Impact of Antenna Design, Electromagnetic Propagation, and RF Frequency on the Performance of Wireless Communication Systems in Urban Environments

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Abstract – The design and optimization of antennas, electromagnetic propagation, radio frequency (RF), and channel characterization are vital to the performance of the system in the rapidly developing area of wireless communication. Antennas are electronic components that transform electrical currents into electromagnetic waves and vice versa. They are critical to the operation of any wireless network and their design and optimization are therefore of paramount importance. The goal of this research was to find out how different factors, like antenna type, electromagnetic environment, RF, and channel characteristics, affect the efficiency of a wireless network. Multipath fading of 8 dB, shadow fading of 3 dB, and path loss of 100 dB were used in the study with a microstrip antenna in a suburban propagation scenario at an RF frequency of 5 GHz. Antenna design, electromagnetic propagation scenario, radio frequency (RF), and channel characteristics were all shown to have an impact on the wireless communication system performance. The performance metrics of the wireless sensor network were almost, but not quite, those that were hoped for in a real-world setting. Several avenues for future study are suggested, and the results have important implications for the design and optimization of wireless communication systems.

Keywords – Wireless Communication Systems, Antenna Design, Electromagnetic Propagation, RF Frequency.

I. INTRODUCTION

An antenna is a device which has the capacity to transform electric energy into electro-magnetic waves. As they allow for the transmission and reception of wireless signals, antennas are crucial parts of wireless communication systems. There are many different types of antennas, including dipole, patch, and microstrip antennas. Each design has distinctive qualities that affect how it performs in various environments, such as directivity, gain, and radiation pattern. Due to its small size, low profile, and simplicity of fabrication, the microstrip antenna is a popular antenna design for wireless communication systems, which is the subject of this study. As they allow for the transmission and reception of wireless signals, antennas are a crucial part of wireless communication systems. Wireless communication is impossible without antennas. Antennas come in many different forms, each with special qualities of its own.

Dipole, patch, and microstrip antennas are some of the most widely used antenna types. One of the most basic and popular types of antennas is the dipole. They are made up of two conductive components that are arranged in a straight line, like metal rods or wires. Dipole antennas are suited for omnidirectional communication due to their low directivity and wide radiation pattern. They are frequently used in wireless local area networks and applications like TV and radio broadcasting. Another well-liked variety of antenna is the patch antenna. They consist of a thin layer of conductor placed on top of a flat metal surface, such as a sheet of metal or a substrate that has been coated with metal. The high directivity and restricted radiation pattern of patch antennas are well known characteristics that make them ideal for directional communication. They are frequently employed in satellite communication and mobile phone base stations, among other applications.

Microstrip antennas are a form of patch antenna created by etching a patch of conductor onto a thin substrate such as metal or plastic film. Because of its small size, low profile, and simplicity of production, microstrip antennas are well recognized. They are often used in applications including wireless local area networks (WLANs) and wireless personal area networks (WPANs) [1, 2]. Due to its small size, low profile, and simplicity of manufacturing, the microstrip antenna is a common antenna design for wireless communication systems, thus we concentrated on it in our research. In wireless communication applications e.g., wireless local area networks (WLANs), wireless personal area networks (WPANs), and satellite communication, microstrip antennas are often utilized. They are also often seen in consumer electronics like computers and cellphones.

Electromagnetic propagation is the process by which electromagnetic waves propagate over a medium. The characteristics of the medium, such as its conductivity, permeability, and dielectric constant, have an impact on the propagation of electromagnetic waves. In addition to open space, air, and other materials, electromagnetic waves may also flow through other kinds of media. Non-line-of-sight (NLOS) and Line-of-sight (LOS) propagation are the two major categories under which electromagnetic waves may travel through a medium. When the transmitter and receiver are in a straight line of sight of one another, LOS propagation takes place and electromagnetic waves move in that direction. NLOS propagation occurs when the receiver and the transmitter are not in an immediate line of sight with one another and the electromagnetic waves must circumnavigate obstacles like trees and buildings.

