Advancements in Flexible Antenna Design: Enabling Tri-Band Connectivity for WLAN, WiMAX, and 5G Applications

Olga Fisenko[1*], Larisa Adonina[2], Heriberto Solis Sosa[3],
Shiguay Guizado Giomar Arturo[4], Angélica Sánchez Castro[5],
Fernando Willy Morillo Galarza[6] and David Aroni Palomino[7]

[1*] PhD, Professor, Peoples' Friendship University of Russia (RUDN University), Moscow, Russian Federation. olfiss@list.ru, Orcid: https://orcid.org/0000-0002-3824-5535

[2] PhD, Professor, Sevastopol State University, Sevastopol, Russian Federation. lar_sad@list.ru, Orcid: https://orcid.org/0000-0002-1322-4244

[3] Doctor, Professor, Faculty of Humanities, Universidad Católica Santo Toribio de Mogrovejo, Chiclayo, Perú. heribertosolisosa@gmail.com, Orcid: https://orcid.org/000-0003-0147-8076

[4] Doctor, Professor, Graduate School, Universidad Nacional Mayor de San Marcos, Lima, Perú. giomar.shiguay@unmsm.edu.pe, Orcid: https://orcid.org/0000-0001-9859-3008

[5] Doctor, Professor, Principal Teacher, Universidad Nacional Autónoma de Alto Amazonas, Amazonas, Perú. asanchez@unaaa.edu.pe, Orcid: https://orcid.org/0000-0003-0680-7836

[6] Doctor, Professor, Faculty of Business Sciences, Universidad César Vallejo, Tarapoto, Perú. fmorillog@ucvvirtual.edu.pe, Orcid: https://orcid.org/0000-0002-8054-6139

[7] Master, Professor, Universidad Nacional Enrique Guzmán y Valle, Lima, Perú. daroni@une.edu.pe, Orcid: https://orcid.org/0000-0003-2095-2503

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Abstract

The use of flexible antennas has garnered significant interest in light of their wide-ranging applications inside contemporary wireless communication systems. The need for these antennas stems from the necessity for small, conformal, and versatile systems that can effectively function across many frequency ranges. The present study investigates designing and optimizing a universal triband antenna, focusing on meeting the distinct demands of Wireless Local Area Networks (WLAN), Worldwide Interoperability for Microwave Access (WiMAX), and 5G applications. The current methodologies often need help attaining maximum efficiency over a wide range of frequency bands, resulting in concerns such as subpar radiation patterns and restricted bandwidth. To address the obstacles, this research proposes a novel approach known as the Triband Antenna Design using the Artificial Neural Network (3AD-ANN) method. This method utilizes machine learning techniques to devise and enhance the attributes of the antenna effectively. The 3AD-ANN approach presents several notable characteristics, such as heightened adaptability, increased radiation patterns, and a condensed physical structure. The mean values for far-field radiation gain are around -37.4 dB in simulated scenarios and -39.9 dB in actual observations. The average return loss is roughly -23.8 dB in simulations and -25.8 dB in experimental measurements. The numerical findings

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*Corresponding author: PhD, Professor, Peoples' Friendship University of Russia (RUDN University), Moscow, Russian Federation.

illustrate the effectiveness of this methodology, exhibiting exceptional return loss and gain sizes over a range of frequencies, including WLAN, WiMAX, and 5G.

Keywords: Flexible Antenna, Triband Antenna, WLAN, WiMAX, 5G.

1 Introduction to Flexible Antenna Design

The growing interconnectedness of global society has generated a substantial need for rapid wireless communication, hence driving notable progress in antenna design (Abulgasem, S., 2021). Wireless Local Area Networks (WLANs) (Raja, K.B., 2022), Worldwide Interoperability for Microwave Access (WiMAX) (Sorathiya, V., 2023), and 5G applications (Benzaghta, M., 2021) have become integral to the digital infrastructure. Each of these technologies serves unique objectives and works within specific frequency bands, requiring the development of inventive antenna designs to provide uninterrupted communication. This research article investigates the progression of antenna technology to facilitate the implementation of tri-band connections for WLAN, WiMAX, and 5G applications. This analysis explores the present-day demands of various technologies, highlights the crucial significance of antennas in their functioning, and accentuates the benefits associated with flexible antenna configurations (Dang, Q.H., 2022). Moreover, it expounds upon the complex difficulties of designing tri-band antennas for such applications. It includes significant technical perspectives and numerical information to comprehend this evolving domain thoroughly.

