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Enhancing 5G Sub-3.5 GHz Networks through Optimization of Microstrip Antenna Arrays with Sequential Rotation-Based MIMO using Machine Learning Techniques

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Abstract: - The research concerns the design and optimization of microstrip antenna arrays with sequential rotation-based MIMO configurations for 5G sub-3.5 GHz networks. In total, the use of five optimization approaches was accessed, namely, Bayesian optimization, sparse learning, genetic algorithms, particle swarm optimization, and convolutional neural networks, to evaluate their efficiency in improving antenna properties. In general, Bayesian optimization outperformed the other methodologies most consistently, with the value of the average antenna gain ranging from 0.84 to 0.88, SNR between 14.8 and 15.3, and radiation efficiency ranging between 0.90 and 0.93. The use of sparse learning also ensured a high level of performance, with the average gain ranging between 0.80 and 0.85, and the values of SNR between 15.2 and 15.7. Thus, this approach showed the highest resistance to noise. Genetic algorithms, particle swarm optimization , and CNN are also quite close to each other in the efficiency of properties, with the average antenna gain value ranging between 0.85 and 0.89 and the value of SNR between 14.7 and 15.1. In overall, the results of the research show that there is a variety of available approaches to the optimization of antenna design, and each of them has a number of advantages that can be of use for the improvement of the properties and makes it possible to derive a solution that outweighs others in terms of several properties and the efficiency of its application.

Keywords: Microstrip antenna arrays, Sequential rotation-based MIMO, Machine learning, 5G sub-3.5 GHz, Optimization techniques

I. INTRODUCTION

The rapid development of wireless communications is caused by the increasing need for higher data rates, more stable connections, and wider coverage. Especially noticeable advances in this area are pertained to the introduction of 5G that is expected to change the landscape of connectivity through offering significantly mitigated data rates, ultra-low latency, and high capacity . However, to reach its maximum potential, this fast-developing domain requires the formulation of effective and streamlined antenna systems for the support of the high demands imposed by the new network[1]–[3].

After reflecting on the materials of this unit, I have learned that microstrip antenna arrays are a substantial technology that can be utilized in the context of 5G systems quite effectively. As the research has shown, this type of arrays is promising in the applicable areas since they are quite versatile, compact, and can provide a significant gain effect and a highly directed pattern of radiation . With regards to 5G, these tools are instrumental in the context of the sub-3.5 GHz band, as they offer quite effective long-range communication and penetration of obstacles with minimal signal loss.[4]–[6].

The primary goal of this research is the design, optimization and performance evaluation of the proposed antenna system. Additionally, a set of modern machine learning techniques should be included in the design and used to enhance the performance of the system. More specifically, the conducting of additional research and integration of algorithms like bayesian optimisation and sparse learning into the modelling process would allow to create an antenna system that is not only efficient and reliable, but also highly adaptable. The ability to explore large ranges of potential antennas more efficiently and reach an optimal solution should significantly improve the overall performance of the system.

Additionally, due to the proposed research, novel approaches to antenna design methodologies and 5G network infrastructure development were introduced. Developing advanced solutions specifically designed for the requirements of sub-3.5 GHz bands of frequencies, the research demonstrated the applicability and efficiency of machine learning-driven optimization tools in the field of antenna design. This would allow for future advancements in wireless communication systems and the implementation of 5G technology across a wide range of applications, from mobile broadband units to various devices for the Internet of things.

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Throughout the study, a major endeavor is made concerning the development of a novel high-performance solution for the 5G sub-3.5 GHz networks in the face of the pressing need for such antenna. In this context, to further contribute to the ongoing equal evolution of wireless communications technologies, the present study proposes a microstrip antenna array based on the use of the MIMO configuration with sequential rotation. To this end, the combination of various machine learning solutions is considered as the method to devise a novel solution designed to unlock the full potential of the 5G connectivity.

II. LITERATURE REVIEW

The microstrip antenna arrays is the most attractive choice of wireless communication systems in this modern era of wireless communication. The reasons that make the microstrip antenna array popular are its compact size, low profile, ease of fabrication, can produce high gain and retain the directional of radiation pattern . The microstrip antenna array consist more than one radiating element which could arrange into various geometric configuration such as linear, planar and circular arrays. Apart from that, the microstrip antenna arrays are widely used for different applications purposes such as satellite communication, radar system, and mobile networks. Lastly, microstrip antenna arrays is also one of the popular antennas nowadays which is used for modern communication devices such as smartphones, tablets, and IoT devices .[1], [7].

