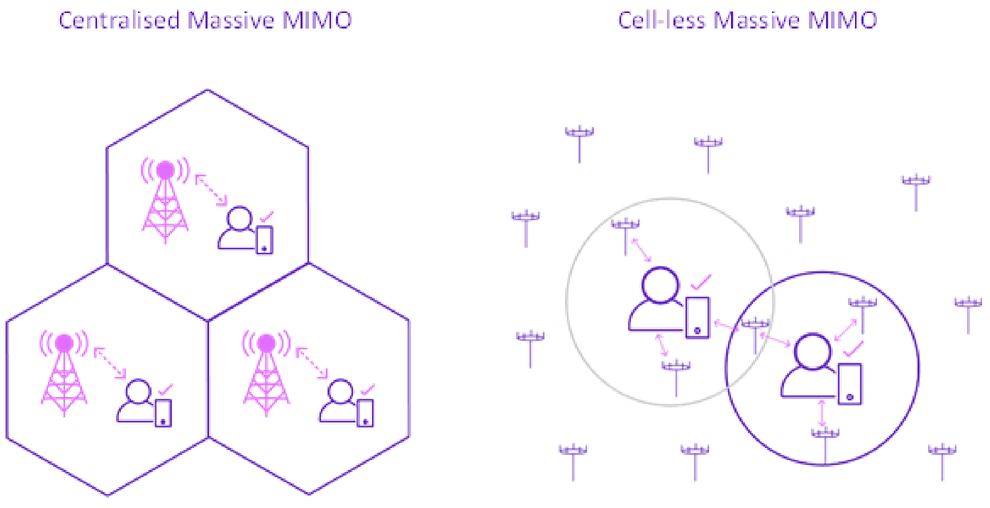

Figure 2. AIMM deployment architectures.

Reconfigurable Intelligent Surfaces

RIS has emerged as a key candidate technology trend for future wireless systems. RIS is defined as a new network node that utilises smart radio surfaces of many small antennas or metamaterial elements with reflection, refraction, and absorption properties which can be reconfigured and adapted to specific radio channel environments using a controller. The configuration of the RIS controller can be handled or assisted by the system through a separate control signalling link for exchanging relevant information such as timing and beam information, as demonstrated in Figure 3.

It has been shown that the unique characteristics of RIS in terms of control over the propagation environment, low hardware cost, the flexibility of deployment, and support for environmentally friendly communications, can bring significant potential in terms of improving network key-performance-indicators (KPIs) and enabling new services in future wireless systems. However, there are many technical challenges across system architecture, air interface models and technologies, and networking protocols that need to be adequately addressed before RIS can be adopted into future standards, towards eventual market adoption of the technology.

Within the AIMM project, we are defining use cases and investigating the potential benefits from the incorporation of RIS in the beyond-5G/6G RAN. Link-level simulations and experiments based on 3D channel models for RIS technologies have been conducted to date within AIMM, generating large datasets to aid system design and optimisation through applications of AI/ML. Another research and development effort in AIMM targets the characterisation of smart radio surfaces for RIS using 3D full-wave or hybrid methods, in order to allow for enhanced accuracy with a particular focus on scaling to large sizes and co-simulation with conventional antenna arrays.

The preliminary results in AIMM WP3 suggest that the applications of RIS in use cases where the surface is close to the end devices are promising, allowing for significant enhancements in the coverage performance, particularly indoors. In addition, the use of deep neural networks is found to be an important enabling mechanism for the identification of appropriate phase shifts (codebooks) for RIS elements as well as transmit and receive beamforming vectors at the transceivers under inherent complexities associated with RIS-based propagation environment modelling. Efforts are ongoing within AIMM to identify specification gaps within standards that are required to realise the full potential of RIS.

