# Artificial Intelligence Techniques and Applications for Massive MIMO in Future Communications Systems 5G

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**Abstract:** The major developments in the field of Artificial Intelligence (AI) have enabled the opportunity to use the results and benefits in any other areas of expertise for example national security, health, agriculture, energy and communication technology. In the communication systems, AI has been a significant factor in the optimization and improvement of the algorithms, techniques and components involved in the processes of communication, especially in the fifth-generation technology standard for broadband cellular networks (5G). New technologies like (massive) MIMO (multiple-input-multiple-output) are used and improved by the advantages of AI in order to develop future communication systems based on 5G, even 6G. In this paper, we aim to define the key concepts of the 5G communication systems, depict various techniques and application of the fusion between 5G and AI and highlight not only the benefits, but also the challenges that can be encountered in the process.

**Keywords:** 5G, Multiple-Inputs-Multiple-Outputs (MIMO), Artificial Intelligence, future communications systems, security

## INTRODUCTION

The fast development of the intelligent mobile devices and the accelerated growth of multimedia applications have created new challenges for the mobile networks. The significant amount of data has contributed to an increase in network traffic, thus creating a new hyper-connected society empowered by the fifth-generation services (5G).

5G technology focuses on the efficient use of the radio spectrum and allows several devices to access internet resources simultaneously. The 5G projection of communication systems faces various challenges in order to satisfy the high users demands, network speed, use of resources in an optimal way, cost efficiency, interference management and spectral efficiency. Due to the numerous technical requests, 5G communication systems will be assisted by different alternative technologies, aimed to highly improve its development. One way through which industry approaches these complexities is by integrating

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artificial intelligence (AI) in the communication network. The fusion between AI and 5G mobile technology has a great potential to improve the productivity, efficiency and costs in the business areas and in the entire society, offering innovative products and services. An ideal communication network would integrate both 5G and AI technologies in order to benefit from all the advantages and development opportunities of the latest technologies.

The main characteristic of the 5G technology implies the simultaneous connections of different IoT (Internet-of-Things) devices, which generate large amounts of data. All this information can be consumed and processed by AI and ML (Machine Learning) algorithms to improve the accuracy of the results and to optimize the efficiency of the techniques.

One of the key concepts when it comes to 5G communication systems is the wireless access technology known as Massive Multiple-Input-Multiple-Output (MIMO). Massive MIMO is the most appealing wireless access technology to deliver the needs of 5G and beyond networks. This technology implies the use of hundreds or even thousands of antennas attached to a base station (BS) in order to improve the spectral efficiency and throughput. The Massive MIMO capacity of increasing throughput and the spectral efficiency made it a crucial technology for the emergent wireless standards. The main advantage is the considerable array gain due to the big number of antennas. In comparison with the traditional multiple access schemas which eventually generate excessive latency, low data rate and reduced reliability, Massive MIMO can detect data through simultaneous transmission of sensors, improving latency, data rate and reliability, thanks to multiplexing and beamforming capabilities (Chataut & Akl, 2020).

Artificial intelligence (AI) is an essential paradigm that allows the programming and design of hardware systems as well as those with certain characteristics that are typically considered human, for example, visual perceptions, time and decision space. The development of AI systems is based on certain factors of human behaviour such as non-sterile knowledge, the ability to make logical decisions and the possibility to solve various problems according to existing circumstances. Intelligent systems have the potential to further enhance the different behavioural abilities of human beings through neural networks and algorithms capable of reproducing people's reasoning in different situations. At the basis of artificial intelligence is the development of artificial neural networks, whose mathematical model, starting from neurons and human neural networks, aims to solve different problems depending on the possibility of knowing the beginnings and the results obtained from previous choices. Similar to biological neural networks, an artificial neural network has the intelligence to know how to change its own structure, adapting to the specific needs generated by the information obtained in different stages of learning (Jurnal de Digital Marketing, 2021).