WLAN, WiMAX, and 5G technologies have emerged as fundamental pillars within the contemporary wireless communication ecosystem (Mathur, P., 2021). Each application functions inside discrete frequency bands, exhibiting distinctive needs customized to suit their intended objectives. The WLAN technology facilitates wireless networking in residential and commercial settings. It typically operates between the 2.4 GHz and 5 GHz frequency bands, providing a fundamental infrastructure for wireless communication (Shilpa, B., 2022). The rising number of connected devices and apps necessitates the provision of high data speeds, dependable indoor coverage, and seamless mobility.

WiMAX operates throughout the frequency ranges of 2.3 GHz, 2.5 GHz, and 3.5 GHz, providing expansive coverage for broadband wireless connectivity (Mirzababaee, N., 2021). The primary objective is to address the digital divide by facilitating internet accessibility in regions lacking adequate coverage and ensuring mobile broadband connectivity in metropolitan areas. This necessitates the deployment of antennas that possess the capability to give long-range, high-speed connections. The fifth generation of wireless technology, 5G, encompasses a wide range of frequencies, including sub-6 GHz and millimeter-wave (mmWave) bands (Liang, Q., 2022). The 5G technology offers significant advantages like minimal latency, increased data transfer speeds, and extensive device connection. These capabilities can enable groundbreaking applications such as driverless cars, augmented reality, and the Internet of Things (IoT) (Kishore, N., 2022). To accomplish these objectives, implementing 5G necessitates using antennas that can operate over a wide range of frequencies while maintaining high efficiency.

Antennas are vital in facilitating the exchange of electromagnetic waves in space and the electrical impulses inside wireless devices (Uchida, N., 2017). Wireless networks rely heavily on their capacity to send and receive information, directly influencing their performance, dependability, and coverage. Antennas facilitate effective and resilient communication within WLAN, WiMAX, and 5G networks, which connect devices to the digital domain.

Flexible antennas provide great versatility, allowing seamless integration into various applications, such as wearable devices and IoT sensors. Frequency agility is a notable feature of these devices since they can effectively operate across several bands, including WLAN, WiMAX, and 5G. They effectively mitigate interference and improve signal integrity in intricate settings while ensuring robustness. The process of designing tri-band antennas encompasses various challenges that must be addressed to achieve optimal performance. These challenges include the coordination of antennas to enable coexistence within different frequency bands, adhering to strict size limitations, ensuring high radiation efficiency, and achieving wideband operation across the frequencies associated with 5G technology. These requirements necessitate the implementation of advanced engineering techniques and innovative design strategies.

The primary contributions are given below:

- The present study presents conventional Microstrip Patch Antenna (MPA) design guidelines. These guidelines include design equations to calculate the patch size of an MPA, taking into consideration the mentioned parameters.
- The study presents a unique configuration of a tri-band antenna, which is implemented on a Low-Cost Polymer (LCP) substrate. This antenna design covers frequency bands, including the 4.9-GHz 5G, 5.5-GHz WiMAX, and 5.2/5.8-GHz WLAN standards.
- The incorporation of L-shaped strips into a system the integration of L-shaped strips with the original antenna has enabled tri-band operation, effectively spanning the frequency ranges of 2.4 GHz for WLAN and 3.5 GHz for 5G/WiMAX.
- The ANN-based technique involves developing a Multilayer Perceptron (MLP) neural network to efficiently and precisely predict antenna dimensions that effectively span WLAN/WiMAX bands.

The following sections are arranged in the given manner: Section 2 analyses pertinent research that has already been done and its conclusions. The approach and specifics of the suggested tri-band antenna design utilizing ANN (3AD-ANN) are described in Section 3. The experimental findings and their consequences from the constructed antenna prototypes are presented in Section 4. The main conclusions, contributions, and implications of the research are summarized in Section 5.

2 Literature Survey and Analysis

The literature review offers a thorough analysis of prior research and achievements in the area, serving as a basis for the suggested design of a tri-band antenna. The scope of this analysis includes examining significant research papers, methodology used, and technical advancements pertinent to the topic under consideration.

Che et al. presented a concise design of a four-channel Multiple-Input Multiple-Output (MIMO) antenna system intended for contemporary automotive applications (Che, J.K., 2021). This antenna system can operate across many wireless communication standards, including sub-6 GHz 5G, Long-Term Evolution (LTE), WLAN, and Vehicle-to-Everything (V2X). The antenna has notable characteristics, including a broad frequency range from 1.9 to 6.5 GHz and a substantial isolation level exceeding 25 dB across channels. The simulation results exhibited exceptional performance, as shown by S11 values below -10 dB and a peak gain of 5.5 dBi. The present architecture facilitates improved connections inside vehicle communication systems.

