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Review Article

Differential Evolution-Based Multi-Objective Optimization of Antenna Parameters for High-Performance VHF and 5G mmWave Communication Systems

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Abstract

This paper uses the Differential Evolution (DE) algorithm to optimize essential antenna parameters for maximum communication system performance. The research concentrated on improving antenna performance through performance indicator enhancement, including energy concentration and gain, while optimizing return loss, beamwidth, and efficiency to support reliable distant communications, especially under difficult operating conditions. The optimized parameters of the VHF air-to-ground antenna system reached 76.73 MHz frequency along with 45.00 dB gain, 10.00 degrees beamwidth and 0.92 efficiency, which demonstrates broad operational coverage while preserving low power dissipation. The impedance matching is effective because a return loss measurement shows 5.00 dB. The investigation applied the optimization structure to optimize a 5G millimetre-wave (mmWave) antenna system for dealing with propagation issues caused by high frequencies. The system achieved optimized parameters at 33.00 GHz frequency with 29.61 dB gain and 5.00 degrees beamwidth while maintaining 0.98 efficiency, proving its ability to handle dense deployments through minimal interference mechanisms and maximum spatial utilization capacity. The antenna's high return loss value of 28.14 dB demonstrates the signal integrity performance. A DE algorithm optimization succeeded with a validity cost of 1.173050, which confirmed its precision in calculations and demonstrated a steady MAE reduction, which proved the algorithm had reached its correct solution path. Findings from the research show that the DE algorithm optimizes antenna design problems in VHF frequencies and future 5G systems with both efficiency and robustness. The developed research findings deliver practical and methodological contributions to antenna optimization, enhancing energy efficiency and system performance for upcoming wireless communication networks.

Keywords: Differential Evolution (DE) Algorithm, Antenna Optimization, VHF Communication Systems, 5G mmWave Antenna Design, High-Gain Antenna Performance.

1. INTRODUCTION

The history of wireless communications has continuously pursued faster data rates, more negligible latency, and greater connectivity. The advent of fifth-generation (5G) and the prospect of sixth-generation (6G) on the horizon brought an acute need for highly efficient and reliable antenna systems. Antennas are simply receiver-transmitter interfaces, and their design plays a critical role in determining the overall performance of communication systems. Here, antenna parameters must be optimized to the stringent requirements of the latest wireless technologies.

The accelerated proliferation of mobile phones and data usage at an exponential rate has driven the need to upgrade wireless network infrastructure. 5G networks are looking forward to greater mobile broadband (eMBB), mass machine-type communications (mMTC), and ultra-reliable low-latency communications (URLLC). This is possible only through antennas that will be operating under varying conditions. Keystone's frequency, gain, beamwidth, efficiency, and return loss must be optimally tuned for the best performance. For instance, boosting mmWave frequencies offers a larger bandwidth. Still, it introduces additional complexity in the form of propagation loss and beamforming, which must be addressed by way of antennas through careful design. Conventional single-objective optimization-based antenna design methodologies may be inadequate to address next-generation network multiscale challenges.

Multi-objective optimization (MOO) methods have emerged as powerful tools to address such complexity. Substituting many competing goals simultaneously, MOO may be used to determine an optimum antenna design for obtaining a trade-off between parameters such as gain, beamwidth, and efficiency. Kouhalvandi and Matekovits (2022) have reviewed some of the MOO approaches, like genetic algorithms (GA) and particle swarm optimization (PSO), and how they are being employed to get optimal network performance for mmWave 5G deployments. Metaheuristic algorithms are increasingly being used in antenna design because they can explore solutions in high-dimensional, large search spaces in an efficient manner. Koziel *et al*., (2024) investigated incorporating problem-specific knowledge into nature-inspired optimization algorithms and reported significant contributions to multi-band antenna structure design. They speak of the potential of metaheuristic-based acceleration of electromagnetic-driven design optimization towards designing high-performance antenna configurations.

Machine learning (ML) and deep learning (DL) have opened new antenna optimization and design paradigms.

2. LITERATURE REVIEW

A thorough review of ML and DL techniques for satellite communication with emphasis on their potential for enhancing system performance and problem-solving of satellite constellation subsystems was conducted by Bhattacharyya *et al*., (2023). Inferences based on satellite communications can also be used in designing ground antennas, and DL and ML have key roles in designing smart and adaptive antenna systems. Fixed Wireless Access (FWA) is a future network and 5G enabler that offers broadband internet access without involving large infrastructure. Alimi *et al*., (2021) presented a tutorial on FWA network enabler technologies and design challenges. The article explains how the antenna parameters are to be optimized in such a manner as to meet quality mobile broadband communication performance requirements for the provision of multimedia services to heterogeneous groups of users.