The massive MIMO capabilities can be improved and developed through the integration of AI and ML algorithms with the aim of creating a predictive and proactive 5G communication system. An innovative breakthrough would be the possibility of an intelligent base station to make its own choices and the mobile devices would be capable to create dynamically adaptive clusters based on the achieved data. Despite the advantages in terms of latency, efficiency and so on, AI and ML algorithms are a powerful tool for ensuring the security of the systems, considering the fact that, in general, all the improvements and developments of a technology or system bring vulnerabilities and dangers. AI and ML proved their efficiency in various domains for classification or identification and they could play an essential role in projecting, modelling and automation of the security protocols against various cyber threats. In the case of 5G communication system security, one of the common approaches on AI integration is by using it in securing the networks based on data-driven virtualized software.

## TECHNIQUES AND APPLICATIONS

Massive MIMO is the future technology for 5G and 6G communications and all the research and developments in this direction will improve significantly all the activities from the major sectors. In spite of the various advantages of MIMO techniques, this technology faces several challenges. Among these, the most important are illustrated in the below picture (Figure 1), namely: pilot contamination, channel estimation, precoding, user scheduling, hardware impairments and signal detection (Chataut & Akl, 2020).

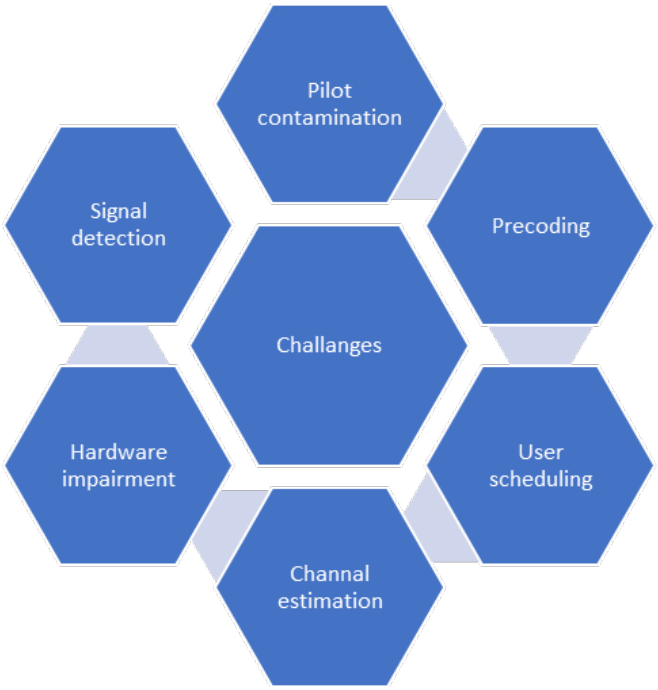


***Fig. 1:*** *Challenges for Massive MIMO technique [own source]*

The benefits of MIMO techniques can be improved and developed by introducing an intelligent system that uses machine learning and deep learning, in order to make the system capable of adapting to the specific needs generated by the information obtained in different stages of learning (Jurnal de Digital Marketing, 2021). That kind of intelligence is integrated into massive MIMO techniques with the following purposes (Arjoun & Faruque, 2020):

- Channel estimation more precise than in the case of usual techniques;
- Symbol detection;
- Mapping channels in the domain of space and frequency;
- Power allocation;
- Determining the optimal weight for the antenna elements;
- Prediction the user's distribution;
- Improving coverage with multiple cells.

In (Paolini & Fili, 2020) it is shown that artificial intelligence / machine learning can be used for any element or function of the wireless network, for example to optimize the operation of massive MIMO and beamforming techniques in radio access network, with a number of beam forms that can be of the order of ten thousand and it can be analysed the multiple combinations of parameters like width, tilt and azimuth.