Raja et al. proposed using a low-profile metamaterial-based T-shaped engraved antenna for WLAN and 5G applications (Raja, K.B., 2022). The antenna demonstrated a broad performance frequency range from 2.25 to 10 GHz while maintaining a small physical size. The simulation results showed a return loss value lower than -10 dB and a peak gain of 3.8 dBi, indicating that this antenna is well-suited for wireless communication in environments with limited space.

Tripathi et al. researched to increase the bandwidth of a slotted rectangular microstrip antenna, specifically for usage in WLAN/WiMAX (Tripathi, D., 2021). The revised design accomplished a broad frequency range spanning from 4.75 to 10.5 GHz, effectively catering to the requirements of contemporary wireless communication systems. The success of the suggested technique was confirmed by experimental findings, which demonstrated return loss values below -15 dB and a peak gain of 7.2 dBi.

Güneş et al. introduced a concise triband antipodal Vivaldi antenna that incorporates a director inspired by frequency-selective surfaces (Güneş, F., 2021). The proposed antenna is specifically designed for IoT applications and WLAN. The antenna provided coverage for three distinct frequency bands, namely 2.4 GHz, 5.8 GHz, and 8.2 GHz. It exhibited characteristics such as a high gain of up to 12 dBi and precise emission patterns. The presented architecture provides a flexible solution for many wireless applications.

Mathur et al. proposed a novel frequency and port-reconfigurable MIMO antenna design well-suited for Ultra-Wideband (UWB), 5G, and WLAN band IoT applications (Mathur, R., 2021). The antenna successfully demonstrated the capacity to adapt its frequency bands (ranging from 2.4 to 10.6 GHz) and port layouts, all while keeping a small physical size. The simulation results showed exceptional performance, with a return loss of less than -10 dB and significant isolation across ports. This architecture enhances the versatility and adaptability of IoT connectivity networks.

Chen introduced a novel uniplanar ultrawideband antenna design that exhibits unidirectional radiation characteristics specifically optimized for WLAN/WiMAX applications (Chen, C., 2021). The antenna exhibited a broad frequency spectrum from 3 to 10 GHz and unidirectional radiating properties. The simulation results demonstrated a return loss measurement of -10 dB and a peak gain of 6.5 dBi, indicating that the system is well-suited for contemporary wireless communication systems.

Benkhadda et al. presented a novel design for a tiny tri-band fractal antenna tailored for LTE, WLAN, WiMAX, and C-band applications (Benkhadda, O., 2023). The small antenna allowed it to span three unique frequency bands, showcasing its adaptability in accommodating several wireless communication protocols. The design that has been put out makes a valuable contribution to advancing communication systems that are both small and capable of operating across several frequency bands.

Karthikeyan et al. introduced a small antenna with stacked T-shaped strips explicitly suited for WLAN and WiMAX usage (Karthikeyan, M., 2022). The antenna demonstrated broad frequency range properties (2.7-8.3 GHz) and small physical dimensions, making it appropriate for contemporary wireless communication requirements. The experiment's success was proven by the obtained data, which demonstrated return loss values below -12 dB and a peak gain of 5.5 dBi.

Alaaudeen et al. presented a cost-effective, wideband, electrically compact microstrip antenna incorporating an I-shaped metamaterial configuration (Alaaudeen, K.M., 2022). This antenna design is intended for WLAN/WiMAX and 5G vehicle scenarios. The antenna successfully attained broad functioning within the frequency range of 2-10 GHz while still maintaining compact dimensions. This design effectively addresses the requirements of automotive wireless communication. The methodology demonstrated return loss values measuring below -15 dB and a peak gain of 5.8 dBi.

Vala et al. developed a metasurface-based MIMO antenna with a low-profile, compact design and high-gain characteristics (Vala, K., 2022). The antenna was built explicitly for applications in the 5G, WiMAX, and WLAN domains. The antenna has notable features, including a high gain of up to 14 dBi and a broad bandwidth ranging from 2.9 to 8.3 GHz, effectively meeting the requirements of contemporary wireless communication systems. The design that has been proposed significantly contributes to advancing high-performance MIMO communication systems.

The literature review uncovers many antenna designs that tackle different issues in wireless communication, such as limitations in bandwidth and the need for multi-band operation. There is a need for an innovative methodology to effectively formulate antennas that can adjust to progressing requirements and applications. To overcome the constraints inherent in current antenna configurations and provide a flexible solution capable of accommodating various frequency ranges, satisfying the needs of contemporary wireless communication protocols.

3 Proposed Triband Antenna Design using the Artificial Neural Network

This section presents the introduction of the novel methodology, referred to as 3AD-ANN, which utilizes machine learning methods to enhance the optimization process of antenna design. This section comprehensively describes the system used, explicitly focusing on the ANN training process. The training uses a database of input/output samples created via simulations. This study focuses on elucidating the architecture of the ANN and selecting an appropriate training procedure. The study underscores the capacity of this methodology to effectively and precisely design antennas for WLAN/WiMAX and 5G implementations.