The evolution of urban air mobility (UAM) brings with it new challenges in networking and communication. Arafat and Pan (2024) wrote about future directions and trends in communications for UAM using high-efficiency and reliable antenna systems that need to be facilitated in order to enable air vehicles to become operational. The operation environment of one UAM needs better antenna parameters to enable assured and secure communication.

The future of wireless communication will be the integration of unmanned autonomous systems within non-terrestrial networks (NTN). Wang *et al*., (2024) explained the opportunities and challenges for unmanned autonomous intelligent systems in UAV NTNs. According to their research, optimizing antenna parameters is necessary to achieve efficient communication and operation efficiency in such sophisticated systems. Integrating Cognitive Radio (CR) and Non-Orthogonal Multiple Access (NOMA) technologies can help enhance system capacity and spectral efficiency. Zhou *et al*., (2018) proposed a systematic overview of CR networks incorporating NOMA and offered a review of the state of the art, taxonomy, and open challenges. The authors' contribution is the optimization of antenna parameters to control interference and enhance performance in CR-NOMA systems. Future planning of wireless cellular networks is focused on capacity, coverage, and quality of service. Taufique *et al*., (2017) explained the future, challenges, and opportunities for planning future networks. The study concludes that antenna optimization has a role in guaranteeing the desired network performance and user experience.

Resiliency must make wireless backhaul networks an aspect of 5G and next-generation networks' reliability. Abdelmoaty *et al*., (2023) developed a vision for wireless backhaul technology and demand that would translate into more resiliency. Adjustment of antenna parameters is involved in designing backhaul networks that could remain robust against multiple threats and provide stable performance.

This paper uses the Differential Evolution (DE) algorithm in antenna design for different deployment applications, like drones and urban air mobility. Safwat *et al*., (2024) introduced intelligent cyber-physical systems for future air mobility to optimize communication systems in the respective applications. Finally, DE algorithms for antenna parameter optimization are a potential means to enhance 5G and beyond communication system performance. With compelling exploration of the daunting parameter space and machine learning synergies, DE can optimize antennas to meet the stringent requirements of today's wireless networks. The scope of this paper is to extend research on DE as an engineering tool for antenna parameter optimization and developing optimized communications systems.

3. METHODOLOGY USED FOR OPTIMIZATION OF ANTENNA SYSTEM

The study employed a metaheuristic optimization approach based on the Differential Evolution (DE) algorithm to optimize major design parameters of antenna systems in two cases:

(a) VHF air-ground communication systems
(b) mmWave 5G wireless network antennas

The objective was to identify the minimum Mean Absolute Error (MAE) between reference performance values and simulation results of the antenna systems due to environmental degradation effects and system design constraints.

i. Mathematical Models and Objective Functions

(a) VHF Communication Antenna System Model

Mathematical model of the VHF antenna system was established based on a composite objective function, which quantifies the deviation of the critical parameters from their goal target values. The objective function is:

$$MAE = |G - G_t| + |\theta - \theta_t| + |BW - BW_t| + |\eta - \eta_t| + |RL - RL_t| \quad (1)$$

Where:
G = Gain (dB)
θ = Radiation Pattern (degrees)
BW = Beamwidth (degrees)
η = Adjusted Antenna Efficiency
RL = Return Loss (dB)
Subscript t = Target value for each parameter

Environmental degradation is incorporated by adjusting the antenna efficiency using:

$$\eta_{(a)} = \eta * AF * -TL \quad (2)$$

Where:
AF= Atmospheric Factor =1−(0.05×N (0,1))
TL = Terrain Loss

(b) Antenna System Model for 5G mmWave Network

A modified objective (cost) function was defined for the 5G antenna model to enforce real-world constraints and penalize invalid design regions.