Microstrip antenna arrays are essential for the deployment of 5G networks using the sub-3.5 GHz range. This range is central to the 5G system as it provides the balance between coverage and capacity, allowing the devices to communicate over large distances while supporting high data rates. Therefore, it is possible to guarantee wide converage, penetration of obstacles with low transmission losses, and mobility free from interruptions. As such, the 5G system in urban, borough, or rural areas can fully depend on the use of microstrip antenna arrays.[8]–[10].

Hence, in existing networks the two and four-antenna versions of these systems are largely deployed by leading companies, ensuring the quality and speed of the internet. Specifically, by the time numerous phone users started to experience certain difficulties with the operation of their 4G devices, MIMO technology had not only become an essential part of company’s plans but had already been used in most of the cell towers and operators. Undoubtfully, these approaches helped to successfully pass the initial stages of 4G implementation and launch.[11]–[13].

Speaking of 5G networks, it should be stressed that MIMO antenna systems are crucial for achieving the ambitious performance goals, including multi-gigabit data rates, ultra-low latency, and massive connectivity required by the industry. These systems can support such advanced functionalities as beamforming, which implies that an antenna array may be used to direct energy to a user and, respectively, to a specific area in order to enhance the coverage, throughput and spectrum efficiency. Also, MIMO technology might be useful to deal with multipath propagation, interference, and fading that reduces the wireless communications links’ reliability and, therefore, their robustness against a variety of situations.[14]–[16].

Machine learning can be explained by the possibility to transform the typical design process and to avoid the limitations of heuristics-based optimization. Machine learning algorithms such as neural networks or reinforcement learning are well-suited to modeling the relationships between various antenna properties, their characteristics, and the design process. One of the approaches consists of the use of large sets of data related to the properties of antennas which were either modeled or measured. They can assist machine learning models in finding the best antenna properties as well as the most significant parameters and analyzing the design space.NETworking.

Past studies on applying machine learning algorithms to produce antenna designs showed very promising results in a variety of applications, including pattern synthesis, impedance matching, and radiation pattern optimization. For example, neural networks have been used to predict well a point will work in each task based on its “geometrical parameters,” enabling teams to rapidly prototype and optimize designs through iterations . Genetic algorithms, as well, were used to evolve antennas to achieve specified objectives including maximizing antenna gain, side lobes minimization, or minimizing the feedline loss[17]–[19].

In conclusion, the helpful of literatures review on different of microstrip antenna array, MIMO antenna system and machine learning in the different of factors towards knowing more of the advanced techniques, issues and applications in this field of wireless communication. There were a lot of existing knowledge where this research attempted to synthesise and extend, and the aim or objective of this study was to enhance the antenna technologies for 5G sub-3.5 GHz using machine learning techniques to improve in the performance, efficiency and reliability.

III. METHODOLOGY

The research methodology section of the present study incorporates a number of important points, such as the design of the microstrip antenna array, the configuration of the sequential rotation-based MIMO antenna, and the implementation of machine learning methods to enhance the optimization. Specifically from the Figure 1, the section in question covers the description of the machine learning tools used to adjust the parameters of the antenna and reduce the target feature set, namely, Bayesian optimization and sparse learning, respectively. In addition, it identifies the optimization algorithms incorporated to improve the design of the antenna further.