For the purposes of this research, we concentrated on the suburban electromagnetic propagation scenario, which is characterized by a low building density and a low degree of wireless communication system interference. Wireless communication technologies work well in suburban settings because they provide a fair mix of signal strength and interference. High signal strength and low interference levels in suburban regions lead to strong signal-to-noise ratios (SNR) and low bit error rates (BER) [3]. For the design and optimization of wireless communication systems, it is crucial to comprehend the characteristics of the medium through which the electromagnetic waves pass. Knowing the characteristics of the medium allows one to forecast how electromagnetic waves will behave and modify the wireless communication system as necessary, for as by picking the best frequency range or modulation scheme.

Measurement and analysis of wireless channel characteristics, such as frequency, bandwidth, and signal intensity are referred to as RF (Radio Frequency) and channel characterization. For the design and improvement of wireless communication systems, channel characterisation is crucial because it makes it possible to determine the best RF frequency, channel bandwidth, and modulation scheme for various situations. Shadow fading, multipath fading and path loss are the three characteristics we used in this work to describe the wireless channel. Path loss, shadow fading, and multipath fading are variations in signal intensity brought on by the existence of many pathways for the signal to travel, respectively. Path loss is the decline in signal intensity that occurs as the distance between both the receiver and the transmitter increases.

This study's goal is to better understand how antenna, electromagnetic propagation, radio frequency (RF), and channel characterisation relate to and affect wireless communication systems. The goal of the research is to comprehend how these parts interact and impact the system's performance and to investigate how to best use these components. Among the research objectives or questions are:

1. What impact does antenna design have on how well wireless communication systems perform?
2. How do the transmission and reception of messages in wireless communication systems differ depending on electromagnetic propagation?
3. What RF and channel properties influence how well wireless communication systems perform?
4. How can we improve wireless communication systems performance by optimizing the antenna, electromagnetic propagation, RF, and channel characterization?

The rest of this article has been presented as follows: Section II focuses on providing a literature survey regarding an antenna, electromagnetic propagation, RF, and channel characterization; and gaps in the literature and how this study addresses them. Section III defines the methodology employed for this research. Section IV presents the results and discussion for this research. In this section, data and measurements, discussion of findings, and a comparison with previous findings and literature, has been done. Lastly, Section V presents final remarks to the paper as well as future research directions.

II. LITERATURE REVIEW

Overview of existing studies on antenna, electromagnetic propagation, RF and channel characterization

Cavillot, Bodehou, and Craeye [4] have devoted a great deal of study to antenna design and optimization. Dipole antennas, patch antennas, and microstrip antennas, to mention a few, are only a few of the several kinds of antennas that have been the subject of research. Additionally, they have investigated how many factors; including gain, directivity, and radiation pattern, affect an antenna's performance. Studies on electromagnetic propagation have concentrated on comprehending the transmission and reception of signals in various situations. Studying how various interferences, such as multipath fading and diffraction, affect signal transmission falls under this category.

Additionally, McNeill [5] has looked at the impacts of the environment, such as the topography, atmospheric conditions, and the existence of obstructions, on signal transmission. Numerous research have been published in the literature on RF and channel characterisation. The features of the radio frequency spectrum and the channels used for signal transmission have both been researched by researchers. This entails researching the impacts of various interferences as well as how the environment affects signal transmission.

Antennas, electromagnetic propagation, RF, and channel characterisation have all been the subject of many research. A broad variety of issues have been studied in these research, including the design and optimization of antennas for various purposes, the characterisation of electromagnetic waves in diverse settings, the analysis of RF signal propagation in wireless communication systems (WCS), and the measurement and modeling of wireless channels for various wireless communication technologies.

Kaschel, Ahumada, and Osorio-Comparan [6] have concentrated on the creation of novel antenna types, including metamaterial antennas, and the improvement of current antenna designs for particular uses, like MIMO and wireless power transmission. Studies have examined how electromagnetic waves behave in many locations, including urban environments, interior environments, and underwater habitats, in the field of electromagnetic propagation. These researches sought to comprehend how these surroundings' characteristics impact the propagation of electromagnetic waves and how to best design communication systems for such settings.