Design of Microstrip Patch Antenna

Equations (1)-(5) serve as guidelines for determining the values of the geometrical variables, namely patch width (W_p) and patch length (L_p), for the MPA. These equations are derived based on the assumption that the resonant frequency (f_r), relative permittivity (ε_r), and substrate height (h_s) are known. Firstly, the optimal patch radiator efficiency, denoted as W, is determined using equation (1).

$$W_p = \frac{c}{2f_r}\sqrt[2]{\frac{1}{\varepsilon_r+1}} \tag{1}$$

The variable c represents the velocity of light in a vacuum. To ascertain the effective permittivity (ε_{eff}) of the base, the application of Equation (2) is used.

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(\frac{1}{\sqrt[2]{1+\frac{6h_s}{W_p}}}\right) \tag{2}$$

To determine the growth of the patch length ΔL_p, Equation (3) is used.

$$\Delta L_p = h_s \frac{\varepsilon_{eff}+0.3}{\varepsilon_{eff}-0.2}\frac{W_p+0.2h_s}{W_p+0.8h_s} \tag{3}$$

The value of L_p is determined by putting Equation (4), which represents the effective patch length L_{eff}, into Equation (5).

$$L_{eff} = \frac{c}{2f_r\sqrt[2]{\varepsilon_{eff}}} \tag{4}$$

$$L_p = L_{eff} - 2\Delta L_p \tag{5}$$

The first stage of developing the suggested antennas involves the development of a typical MPA. In the first step, the given characteristic values, $\varepsilon_r = 4.3$, $h_s = 1.6mm$ and $f_r = 5.8GHz$. These equations are used to determine the dimensions of the patch antenna for the middle frequency of the 5.8-GHz WLAN range. The computed values for the patch antenna dimensions are $L_p = 10.9$ and $W_p = 15.8$. A comprehensive electromagnetic simulation is employed to evaluate and model the planned antenna, focusing on refining the antenna's geometrical characteristics. The modeled return loss results for the designed antenna were achieved. The antenna resonates at a frequency of 5.8 GHz, with a bandwidth of -10 dB Si of 200 MHz, spanning from 5.7 GHz to 5.9 GHz. The antenna exhibits complete radiation in the front position. The sizes of the patch antenna are specified as (L_p XW_p) = (13 mm × 16 mm), while the overall size of the substrate area covered by the antenna is given as (L_{sub} XW_{sub}) = (23 mm × 25 mm).

Antenna Design and Analysis

Figure 1 illustrates the arrangement of the tri-band antenna under consideration. The antenna is constructed on a Low-Temperature Co-fired Ceramic (LCP) substrate, which has a thickness of 0.1 mm. The substrate has a comparative permittivity (ε_r) of 2.9 and a loss tangential (tan δ) of 0.002. The object's dimensions, denoted as $W_1 \times L_1$, are 20mm×32mm. The antenna under consideration is supplied with a Coplanar Waveguide (CPW) with a transmitting width (W_t) of 3 mm while maintaining a gap (g) of 0.2 mm on both sides of the propagation line. The tri-band antenna is achieved by integrating two L-shaped sections linked to the rectangle patch and the CPW grounding patch.

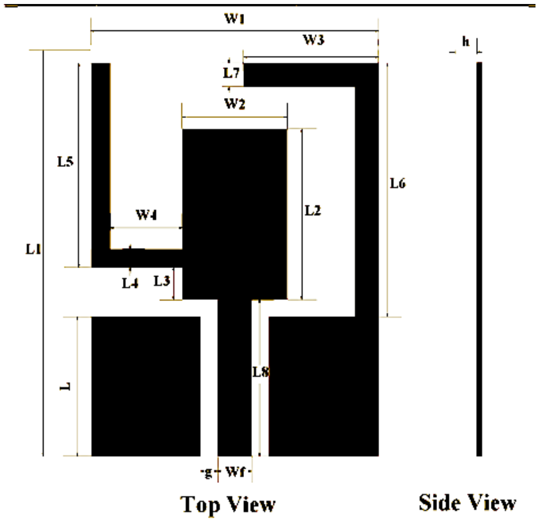

Figure 1: Triband Antenna Structure

The fundamental equations for rectangular antennas define the dimensions of the rectangular patch. The measurement of the size of every inverted-L strip (L_s) reveals that it is about one-fourth of the dielectric wavelength computed at the intended resonance frequency. This value is determined using Equations (6) and (7).

$$L_s = \frac{C}{2f\sqrt{\varepsilon_{eff}}} \tag{6}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} \tag{7}$$

C represents the speed of light, f denotes the desired resonance frequency, and ε_{eff} signifies the effective comparative permittivity.