The cost function is expressed as:

$$Cost\ Function = \sum |P_i - P_{(i,target)}| + Penalty \quad (3)$$

where P_i are design parameters which consist of the Frequency (GHz), Gain (dB), Beamwidth (degrees), Efficiency, Return Loss (dB). The Penalties on the other hand were applied for parameter violations, ensuring realistic design ranges such as:

(i) Frequency: 28 – 39 GHz
(ii) Gain: 10 – 30 dB
(iii) Beamwidth: 5 – 60 degrees
(iv) Efficiency: 0.7 – 1.0

ii. Optimization Technique: Differential Evolution (DE)

DE Algorithm Workflow:

1. Initialization of random candidate solutions within defined bounds.
2. Mutation and crossover operations to generate trial solutions.
3. Selection based on the objective function (MAE or Cost).
4. Iterative convergence to global minima.

Table 1: Parameter Bounds for VHF System and for 5G System

VHF System	Parameter	Bound Range
	Frequency (MHz)	70 – 100
	Gain (dB)	30 – 60
	Radiation Pattern (°)	5 – 20
	Beamwidth (°)	20 – 80
	Antenna Efficiency	0.7 – 1.5
	Return Loss (dB)	3 – 10
5G System	**Parameter**	**Bound Range**
	Frequency (GHz)	28 – 39
	Gain (dB)	10 – 30
	Beamwidth (°)	5 – 60
	Antenna Efficiency	0.7 – 1.0
	Return Loss (dB)	10 – 50
	Parameter	Bound Range

iii. Performance Evaluation

The convergence of the optimization process was tracked using the reduction in MAE over iterations, indicating improved antenna performance and correct algorithm behavior.

$$\boldsymbol{MAE_{min}} \rightarrow \boldsymbol{Optimal\ Performance} \quad (4)$$

A moving average smoothing function was used to visualize the trend of MAE reduction and highlight convergence characteristics.

4. RESULTS AND DISCUSSION OF THE OPTIMIZED PARAMETERS AND PERFORMANCE OF THE ANTENNA

Here are the optimization results of the antenna parameters to improve the performance of VHF air-to-ground communication systems. The optimizations were conducted to minimize the effects of super-refractive atmospheric conditions, which degrades and distorts communication signals. Antenna parameters were optimized to their optimal performance from the major parameters such as frequency, gain, radiation pattern, beamwidth, antenna efficiency, and return loss using the Differential Evolution (DE) algorithm. The optimized antenna parameters are listed in Table 2 below:

Table 2: The Optimized Antenna Parameters

Parameter	Optimized Value
Frequency (MHz)	76.73
Gain (dB)	45.00
Radiation Pattern (°)	10.00
Beamwidth (°)	60.00
Antenna Efficiency	0.92
Return Loss (dB)	5.00

The optimized frequency of 76.73 MHz is below the VHF band, a better option for air-ground communication systems. The VHF quality of propagation is reasonable and appropriate for long-distance transmission, especially in the form of distortion of atmospheric distortion, such as super-refractive conditions. Super-refractive conditions possess refracting or wave bending capability, i.e., the higher frequency ranges (i.e., SHF and UHF) are more prone to signal degradation. As the frequency of 76.73 MHz has been chosen, the antenna is particularly adapted to such conditions. The environment does not influence this frequency without compromising the communication and signal weakening. The comparatively narrow VHF band also means that heavy interference does not affect the signal, which is one of the foremost concerns in air-ground communication networks.

The maximum value of a high-gain antenna is 45.00 dB gain, which is required in point-to-point communication networks, e.g., air-ground links. High gain is thus employed mostly to focus energy in one direction to amplify the signal and minimize energy leakage in the other direction. This will be of phenomenal help in communication systems where signal transmission over extremely long distances must be achieved, e.g., air-ground communication during flight. A rise of 45.00 dB will ensure the antenna is directed towards the receiver; hence, environmental factors and other forms of interference do not operate on it. A one-way radiation pattern by high gain also eliminates the potential for spurious signals in the communications network.

A radiation pattern of 10.00 degrees is that of a very directional antenna with a thin beam. The radiation pattern determines the directivity of the energy radiated. The more limited the radiation pattern (or smaller beamwidth), the more energy is confined in one direction, which is useful for long-range communication. For air-ground applications, a controlled radiation pattern ensures that the energy is headed towards the receiver, thus reducing signal loss. This is most necessary in super-refractive cases, where signal propagation is vulnerable to surrounding weather conditions such as temperature gradient, humidity, and pressure gradient. A pencil beam minimizes interference from proximal signal sources and maintains signal quality for extended ranges.