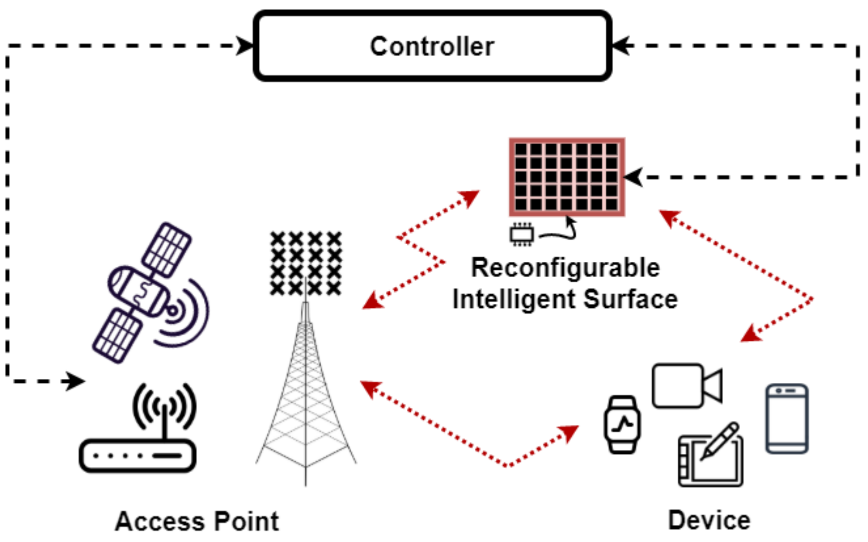

Figure 3. RIS-aided system depiction.

Power Amplifier Enhancements

In an antenna array, hardware complexity and energy consumption are crucial factors for implementation, with a major part being the design of the signal stream for each MIMO path. The implementation includes the analogue frontend as well as many digital algorithms for signal processing of the array elements. The power amplifier is only one component within this complex framework, but it is surrounded by a bunch of supporting measures to minimize the power losses. Further in high-order MIMO antenna arrays, dozens to hundreds of power amplifiers come to work, highlighting the importance of power amplifier enhancements. Such optimisations can be done with two different approaches including (1) improving the efficiency of every single amplifier, and (2) exploiting a-priori knowledge of the amplifier array to save computing power.

Within the AIMM project, digital pre-distortion (DPD) algorithms are being developed which (1) minimize the complexity of each DPD model template with help of AI methods and (2) exploit the similarities of the different power amplifiers of a MIMO antenna array. Using the a-priori information of model correlations between the power amplifiers, the problem of many independent DPD estimation loops may be reduced to a system where each DPD loop benefits from calculations and results of the other parts. Thus, computational complexity in terms of the number of needed iterations and matrix sizes may be significantly reduced.

AI methods are being evaluated and developed and benchmarked against traditional signal processing theory to assess the feasibility of such solutions. The required input datasets for the training of the algorithms are gathered through test bed implementation efforts within the AIMM project. The two most important optimisation requirements are the EVM (Error Vector Magnitude) of the modulated signal and the out-of-band spectral energy imposed by the nonlinearities. A schematic diagram of the AIMM architecture of DPD for power amplifier enhancements is depicted in Figure 4.

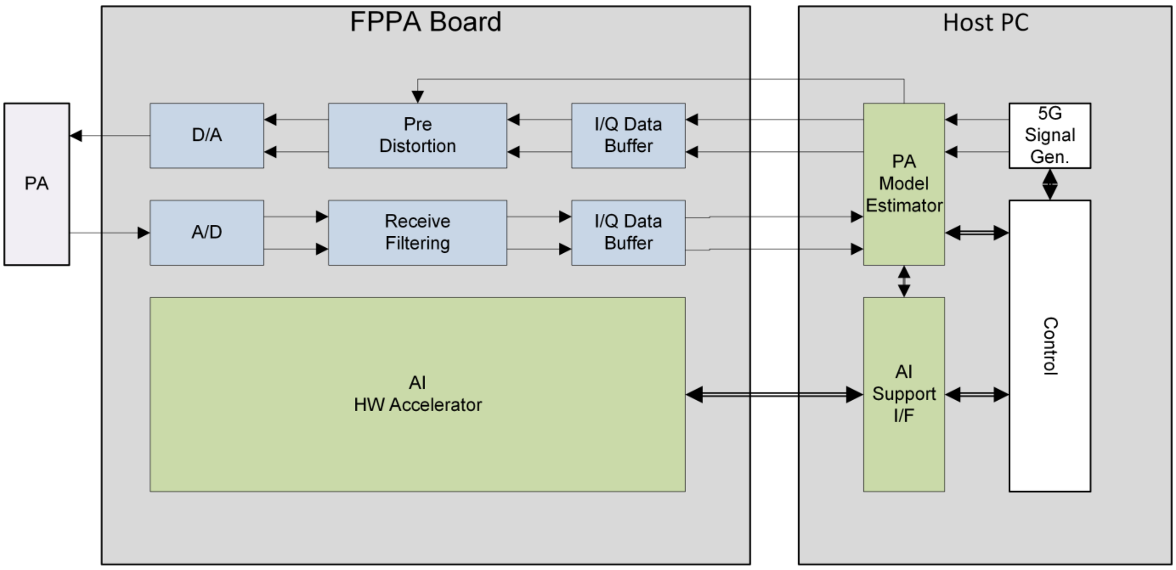

Figure 4. AIMM architecture of DPD for power amplifier enhancements.

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