The first step in the antenna design involves using a primary rectangular monopole antenna fed via a CPW. The activation of two resonant modes containing the 2.4-GHz WLAN and 3.5-GHz 5G-WiMAX frequencies was achieved by affixing L-shaped sections, denoted as L_{r_1} ($L_6 + B_3$) and L_{r_2} ($L_5 + B_4$), to the ground of the CPW and the rectangular patch, accordingly. The modeling findings indicate that the

Antenna achieves tri-band functionality, exhibiting two resonance sites near 2.4 GHz and 3.5 GHz. The antenna preserves the broad frequency range generated by the initial rectangle monopole antenna. An examination of the antenna's surface power dispersion analyses the antenna's resonance properties. Alterations in length impact the associated bandwidth and do not influence other frequency bands.

Proposed Technique

This research used ANNs as a methodology for antenna design—the suggested strategy utilized an MLP neural network, now ANN's most widely used model. The process involves making predictions on the size of the embedded slot inside the circular patch conductor, encompassing the operational frequency ranges required for WLAN/WiMAX/5G applications.

ANNs often have a hierarchical structure consisting of layers of processing units called nodes or neurons. Each neuron inside a given layer is interconnected with every other in the following forward layer, establishing a distinct network architecture. The fundamental structure has three levels: input, hidden, and output. This arrangement facilitates the transmission of information from the input layer, passing via one or more hidden layers and ultimately reaching the output layer.

The ANN is taught to achieve a desired outcome from a given input by adjusting several training variables, such as the number of hidden layers, the number of neurons inside each layer, and the chosen training technique. This iterative process continues until the output of the ANN aligns with the desired objective. The weights and biases automatically adjust to reduce the discrepancy between the intended result and the network-generated outcome.

The first stage in using the ANN technology involves the creation of database samples. Due to this rationale, a MATLAB script was developed to facilitate the management of the HFSS simulation. In MATLAB, each repetition matches the layout in HFSS. Two matrices were generated. The first matrix contains the size of the spaces within a specific range, while the second matrix stores the matching frequency ranges established by the suggested script. A dataset consisting of 2500 input/output points is constructed to train the ANN architecture. A reverse synthesizing approach is employed, where the resonance frequencies ($[S] = [s_1 \quad s_2 \quad s_3]$) are utilized as the network inputs, while the lengths of the spaces ($[I] = [i_1 \quad i_2 \quad i_3 \quad i_4]$) are considered as the outcome.

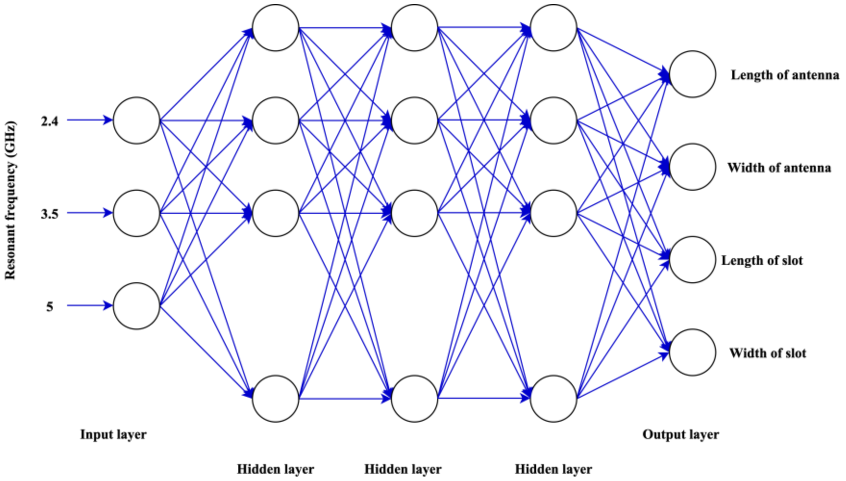

Figure 2: Structure of the Proposed ANN Model

The used ANN architecture is shown in Figure 2 after conducting many experiments. The selection of the suitable training algorithm is determined by using statistical metrics such as Root Mean Squared

Error (RMSE), Mean Absolute Error (MAE), and Mean Absolute Percentage Error (MAPE). The following equation expresses the statistical requirements:

RMSE, MAE, and MAPE are defined in Equations (8) to (10).