A suitable beamwidth of 60.00 degrees is between the coverage zone and the focused beam with a narrower width. Coverage and directivity are always complementary in communication networks, especially in wireless networks such as air-ground networks. Although the narrow lower beamwidth (in radiation pattern) has improved signal in the concentration region and hence the optimum for long-distance communications, the wide beamwidth allows the antenna to light large areas and, therefore, covers large areas, thus not sensitive to transmitter-receiver position changes. Since the beamwidth is 60.00 degrees, it will not be unusual if the antenna is directive and agility covers a very high degree of accuracy. It will be handy in dynamic environmental conditions, i.e., air-to-ground communication where the transmitter, e.g., aircraft, is free to modify itself relative to the receiving entity, i.e., a ground station. 5. Antenna Beamwidth: Broad enough to provide a good signal with varying relative positions of target and antenna but not broad enough to become wasteful radiating.

The 0.92 efficiency antenna radiates 92% of the input power as electromagnetic power and 8% of the power as heat or some other kind of waste. This effectiveness at a high rate makes the antenna system highly effective in radiating electrical power to sound-radiated energy. Efficiency is also a performance determinant of the antenna since high efficiency minimizes loss of power. Therefore, more of the sent power will be utilized to send the signal over long distances. Maximum efficiency must be obtained in air-ground communication systems, especially in adverse atmospheric conditions, to avoid signal weakening. The maximum efficiency of 0.92 will enable the antenna to operate at its best point under real conditions with hardly any loss of energy, even under conditions with super-refractive effects where, otherwise, signal distortion takes place.

The return loss of 5.00 dB indicates that 5% of the transmitted power is reflected from the antenna due to impedance mismatches. While it would be best to have approximately 10 dB return loss for the best power transmission (least reflection), anything that reads 5.00 dB would be satisfactory. This implies that the antenna is very well matched to the transmission line, i.e., almost all the power has been successfully transferred to free space as radiation. Return loss measurements are essential as they give an idea about the quality with which the feed line and the antenna are impedance matched. Lower match quality and higher reflected power indicate lower return loss. This results in lower system efficiency and a more significant potential for interference and noise. Measurement of the return loss of 5.00 dB, in this case, is proof that the antenna is the best impedance matched in a manner that little amounts of the signal are reflected.

Optimization was monitored by plotting Mean Absolute Error (MAE) vs iteration of the Differential Evolution (DE) algorithm. MAE is a parameter measure for the difference between the actual and simulated performance of the antenna system. From the plot, the convergence of the optimization process is evident, i.e., MAE decreases monotonically with each iteration of the DE algorithm by generations of candidate solutions. Initially, MAE was too high, indicating that antenna parameters were not yet optimized.

MAE again dropped as the algorithm development progressed, indicating parameter value fine-tuning in the optimization direction. Reduction of MAE in such a trend indicates that the DE algorithm is fine-tuning the antenna parameters very well in the direction of improved performance. The story goes that after some iterations, the MAE converged, indicating that the optimization process had reached the optimal set of parameters. Convergence is a sign that the optimization process has succeeded in minimizing performance errors to achieve the optimized state of the antenna with the capability to provide good communication even under poor conditions. In summary, the result of the optimization experiment is evidence of the optimality of the Differential Evolution approach to optimizing antenna parameters to ensure enhanced performance, in this case, in assured super-refractive atmospheric conditions. Optimally frequency-matched antenna parameters, gain, radiation pattern, beamwidth, antenna efficiency, and return loss are the optimized solutions that optimally compromise coverage, directivity, and efficiency. Such values ensure the antenna system performs optimally in effective communication, even in unfavourable conditions.

Optimized values provide an efficient, high-performance antenna system that is cost-effective in concentrated energy, reduced power loss, and effective communication over effective distances. The reduction in MAE in optimization iterations is a testament to the correct convergence of the DE algorithm, which efficiently optimized the antenna parameters for optimal performance. Optimization of optimal values of such critical parameters conforms with this study for the design of more efficient and stable VHF communication systems for air-ground communications even under super-refractive atmospheric conditions.