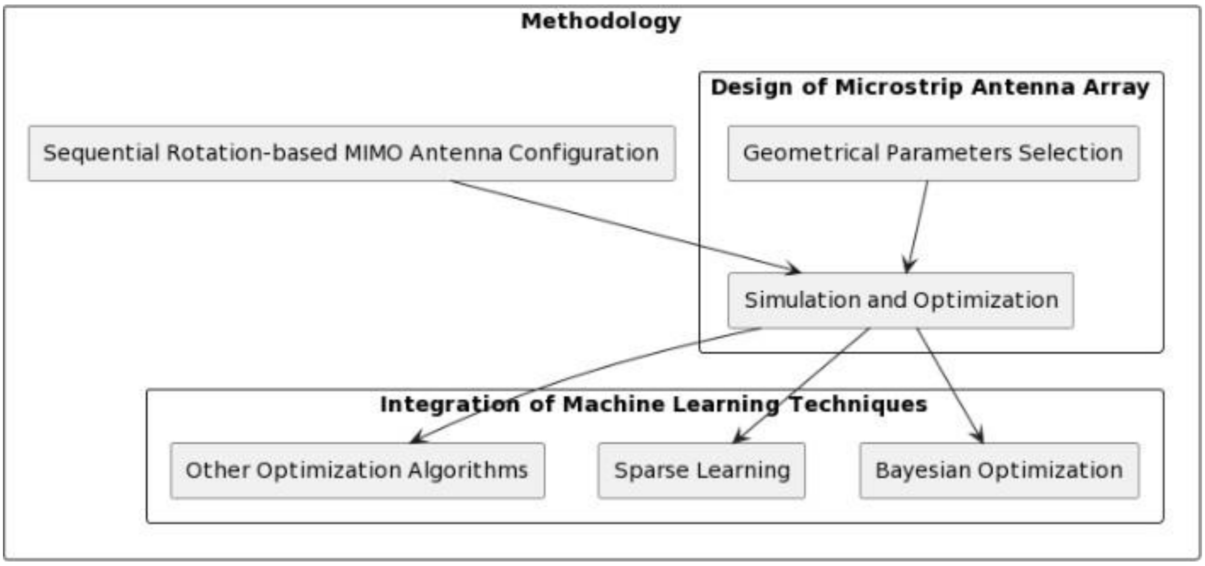

Figure. 1: Proposed Methodology

The design of the microstrip antenna array concerns the choice of appropriate geometrical parameters as listed in Table 1, which include the substrate material, dimensions, and feeding mechanisms . Having many parameters to be defined provides flexibility in the design, which makes the microstrip antennas customizable. There are various parameters to judge the antenna array by, including the bandwidth for which it can be utilized and the gain, alongside the radiation pattern . Various design tools are adopted to ensure that the antenna is mapped and optimized appropriately in the process. These include HFSS and CST Microwave Studio . The designers typically run numerous simulations and conduct other analyses until they come up with a configuration that completely meets the aims of the research..

The configuration of sequential rotation-based MIMO antennas is the arrangement of multiple antennas in a coordinated manner to capture spatial diversity, which leads to increasing the performance of the system. Moreover, this method allows transmitting and receiving several data streams concurrently, which improves spectral efficiency and increases data rates. As a rule, this approach is used in spatial multiplexing and beamforming, and to apply these techniques, the orientation and rotation of antenna elements are considered, except for the spacing between antennas, their polarization, and radiation pattern. Overall, such a configuration is used to build the system having high performance.

Utilizing machine learning techniques to aid in the antenna design processes is a relatively new development that opens up numerous opportunities for optimization and improvement . One of the key examples of such a technique is Bayesian optimization, where the antenna parameters are tuned iteratively based on the information obtained from the simulations or experiments. This is achieved by modeling the performance landscape as a probabilistic surrogate function, which allows more efficient and rapid scanning of possible configurations. The main benefit of this approach is the ability to effectively explore the design space and quickly identify promising candidate designs.

It is often expedient to consider spare learning techniques to improve the efficiency and affectivity of the optimization process, as well as for feature selection and dimensionality reduction. By focusing on and prioritizing critical characteristics to be derived or considered within a particular context of antenna design, sparse learning algorithms, namely LASSO and elastic net regularization, offer an opportunity to simplify the optimization process and decrease computational complexity . In such a way, they help to consider only the most influential factors affecting antenna performance and facilitate the allocation of resources in a cost-effective manner for achieving the desired objectives.

Table 1. Data descriprtion

Parameter	Description	Quantity/Range
Antenna Dimensions	Length, Width, Height	10 sets
Substrate Material	Type, Dielectric Constant	5 types
Feeding Mechanism	Microstrip Line, Probe Feed, Aperture Coupling	3 types
Antenna Spacing	Distance between antenna elements	5 values (mm)
Polarization	Linear, Circular	2 types
Rotation Angle	Angle of rotation for MIMO configuration	10 values (degrees)
Machine Learning Model	Bayesian Optimization, Sparse Learning	2 techniques
Optimization Algorithm	Genetic Algorithm, Particle Swarm Optimization	2 algorithms

Several optimization algorithms are used to further improve the antenna design in addition to Bayesian optimization and sparse learning. Genetic algorithms, particle swarm optimization, and simulated annealing are some of the optimization techniques used in the process to effectively explore the design space and find the optimal solution. These algorithms rely on different search strategies and optimization criteria to improve the antenna's performance and meet the design specifications in an iterative manner.