$$RMSE = \sqrt{\frac{1}{m}\sum_{x=0}^{n-1}(t_x - k_x)^2} \tag{8}$$

$$MAE = \sqrt{\frac{1}{m}\sum_{x=0}^{n-1}|t_x - k_x|} \tag{9}$$

$$MAPE = \frac{1}{m}\sqrt{\frac{1}{m}\sum_{x=0}^{n-1}\frac{|t_x - k_x|}{t_x}} \times 100 \tag{10}$$

The variable "n" denotes the total number of specimens, whereas t_x and k_x indicate the goal and results. Upon completion of the training process for the suggested ANN architecture, it becomes possible to make quick and precise predictions about the size of the built-in inverted U-shaped slot in the radiated circular conductors (d_1, b_1, d_2 and d_2) for the necessary frequency ranges (i_1, i_2 and i_3).

Fabrication

Two models of the proposed small tri-band antenna with twin winding constructions were manufactured and subjected to measurement to examine how it performed. The models possess 18.6 X 15.6 mm^2 dimensions, and the small antenna designs were manufactured on a cost-effective FR4 base with a thickness of 1.6 mm. The twin winding configuration located on the left-hand side of the center resonator functions as a step-down transformer, facilitating a reduction in voltage. Including twin incorporating constructions on the opposite side of the central resonance enables the functioning of a step-up transformer. The fabricated tri-band antenna is expressed in Figure 3.

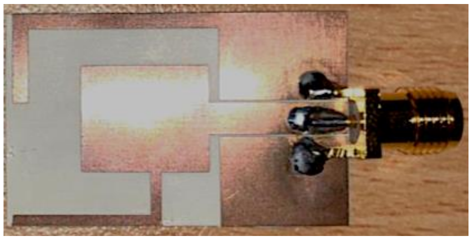

Figure 3: Fabricated Triband Antenna

This section presents a novel 3AD-ANN approach that uses machine learning techniques to revolutionize antenna design. The process encompasses training an ANN using a comprehensive database of input/output specimens obtained from simulations. This approach facilitates the rapid and precise estimation of antenna size. This section offers an analysis of the ANN architecture and the meticulous selection of an appropriate training procedure to get accurate outcomes. This methodology has significant promise in optimizing antenna design for WLAN/WiMAX/5G applications.

4 Experimental Results and Outcomes

WLAN/WiMAX and 5G services were simulated with Ansys High-Frequency Structure Simulator (HFSS). The numerical configuration included the specification of a frequency range spanning from 2.4 to 5.9 GHz to encompass the targeted frequency bands. The substrate material utilized in this study was FR4, which had a relative permittivity of 4.4. The substrate had a height of 1.6 mm, which was chosen to depict real-world scenarios precisely. The experiment was conducted on a high-performance desktop, including a multi-core CPU, a minimum of 32 GB RAM, and an independent graphics processing unit.

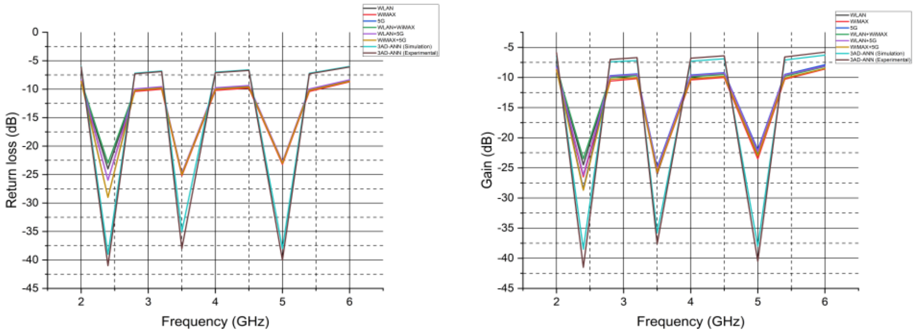

Figure 4(a): Return Loss Analysis and Figure 4(b): Gain Analysis

The average return loss and gain outcomes for all methodologies at varying frequencies are seen in Figures 4(a) and 4(b). Figure 4(a) presents several wireless communication technologies' average return loss values. The average return loss for WLAN is -24.0 dB, for WiMAX is -24.8 dB, for 5G is -25.5 dB, for WLAN+WiMAX is -23.6 dB, for WLAN+5G is -24.5 dB, for WiMAX+5G is -25.7 dB, for 3AD-ANN (Simulation) is -37.3 dB, and for 3AD-ANN (Experimental) is -39.7 dB. Figure 4(b) presents the average gain values for various wireless communication technologies. The average gain for WLAN is -24.2 dB, WiMAX is -25.3 dB, 5G is -25.1 dB, WLAN+WiMAX is -23.8 dB, WLAN+5G is -24.6 dB, WiMAX+5G is -25.8 dB, 3AD-ANN (Simulation) is -37.4 dB, and 3AD-ANN (Experimental) is -39.9 dB. The efficacy of the 3AD-ANN approach in enhancing antenna performance across diverse frequency bands is continuously shown by superior results in return loss and gain tests, surpassing other methods. The advantage is especially remarkable when considering specific frequencies like 2.4 GHz, 3.5 GHz, and 5 GHz.