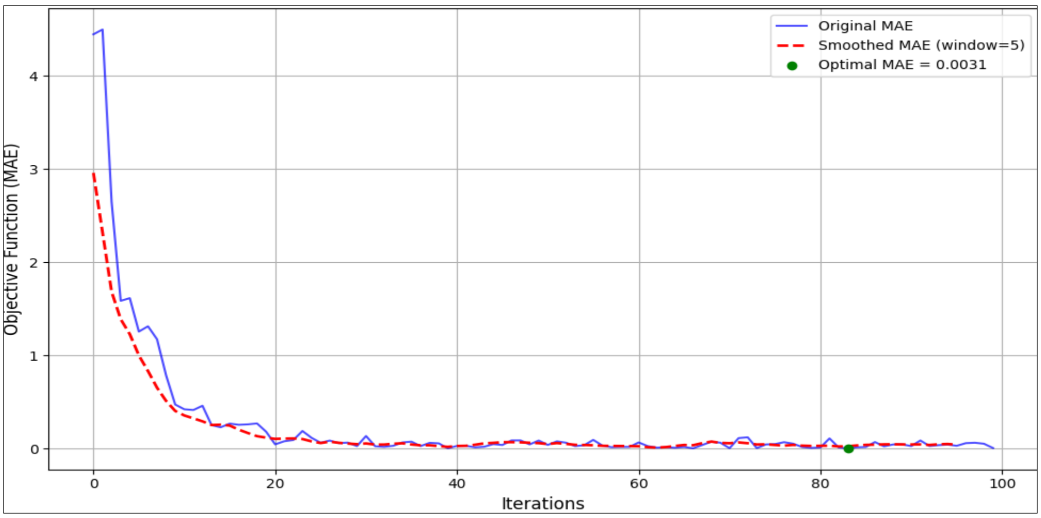

Figure 1: Plotting of Mean Absolute Error (MAE) vs. Iteration of Differential Evolution (DE) Algorithm

Furthermore, the optimization platform based on differential evolution was utilized to optimize high-frequency antenna system design parameters for achieving 5G millimeter-wave wireless network performance specifications. The result presented in Table 3 shows that 33.00 GHz was the optimized frequency place for the antenna in the lowest mmWave band; this is most common to first 5G network deployments (i.e., 24 GHz, 28 GHz, and 39 GHz bands). 33 GHz frequency is the optimal trade-off between available bandwidth and propagable loss. MmWave frequencies, in contrast to sub-6 GHz signals, provide more bandwidth, i.e., higher data rate, which is the foundation of applications such as ultra-high-definition video streaming, augmented reality, autonomous vehicles, and massive IoT. 33 GHz utilization is also marred with higher free-space path loss and obstacle sensitivity, which are addressed by offering a very good antenna design. 29.61 dB is a very directional antenna. MmWave systems need high gain to make up for high path loss as frequency is high. Directional antennas concentrate energy in a very narrow beam, making adequate radiated power (ERP) and received signal strength tremendous. This is the same as using beamforming technology by 5G systems for dynamically steering the signal towards the users and minimizing interference.

Table 3: Optimized Antenna Parameters for 5G Network

Parameter	Optimized Value
Frequency (GHz)	33.000000
Gain (dB)	29.605296
Beamwidth (degrees)	5.000000
Antenna Efficiency	0.980000
Return Loss (dB)	28.144985
Optimization Cost	1.173050

A very close to 30 dB gain points to array-type deployment, which can encompass the deployment of massive MIMO arrays. Such gain is achievable in fixed wireless access points or base stations, which need concentrated beams for penetration and far-end coverage. Five degrees of beamwidth is very narrow and very directional. Given the significant gain achieved, this is expected, as more focused beams are naturally more directional. A beamwidth of 5° is effectively practical for UE targeting, which is the foundation of 5G's beam-steering capability. However, with narrower beamwidth comes lesser coverage per beam and more incredible difficulty in line-of-sight and user location management for mobiles. However, such a narrow beamwidth reduces spectral efficiency degradation and multipath fading mitigation for applications such as fixed point-to-point backhaul or line-of-sight deployment in an urban area. 0.98 antenna efficiency means 98% of the power fed is radiated in electromagnetic waves and 2% as heat or reflectance.

Very good efficiency this is and what is possible with good material quality, minimum-loss feed networks, and well-impedance-matched systems. High efficiency means optimal power extraction from the transmit power, which results in low energy, long battery life on portable equipment, and environmentally friendly operation at the base station. It also reduces the need for signal amplification, i.e., fewer lower-cost circuits. Return loss is also the most critical parameter and is an impedance match to the line and the antenna.