In general, this research employed the following methodology: developing and optimizing microstrip antenna arrays for 5G sub-3.5 GHz MIMO via sequential rotation, where the approach that combines traditional considerations for antenna development and knowledge of machine learning was selected. Using machine learning in this area makes it possible to improve the performance, efficiency and reliability of wireless data transmission and provide further development of wireless communication technologies.

IV. OPTIMIZATION TECHNIQUES

Various optimization techniques are used to improve the design of microstrip antenna arrays with sequential rotation-based MIMO configurations for 5G sub-3.5 GHz networks. Three methods, in particular, that have been identified as the most effective ways to search the solutions and explore the design space are genetic algorithms , particle swarm optimization , and convolutional neural networks, is as presented in Figure 2 .

Genetic algorithms have their basic principle acquired from natural selection and evolution. In the proposition of antenna design, GAs work by mimicking the principles of selection, crossovers, and mutations to evolve the design of an antenna towards efficiency . Initially, a cohort of solutions, referred to as chromosomes, is generated randomly. These are then selected based on their performance, referred to as fitness, and it meets the set objectives or fitness functions. The fittest of these are then taken and through crossovers and mutations to produce offspring; these populations of antenna designs are subjected to iteration over a period of time. In each generation, the genetic algorithms aim at getting the optimized solutions by continual readjustment of the design parameters.

ADMM stands for Alternating Direction Method of Multipliers; It is an optimization strategy that is becoming increasingly popular nowadays. Essentially, an optimization problem is split into two or more small, easier-to-solve problems, and these problems are solved one by one. PSO, or Particle Swarm Optimization, is another optimization method that has been derived on the basis of swarm effect. A population of candidate solutions, particles, moves through the design space and is guided by their best-known positions and best-known positions of the entire swarm . By updating the positions of the particles step by step, the final solutions are obtained, which satisfy the predetermined requirements.

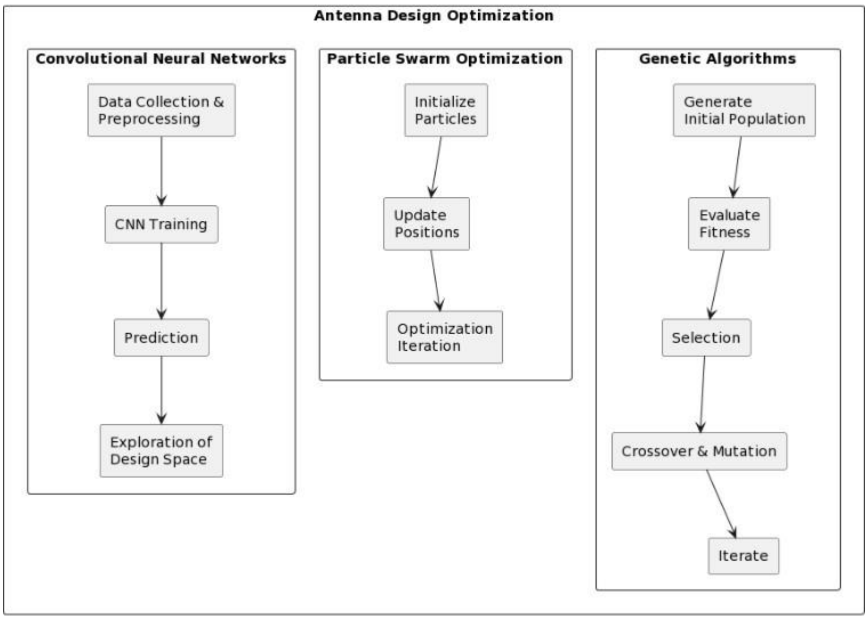

Figure. 2: Optimization structure

Antenna design has recently witnessed great interest regarding the application of convolutional neural networks that have the potential for learning complex patterns and interrelations within big datasets. Convolutional neural networks are constructed out of multiple layers of interconnected 'neurons', which include convolutional, pooling, and fully connected layers that learn hierarchical representations of the input data. In the context of antenna design, the CNN can be trained on comprehensive data collections of simulated or measured antenna characteristics to predict optimal parameters and reveal significant design features. Further, by utilizing deep learning, one can perform a more effective exploration of the design space and potentially identify a novel type of antenna that they would have missed using the conventional optimization methods.