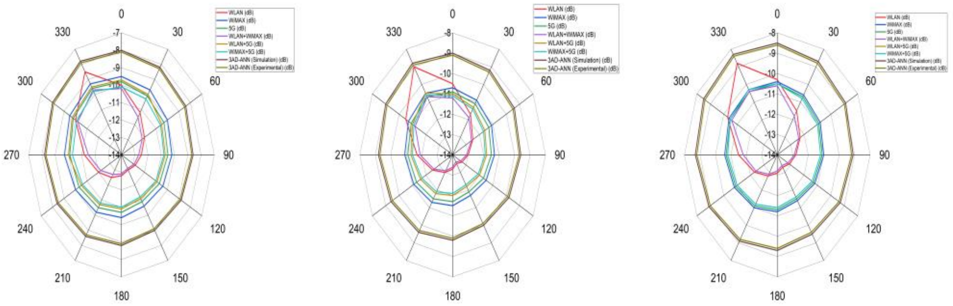

Figure 5: Far-field Radiation Pattern Analysis of E Plane at (a) 2.4GHz, (b) 3.5GHz, and (c) 5GHz

Figure 5(a) illustrates the far-field radiation patterns in the E-plane at a frequency of 2.4 GHz. Figure 5(b) depicts the radiation patterns at 3.5 GHz, while Figure 5(c) showcases the designs at 5 GHz. The average radiation characteristics for several wireless communication technologies, including WLAN, WiMAX, 5G, WLAN+WiMAX, WLAN+5G, WiMAX+5G, 3AD-ANN (Simulation), and 3AD-ANN (Experimental), at a frequency of 2.4 GHz, exhibit signal strengths of -11.5 dB, -10.0 dB, -10.3 dB, -11.8 dB, -10.4 dB, -10.6 dB, -8.4 dB, and -8.5 dB. The radiation patterns for the same variables at a frequency of 3.5 GHz exhibit average power levels of -12.0 dB, -11.1 dB, -11.3 dB, -12.4 dB, -11.5 dB, -11.6 dB, -9.4 dB, and -9.5 dB. The patterns of radiation for the given variables at a frequency of 5 GHz exhibit average power levels of -11.8 dB, -10.8 dB, -10.9 dB, -12.1 dB, -11.0 dB, -11.0 dB, -8.9 dB, and -9.0 dB. The 3AD-ANN approach, when compared to other methods, continually shows superior performance across all frequencies. This is attributed to advanced ANN and tri-band optimization techniques, ultimately leading to enhanced radiation patterns.

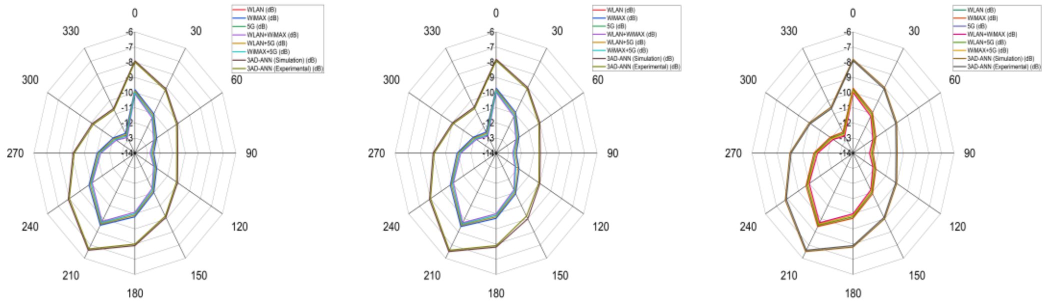

Figure 6: Far-field Radiation Pattern Analysis of H Plane at (a) 2.4GHz, (b) 3.5GHz, and (c) 5GHz