Beamforming is a technique used to obtain the characteristics of radiated beam of antennas by (Ali, Ismail, Nordin, & Abdulah, 2017):

- Maintaining the processed signals on the direction of the considered terminals (the so-called desired signals);
- Nullifying the beams of interference signals.

In the domain of cellular communications, the reference to beamforming consists in directing a power lobe in a certain direction to a user, as seen in Figure 2 (Masterson, 2017).

***Fig. 2:*** *Beamforming with directing a power lobe to a user (Masterson, 2017)*

In (Maksymyuk, Gazda, Yaremko, & Nevinskiy, 2021) a smart algorithm was presented, looking to optimize performance related to beamforming in massive MIMO systems. Specific to this algorithm is the association of three neural networks (NN):

1. The first NN generates realistic mobility patterns for the users;
2. The second NN uses these mobility patterns for the most appropriate antenna diagram;
3. The third NN estimates the efficiency of this diagram and provides the corresponding reward to first and second NN.

The advantages of this approach consist in:

- Provides its own support;
- Large sets of training data are not used.

Based on the self-learning capabilities of this solution, a greater capacity of 5G networks can be ensured.

In (He, et al., 2021) the authors proposed an efficient and new framework for signal detection, when the noise data is unknown, named maximum a normalizing flow estimate (MANFE). This framework presents a pure probabilistic model which is able to approximate the unknown distribution of the noise by normalizing the flow. In addition, the detection framework is very flexible because is driven by unsupervised learning, without the need of any labels for training. Also, the authors went even further with their research and extend the MANFE framework to G-GAMP-MANFE by integrating and combining GAMP (Generalized Approximate Message Passing) and MANFE algorithms. This low-complexity version reduces the computational complexity of MLE (Maximum Likelihood Estimation) and is more practical and easier to implement in real applications.

A complex approach of channel detection problem is presented in (Gomez, 2022). The work of the author has focused on reducing the computational complexity by using ML and Deep Learning. He explored the cross-frequency subband prediction intra-TTI (transmission time interval by proposing three models. The first two algorithms are based on Probabilistic Principal Components Analysis (PPCA) and the third one is based on Bayesian Principal Components Analysis (BPCA). These three models are supposed to deal with enormously high dimensional space of the four datasets that were used for dimensionally reduction.

In (Towliat, Tabatabaee, & Rajabzadeh, 2018) the focus in on the generalized frequency division multiplexing (GFDM) which is the perfect candidate for the physical layer of 5G networks. GFDM has numerous advantages like considerable higher bandwidth efficiency, more samples per subchannel and higher spectrum resolution. This technology can easily adapt to MIMO channels in order to increase performance and reliability. The authors proposed a simple and near-optimal ML detection algorithm for Alamouti STC, which is the only orthogonal space-time-coding that can achieve full transmission diversity gain in MIMO code GFDM.

In the paper (Choi, Cho, Evans, & Gatherer, 2019), authors investigated the learning-based maximum likelihood detection for MIMO uplink systems. They proposed two one-bit detection algorithms, namely biased-learning method and dithering-and-learning method in order to tackle the dependency between the learning-based detection and training length.

The biased-learning method is based on keeping likelihood functions with zero probability to lose obtained information from learning. This algorithm provides more robust detection performance. The dithering-and-learning method is an extension of the biased-learning algorithm to a system with knowledge of the received SNR (signal-to-noise ratio) and is based on the estimation of more likelihood functions by adding dithering noise to the input.

Another application of interest, when it comes to AI and 5G, is the generation of datasets that can be used to predict with more accuracy some important parameters like 5G millimetre wave (mmWave).