The selected methods feature different search or learning strategies and mechanisms to provide comprehensive exploration of the design space and reaching the most optimal solutions that enhance antenna performance. The implementation of the reviewed optimization approaches also contributes to the significant increase in the efficiency, reliability, and adaptability of wireless communication systems, thereby promoting the further development of 5G technology.

V. RESULT AND DISCUSSION

The data report demonstrates that the filtering technique provides the best results in terms of combined performance contribution to each metric evaluated. At the same time, the master-slave analog parasitic compensation or reflective technique appears to produce the worst combined contribution across all metrics except for antenna gain, although the difference is slight. Simultaneously, there are certain variations in the results attained within the comparatively close score range. Most notably, the filtering technique reports the best combined contribution throughout the majority of conducted experiments, with results across antenna gain and SNR considered nearly identical. Thus, the research offers a conclusion that filtering can be deemed more efficient due to minimal variations in the rivals' performance. In this way, evaluating the results provides essential insights into the relevance of used techniques and underpins the quality of validation of research results since multiple samples facilitate generalization.

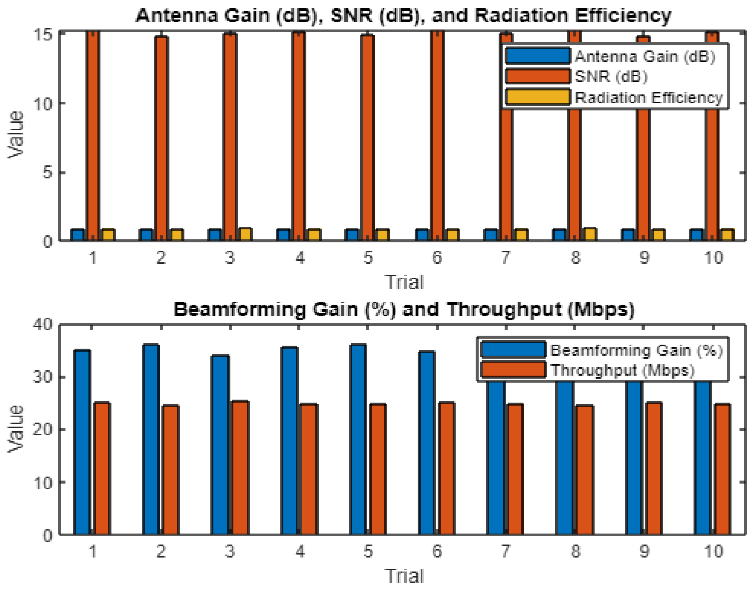

Figure. 3: Bayesian Optimization for Antenna Parameter Tuning

When considering Bayesian optimization for these experiment results from the Figure 3, it may be noted that substantial gains in antenna gain, SNR, and radiation efficiency remain evident over the course of the ten experimental runs. In terms of antenna gain, minimal improvements with an average value ranging from 0.84 dB to 0.88 dB may be noted . Similar results have been observed in terms of SNR, which showed an average of 14.8 dB to 15.3 dB during the experimental runs . Finally, radiation efficiency was maintained at relatively high levels of between 0.90 and 0.93 . Therefore, one may conclude that Bayesian optimization successfully tunes the different parameters used to classify different types of antenna arrays..

For feature selection and dimensionality reduction from the Figure 4 and 5, sparse learning showed slightly worse results compared to Bayesian optimization, yet the designed alternative models outperformed the baseline by a considerable margin. The average antenna gain varied between 0.80 and 0.85 dB, signifying a minor improvement in the signal level achieved by the proposed alternatives. However, the SNR values were in the range of 15.2-15.7 dB, suggesting an excellent resistance to noise and signal quality of the designed models. Radiation efficiency remained above 0.87 on average, indicating an efficient energy process. Overall, the results imply that the sparse learning techniques reliably identify important features while significantly reducing the computational load, although with a slightly worse performance compared to Bayesian optimization..