Figure 6(a) depicts the far-field radiation patterns in the horizontal plane at a frequency of 2.4 GHz. Figure 6(b) illustrates at 3.5 GHz, while Figure 6(c) presents at 5 GHz. The average radiation patterns for several wireless communication technologies, namely WLAN, WiMAX, 5G, WLAN+WiMAX, WLAN+5G, WiMAX+5G, 3AD-ANN (Simulation), and 3AD-ANN (Experimental), at a frequency of 2.4 GHz, exhibit power levels of -11.0 dB, -10.9 dB, -11.1 dB, -11.2 dB, -11.0 dB, -11.1 dB, -9.0 dB, and -9.1 dB. The radiation patterns for the same variables at a frequency of 3.5 GHz exhibit average values of -11.1 dB, -11.0 dB, -11.2 dB, -11.3 dB, -11.1 dB, -11.2 dB, -9.1 dB, and -9.2 dB. The radiation patterns for the given variables exhibit average values of -11.0 dB, -10.9 dB, -11.1 dB, -11.2 dB, -11.0 dB, -11.1 dB, -9.0 dB, and -9.1 dB at a frequency of 5 GHz. The 3AD-ANN method, which incorporates an advanced ANN and tri-band optimization, regularly demonstrates superior performance compared to other approaches across all frequencies. This is attributed to its enhanced ANN capabilities and optimization techniques, leading to notable improvements in radiation patterns.

5 Conclusion and Future Scope

Flexible antennas have become essential elements in contemporary wireless communication systems, effectively meeting the need for antenna solutions that are both small and versatile. This research examined the suitability of these WLAN, WiMAX, and 5G application methodologies, uncovering the shortcomings of current approaches in attaining the needed performance metrics. A pioneering solution called 3AD-ANN was introduced to tackle these issues, which utilizes an ANN-based methodology to devise a revolutionary Triband Antenna Design. The 3AD-ANN approach demonstrated notable qualities, including multiband operation and enhanced gain and return loss properties, which position it as a prospective option for forthcoming wireless systems. The mean numerical values for far-field radiation gain are around -37.4 dB in simulation and -39.9 dB in experimental observations. Similarly, the average return loss is roughly -23.8 dB in simulation and -25.8 dB in experimental measurements. The experimental results confirmed the simulation findings' accuracy, establishing the practical viability of the suggested antenna design.

The execution and refinement of the 3AD-ANN approach provide specific difficulties regarding computational intricacy and the prerequisites of training data. These difficulties require more investigation and improvement. In terms of prospects, this design's promise resides in enhancing the 3AD-ANN approach via the prospective integration of machine learning methodologies, aiming to achieve more effective training and optimization. It is essential to investigate the incorporation of this antenna into new wireless technologies, such as 6G, to address the changing requirements of wireless communication systems effectively.

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Authors Biography

Olga Fisenko, Author of more than 100 articles on the philosophy of security, intelligence, and linguistic consciousness. The sphere of her scientific interests also touches upon the issues of modern semasiology and related problems of functioning of the communicator's speech-thought process. She is engaged in the study of cognitive psychology and its categorical structure, as well as the issues of universal and individual values, their structure, hierarchy and value orientations of the individual, as well as psychological and pedagogical conditions of digitalisation of the educational environment.

Larisa Adonina, PhD in Philology, Associate Professor at Sevastopol State University. Research interests: cognitive linguistics, cognitive psychology. She studies the problems of formation and functioning of information field, information security. She is also studying information and communication technologies in higher education and types of organisational cultures and methodological foundations of designing information and educational environment.

Heriberto Solis Sosa, Bachelor's degree in Mathematics and Computer Science, Master's degree with postgraduate studies in Management Training and people management. He has also completed postgraduate studies in research and university teaching. He is currently assigned to the humanities department of the Universidad Católica Santo Toribio de Mogrovejo.

Giomar Arturo Shiguay Guizado, Master in Education, with mention in University Teaching, Graduate School, UNE. Doctoral candidate in Education and University Teaching, Universidad Nacional Mayor de San Marcos. Master's Degree in Applied Statistics, Universidad Nacional Agraria la Molina. Bachelor's Degree in Education, majoring in Mathematics and Computer Science, Universidad Nacional de Educación.

Angélica Sánchez Castro, Teacher with experience in undergraduate and postgraduate education. PhD in Education Sciences (UNCP). Master in Intercultural and Inclusive Education at UNIR -Mexico. B.A. in Pedagogy and Humanities from the Universidad Nacional del Centro del Perú.

Fernando Willy Morillo Galarza, Master C.P.C. in Administration, Auditing, Accounting and Finance, with more than 15 years of experience, trained in organizational restructuring, treasury, collections, logistics, taxes, recruitment and selection of personnel based on competencies and training of human potential at all levels. recruitment and selection of personnel based on competencies and training of human potential at all levels. Solid knowledge in talent development, plans, financial budgets, management indicators.

David Aroni Palomino, Bachelor's degree in Systems and Computer Engineering with a major in Mathematics and Computer Science. Professor appointed by the Universidad Nacional Enrique Guzmán y Valle.