In (Klautau, Batista, González-Prelcic, Wang, & Heath, 2018) the authors define and describe a new methodology for data channel generation, with the aim of facilitating the ML based-problems in terms of PHY of mmWave in 5G. The authors proposed a method that creates more simple data for intricate mobility scenarios by repeatedly using a traffic and ray-tracing simulator. Furthermore, (Alkhateeb, 2019) proposed the DeepMIMO dataset that is defined as a generic dataset for mmWave/massive MIMO channels. In the paper, DeepMIMO dataset is used in an example of mmWave beam prediction. The proposed dataset generation has two basic principles:

1. The DeepMIMO channels are constructed considering ray-tracing data from Remcom Wireless InSite. They capture the dependency on the environment and locations, which in general is crucial for ML applications.
2. The DeepMIMO dataset is generic, fact that allows users to adapt a pair of system and channel parameters in order to tailor the data for the targeted application.

In the paper (Hu, Gao, Zhang, Li, & Xu, 2021), the authors investigated the DL-based MIMO detection with the aim of identifying the strengths and weaknesses of this method.

They approach two different architectures:

1. First, there is a data-driven DL (Deep Learning) detector, using a neural network activated by rectifier linear unit (ReLU) function;
2. The second one is a model-driven DL detector extended from a traditional iterative detection algorithm.

The final results of the simulation demonstrate the success of the DL-based MIMO detection method for linear signal system, as well as nonlinear.

## ADVANTAGES AND SECURITY CHALLENGES IN MASSIVE MIMO AND AI

Recent developments in the field of wireless communications have had a huge impact on society infrastructures, where the tendency is to virtualize all the network functions. Along with the significantly evolution come the dangers, threats and vulnerabilities regarding the cyber security of a system. Both AI and massive MIMO technologies have their specific vulnerabilities, so there are many weaknesses to exploit.

Massive MIMO is the future technology for assuring the benefits of 5G communication systems. There are two types of attacks associated with massive MIMO technology: passive and active. In a case of a passive attack, the transmissions are eavesdropped by a malicious attacker, whereas in an active attack, the attacker try to disrupt or corrupt the communication. Moreover, the active attack can also be divided in two types of attacks: jamming and pilot spoofing. The aim of a jamming attack is to disrupt the communication by sending a huge amount of data to the base station or the users, while a pilot spoofing attack is executed by an attacker who pretends to be a valid user and contaminates the pilots. Usually, the ML algorithms are a very useful tool in terms of detecting active attackers due to the capabilities of predicting values and extracting data and features. The main problem in securing massive MIMO systems using ML is the high overhead generated by the huge amount of training data needed for the ML algorithms when we have a large number of antennas. Another challenge for a secure 5G network is the mobility of the users. ML algorithms are trained for specific parameters and channel quality. These characteristics change and vary dramatically in time. Generally, a massive MIMO system can not be trained

only for a specific environment because of the possibility of not working properly if we change the environment. Usually, the training is executed offline because the retraining in the online environment can be a challenging task because of the complexity and required time resources of the ML algorithms. Another issue that should be addressed is the fact that researchers are unable to design accurate algorithms because of restricted access to real base station data.

This happens because data sponsors are usually bond by non-disclosure agreements and sharing the information can lead to revealing sensitive data. The majority of researchers depends on simulated data sets, which are considered to generate irrelevant and unrealistic experiments. In addition, the training of a massive MIMO system has some difficulties regarding the type of learning. Supervised learning can be approached only if we can guarantee that the system is not eavesdropped by an attacker. Otherwise, unsupervised learning should be applied, but this type of learning complicates the process because the input data is unknown and unlabeled beforehand (Suomalainen, Juhola, Shahriar, Mammela, & Ahmad, 2020).

The challenges mentioned above have a huge impact on the future developments and improvements in the field of 5G communication systems. The experts try to solve or optimize the difficulties of massive MIMO technology by proposing solutions. For minimizing the risk of jamming attacks, the use of 64 antennas or less in a communication system is recommended. The data overhead can be averted by using methods that works with little to no loss accuracy for DL networks. Quantization and pruning are two strategies that assure a high level of accuracy. For the user mobility problem, it is very important to have a stable ML algorithm. The stability can be ensured by introducing a training method that aligns the outputs for perturbed and non-perturbed samples. Due to the fact that radio signals are synthetically produced, data obtained by choosing the right simulation parameters and suitable channel models can be used for benchmarking various ML algorithms for a massive MIMO BS (Suomalainen, Juhola, Shahriar, Mammela, & Ahmad, 2020).