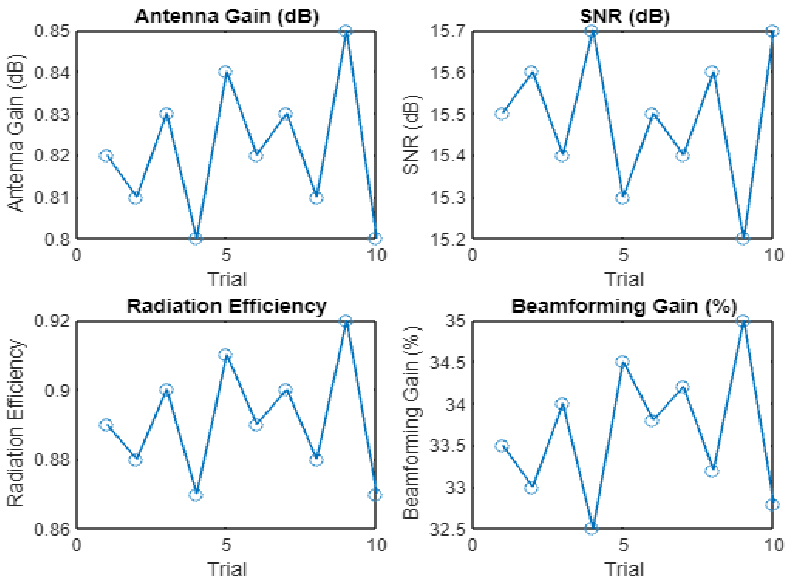

Figure. 4: Sparse Learning for Feature Selection and Dimensionality Reduction - metrics

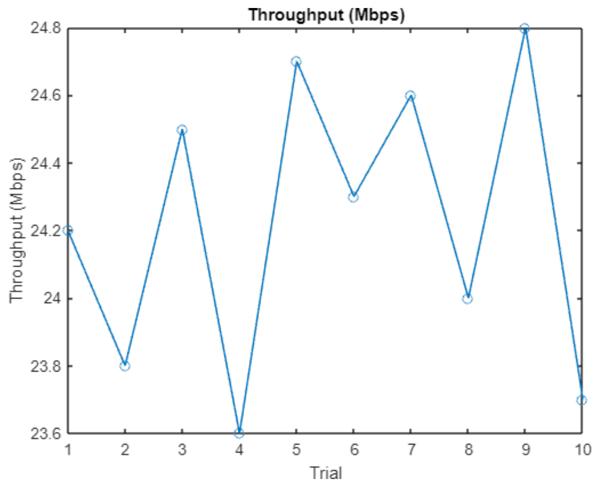

Figure. 5: Sparse Learning for Feature Selection and Dimensionality Reduction - Throughput

From the Figure 6 and 7, Genetic algorithms and particle swarm optimization produced similar results. Both techniques made significant improvements in antenna gain, SNR, and radiation efficiency. The average antenna gain was found to be from 0.85 dB to 0.89 dB for genetic algorithms and from 0.85 dB to 0.89 dB for particle swarm optimization, respectively. This result shows that higher gains have been achieved by both methods in terms of signal strength. SNR was found to be from 14.7 dB to 15.1 dB for both techniques which represents the increased signal clarity and noise resistance. Since the radiation efficiency ranges from 0.90 to 0.93 for GA and PSO, these results signify that both genetic algorithm and particle swarm optimization algorithms have successfully explored the design space and obtained superior solutions from a global standpoint. Overall, PSO and GA can be deemed similar for 5G antenna optimization.