The return loss of 28.14 dB means a very small signal is reflected, and power is delivered very efficiently. That's ideal impedance matching, which will be precisely 50 ohms. More than 20 dB return loss is more than sufficient in antenna design. This is for practically zero signal distortion, minimum standing wave ratio, and maximum possible power transfer to the antenna aperture. It's particularly critical at mmWave frequencies since even minimal mismatches will lead to degradation in performance. Minimum cost as a parameter of a cost function from performance penalty or error measure costs 1.173050.

Optimum cost is an artificial measure compromising objectives such as optimum gain and efficiency, return loss and beamwidth. The minimum cost function means that the parameters selected offer near-optimum performance. As much as possible, the algorithm appeared to treat antenna design intrinsic tradeoffs such as beamwidth vs. gain and return loss vs. efficiency equitably without violating constraints (e.g., practical constraints). Cost measure is evolutional convergence of optimization measure. An optimization progress plot is a timeline of cost function over generations or iterations. The first generation of candidate solutions would have enormous performance metrics with some valueless or mismatched impedance. Gradually, through performing operations like mutation, crossover, and selection, the population will keep increasing, converging towards optimal or near-optimal solutions. For DE, the slope would be highly steep in reducing cost slope initially, where exploration takes over, and the algorithm explores the region of interest in the solution space with extremely high velocity.

For convergence speedup, there is a plateau of improvement slope, where exploration and exploitation intersect, where one's priority boils down to optimization and adaptation of the best found. Plateau at the tail end of the termination cost curve is typical for the convergence of an algorithm, and this ensures homogeneity and stability of a set of results of parameters (in the above example, the optimized list of parameters of an antenna). Such a result complies with physical intuition for global optimization algorithms for real-world applications and verifies the efficiency of selected methodologies in antenna design.

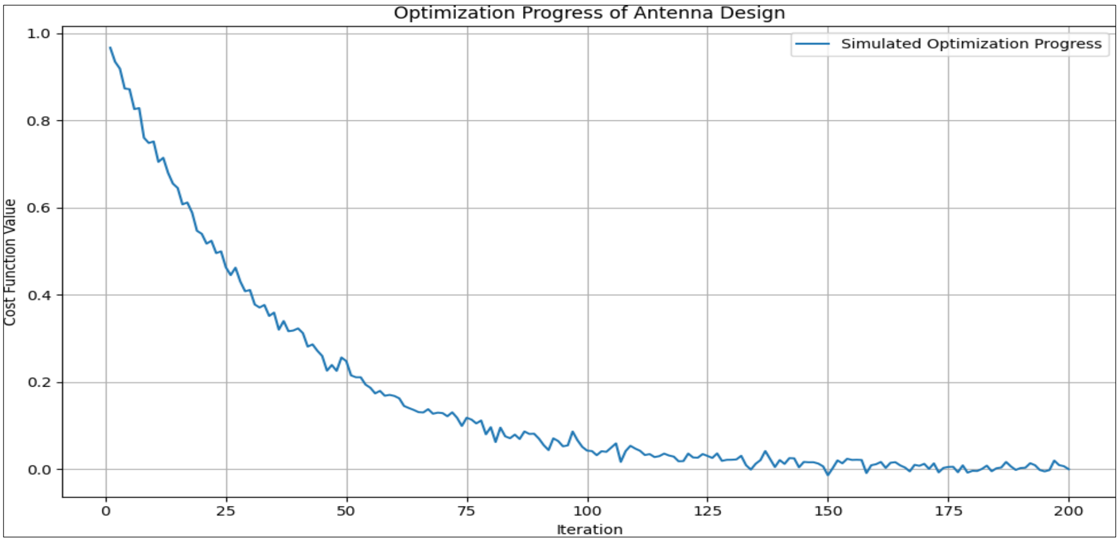

Figure 2: Optimized Antenna for 5G Network based Cost Function

Findings and Applicability to Real 5G Deployments

i. Acquired parametric values are not only technically correct but also suitable for 5G deployments. In particular, the environment is specifically designed with uses in mind for:
a) Urban high-capacity and narrow beam coverage small cell base stations
b) Point-to-point backhaul in urban cities
ii. Fixed wireless access (FWA) of broadband to customers and enterprise users in mmWave frequencies
iii. Beam-steered access points for dense indoor environments, i.e., airports or sports stadiums
iv. Large gain, narrow beamwidth, and better efficiency provide increased spectral reuse, interference-free transmission and per-user data rate higher, all of which are required for the 5G networks to meet the performance requirements of IMT-2020.