In terms of integrating AI in 5G communication, the communication system also faces many challenges as follows (Arjoun & Faruque, 2020):

- Reduced speed and reliability: the reliability of ML techniques is far less than traditional methods. The deep learning inference can generate a slow time response and feedback. Usually, this is caused by the poor access of the devices to cloud computing resources, but even if they are connected, cloud servers have the habit to introduce extra delays.
- High complexity: most of the wireless devices have limited memory and computing capabilities, which can be an impediment to the execution of ML algorithms. These algorithms require time resources for collecting and processing large samples and is hard to deploy them on devices that cannot fulfil the minimum condition for an acceptable execution. Moreover, some applications need real-time processing and training and the lack of resources can affect the accuracy of the results.
- Data collection and cleansing: the training of AI models requires large and comprehensive sets of data, which sometimes is not easy to obtain due to the mobile service providers, who refuse the access to various data for GDPR (General Data Protection Regulation) reasons. Even in the case of transfer learning, it is obligatory to adapt the models for specific networks and isolated scenarios, which implies retraining the algorithms.
- Privacy: keeping the privacy of the users protected is a big challenge when all the ML algorithms require data to run in order to offer the needed results. The main concern is the fact that when you share the data for training, you put the personal information of the users at risk. For this matter, the presence of a secure and privacy-friendly approach is mandatory.

- Security: the ML algorithms themselves are very vulnerable. The attackers can attack network by injecting fake datasets, for example. This can cause problems in terms of the network design and reduced accuracy, which may significantly affect the performance of the system.

Despite all the challenges and concerns regarding the integration of AI and 5G communication, this concept has a bright future ahead of it. For instance, deep learning can even replace the need for human expertise in signal processing, being capable of performing automatic feature extraction. This is not an easy task, but DL-algorithms can execute it with high accuracy. In some cases, DL methods outperform traditional approaches and offer high-performance accuracy (Arjoun & Faruque, 2020).

Among all the advantages of AI used in 5G communication, it is also worth mentioning the following general benefits: flexible algorithm modelling with scalable opportunity, adaptive system of security management and automation, supporting of human resources in several working task, reduced security operational cost, adaptable capabilities for dealing with various security threats, support for decision making problems, real-time implementation, complex optimization to solving unexpected problems and so on (Haider, Baig, & Imran, 2020).

The advantages and benefits provided by the fusion between AI and 5G are way more important than the difficulties. The intention of using artificial intelligence to build a 5G communication system that fulfils all the perks of the technology can be a future tool for developing methods and applications for the sixth-generation mobile system standard.

## CONCLUSIONS

In the following years, all the disruptive technologies will improve and develop, and society will have to be prepared for the evolution of all the systems. The fifth-generation mobile system standard represents one of the most important technology due to all the benefits that are brought by adopting and integrating it. As it can be noticed, there are substantial efforts in terms of research with the aim of developing and finding new and innovative methods to facilitate the adoption and usage of 5G communication systems. So, AI concepts have a crucial role in fulfilling the objectives, namely network speed, use of resources in an optimal way, cost efficiency, interference management and spectral efficiency.

The scope of this paper was to present the basic concepts of AI and 5G technologies, to illustrate concrete applications and techniques of the fusion between them, to analyse and discuss the benefits but also the challenges that we must face and overcome.

In addition, this paper aimed to draw attention to future developments and research regarding the security of 5G communication system, as well as to the deployment of ML techniques in a safe approach. All the efforts and advancements in wireless networks, having the 5G technology defined and adopted, will represent a step towards the evolution of the sixth-generation mobile service standard (6G).

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