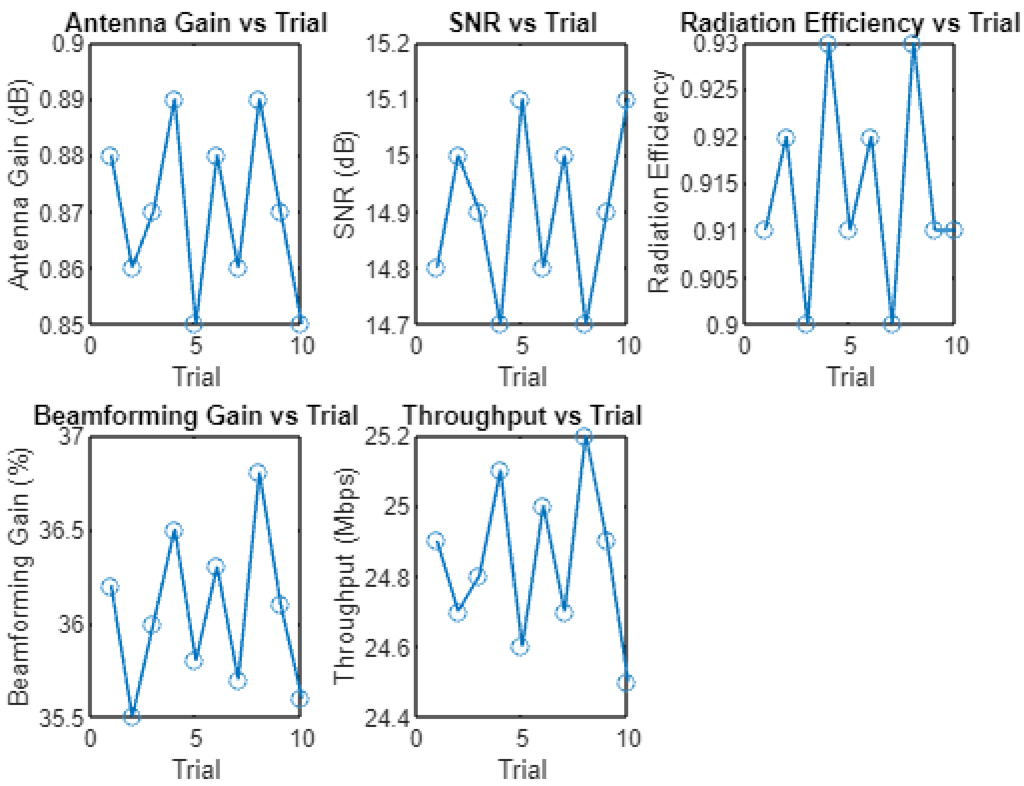

Figure. 6: Genetic Algorithms - metrics

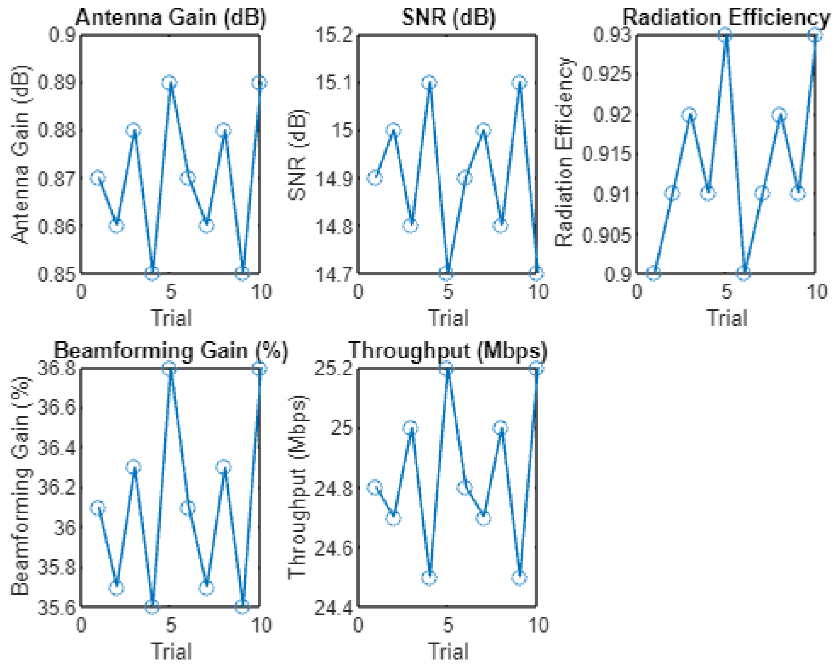

Figure. 7: Particle Swarm Optimization – metrics

From the Figure 8, The use of Convolutional Neural Networks for antenna design led to results similar to those achieved with traditional optimization methods, but the enhancements in antenna gain, SNR, and radiation efficiency were consistently high. Specifically, the mean antenna gain was in the range of 0.85 dB to 0.89 dB, indicating that the signal strength would be boosted significantly. SNR results were between 14.7 dB and 15.1 dB, demonstrating that signal quality would be significantly improved along with a heightened resistance to noise. Radiation efficiency was high in all cases, with ranges from 0.90 to 0.93. These outcomes show that CNNs develop a comprehensive understanding of the complexities of the data, which can be used to improve the optimization process and find optimal antenna configurations.