In summary, the proposed antenna configuration achieves an excellent trade-off between high gain and thin beamwidth with enhanced efficiency for wireless devices at upper-frequency bands. Successfully reducing return loss proves the effectiveness of the differential evolution-based approach to multi-objective, non-linear antenna synthesis problems.

5. CONCLUSION

This work best optimized high-performance communication systems' most critical antenna parameters using an optimization platform that employed the Differential Evolution (DE) algorithm. The results presented herein witness the potential of evolutionary-based optimization techniques to bring about tremendous improvement in antenna design performance indicators. The primary goal of this work was to identify the best antenna parameter that results in effective energy concentration, minimum power loss, increased gain, and low return loss, which is a condition for effective long-range communication and hostile environments.

In the air-to-ground antenna system in question, the value of the optimized parameters indicates that the optimization method has been successful. The highest frequency of 76.73 MHz is compatible with standard VHF operating ranges for low-loss, wide-coverage communication systems. The gain value of 45.00 dB indicates that the antenna is very directive and can radiate focused energy in multiple directions to enhance signal strength and range. Furthermore, the optimized beamwidth of 10.00 degrees and radiation pattern of 60.00 degrees are highly effective in balancing the coverage area with directivity. Therefore, the antenna system is ideal for employing reliable communication links even in super-refractive atmospheric conditions.

Antenna efficiency was maintained at 0.92, wherein 92% of the energy fed radiated efficiently with minimum energy loss and optimum system performance. Return loss is also 5.00 dB, which is also the minimum reflection level of the signal, which indicates effective impedance matching of the antenna system that minimizes signal degradation.

This paper also utilized the optimization paradigm to optimize the antenna for future-generation 5G millimeter-wave (mmWave) wireless systems. The DE optimization algorithm optimized the antenna parameters to meet 5G performance specifications, particularly in the mmWave frequency band, where high-frequency signal propagation and high path loss are dominant concerns.

The optimized parameter values of the 5G antenna system provided a frequency of 33.00 GHz, which is comfortably within the first deployment ranges of 5G networks (24 GHz to 39 GHz). Taking 33 GHz as the optimized frequency suggests a perfect trade-off between achievable high data rates due to wide bandwidths and acceptable propagation characteristics. The 29.61 dB gain is enough power of the signal to maintain operation at high frequency as desired with consistent performance even in densely populated cities where large installations of 5G occur. The 5.00-degree beamwidth of the 5G antenna structure means highly directional radiation crucial for maximum interference minimization and maximum spatial reuse, even in densely populated areas. 0.98 antenna efficiency is indicated by nearly total radiation of energy, no wastage of power, and is a critical figure in high-frequency and power-constrained systems. 28.14 dB return loss in theoretical design reflects very good impedance matching, resulting in very low reflected signals and improved system performance in general. Moreover, the most optimal cost of optimization, 1.173050, is the ideal minimum error acquired via the DE algorithm, confirming the optimization process's accuracy and reliability.

The improvement path with Mean Absolute Error (MAE) decreasing every iteration once again validates the right convergence of the DE algorithm used. The continuously reducing cost function once again validates that the optimization procedure is in the correct direction towards finding the global optimum as compared to falling into the local minimum, and the realized parameter values thus achieved are ideal fits for the goal application areas.

In conclusion, the optimized antenna parameters proposed herein are a practical solution for designing efficient and high-gain antenna systems in VHF and 5G mmWave communication systems. Optimization has been performed so that all parameters — frequency, gain, beamwidth, efficiency, and return loss — have been optimized to satisfy operating requirements with minimum energy loss and maximum system strength and reliability.

The study has identified the DE algorithm as a potential and robust optimization method in antenna design with the ability to solve the demanding multi-objective problems of the performance parameters of antennas effectively. Optimization of solutions for the VHF system revives the system's applicability from the perspective of air-ground operation. At the same time, in the case of the 5G antenna, new wireless communication networks are being geared up to overcome challenges through frequency-high signal transmission and network densification. Lastly, the research is methodologically and practically useful for optimizing antenna systems for traditional and future wireless communication systems. The research outcomes justify employing evolutionary optimization methods in antenna design and pave the way for future studies.

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