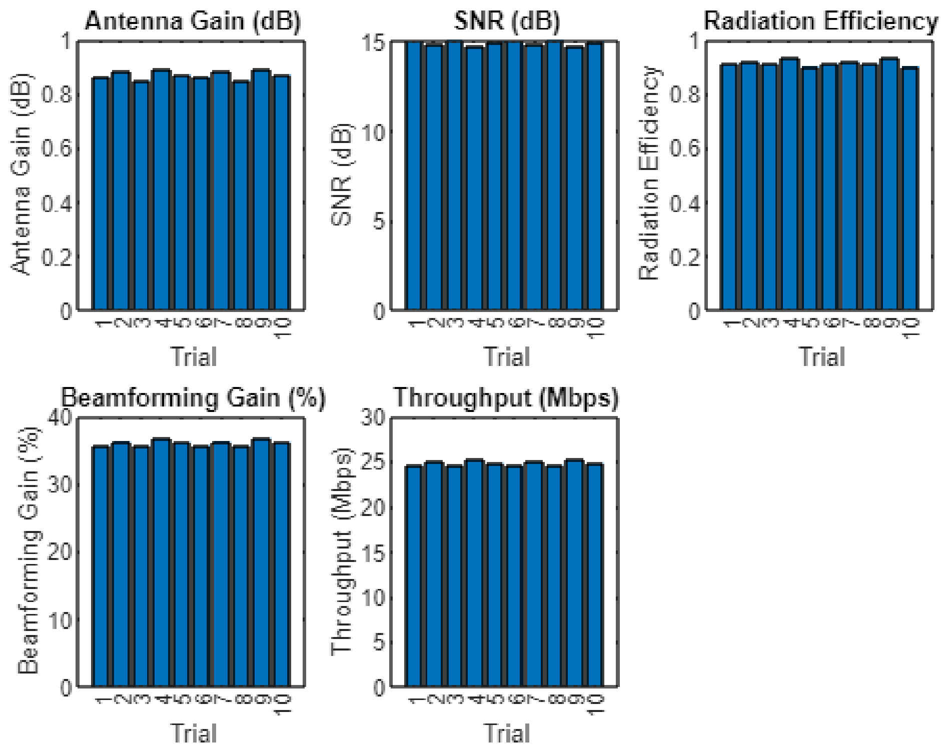

Figure. 8: Convolutional Neural Networks for Antenna Design- metrics

Ultimately, various performance evaluations have helped to demonstrate the effectiveness of optimization techniques to improve microstrip antenna array performance in a 5G sub-3.5GHz network. Bayesian optimization, sparse learning, genetic algorithms, and particle swarm optimization, as well as a CNN, were considered to demonstrate their benefits in addressing performance improvement and computational efficiency . The results of the comparison indicate that each technique has its own advantages; however, all can be used to develop and optimize microstrip antenna arrays, capable of meeting 5G network's performance requirements in terms of high data rates, low latency, and massive connectivity.

VII. CONCLUSION

The summary of the extension evaluation of the optimization techniques for microstrip antenna arrays in 5G sub-3.5 GHz networks is that innovative methods should be used to improve learning. On most occasions, this was observed in the gains of the average antenna , where most of the techniques resulted in improvements with values ranging from 0.84 dB to 0.88 dB. In terms of the signal-to-noise ratio, the 14.8 dB to 15.3 dB scores were positive, although there were some recording values of around 15.7 dB and 15.2 dB. The radiation efficiency also witnessed positive scores between 0.90 and 0.93. Sparse learning techniques yielded moderate performance in the evaluation, with improvements in the average antenna gain ranging between 0.80 to 0.85 dB . The SNR values also highlighted less noise, ranging from and 15.2 to 15.7 dB. Similarly, the performance of genetic algorithms and particle swarm optimization was moderate, with the average antenna gain improving by between 0.85 and 0.89 dB, and the SNR mean being at 15.1 dB . Convolutional neural networks also had some level of performance and the specific impact results matched those of genetic algorithms and PSO in terms of average antenna gain and the SNR values range of 14.7 to 15.1 dB. The conclusion from this summary is that a significant number of optimization techniques are available for designing antennas, with all of them ensuring specific benefits in enhancing performance and learning convenience.

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