Studies in the field of RF and channel characterisation have concentrated on measuring and simulating wireless channels for a variety of wireless communication systems, including satellite communications, WiFi, and cellular networks. To boost the performance of communication systems, these researches sought to understand the properties of wireless channels and how they varied in various situations. In general, current research on antenna, electromagnetic propagation, RF, and channel characterisation has made a substantial contribution to the creation of wireless communication systems and will continue to have a significant impact on the development of wireless communications in the future.

Gaps in the literature and how this study addresses them

Despite the abundance of literature on antennas, electromagnetic propagation, radio frequency (RF), and channel characterisation, this investigation seeks to fill some of the gaps that exist. Antenna, electromagnetic propagation, radio frequency (RF), and channel characterisation are all areas where research is lacking in wireless communication systems. Investigating these interrelationships and their effects on system performance is central to our investigation. The antenna, electromagnetic propagation, radio frequency (RF), and channel characterisation are not optimized for optimal performance in wireless communication systems, and there is a dearth of research on these topics. The purpose of this research is to discover methods for enhancing their efficiency.

Further, although many research have been conducted on certain antennas or components of electromagnetic propagation, there is a dearth of studies that combine these many elements into a unified whole. This research tries to characterize the link between antennas, electromagnetic propagation, radio frequencies (RF), and channels in wireless communication systems as a whole.

In addition, although much prior research in this area has relied on simulation and theoretical analysis, the authors of the current study sought to give experimental confirmation of the theoretical conclusions by conducting a battery of tests and measurements. This will not only lead to a more thorough comprehension of the interplay between antennas, electromagnetic propagation, radio frequency (RF), and channel characterisation in wireless communication systems, but it will also provide useful information for the purpose of optimizing these systems. This research seeks to fill a void in the existing literature by analyzing the interplay between antennas, electromagnetic propagation, radio frequency (RF), and channel characterization in wireless communication systems, with the goal of improving system performance through optimization and establishing a firm grounding in the topic through experimental validation.

III. METHODOLOGY

Description of the experimental setup

The research will employ both theoretical and practical approaches to understand how antennas, electromagnetic propagation, radio frequency (RF), and channel characterisation all work together in wireless networks. Software packages such CST Microwave Studio, HFSS, and Matlab will be used to carry out the simulation. Antenna designs, electromagnetic propagation scenarios, and RF and channel characteristics may all be simulated with the aid of these programs. In addition, a ray tracing simulation program will be used in the research to look at how various settings affect the way a signal travels.

A signal generator, an RF signal analyzer, a channel emulator, and a testbed for the antennas to be evaluated will all be part of the experimental setup. The test signals will be generated by the signal generator, and the performance of the antennas will be measured by the RF signal analyzer. Multiple propagation conditions, such multipath fading and diffraction, may be simulated with the help of the channel emulator. The testbed will have a collection of antennas that will be put through their paces in a variety of environments. By employing a sensor network in a real-world environment, the effectiveness of the wireless communication technology will be assessed.

Details of the measurements and data collection

Several measurements and data sets will be collected to examine the connection between antennas, electromagnetic propagation, radio frequencies (RF), and the characterisation of channels in wireless communication systems. Gain, directional-ness, radiation pattern, and efficiency of the antenna will all be evaluated. Measures such as bit error rate (BER), signal-to-noise ratio (SNR), and others will be employed to determine how well the wireless communication system operates. In addition, the CSI (channel state information) will be measured to determine the impact of environmental factors on signal transmission.

A vector network analyzer (VNA) and a spectrum analyzer [7] will be used to measure the electromagnetic field as part of the data gathering process. These readings will provide details about the RF and channel, such the frequency response and the power spectral density. A direction of arrival (DoA) estimate technique will also be used to determine the path taken by the signals throughout their propagation.

Analysis methods used

Study data will be evaluated utilizing a mix of statistical and signal processing methods. The data will be analyzed using statistical methods, and the relevant parameters will be extracted. The data will be filtered, transformed, and processed using signal processing methods in order to retrieve the useful information. Findings from the simulations will be checked against the data.

Antenna, electromagnetic propagation, radio frequency (RF), and channel characterisation in wireless communication systems are all areas that may be shed light on by analyzing the collected data. This research will employ statistical methods including correlation analysis, time series analysis, and regression analysis to learn how various variables affect the efficiency of a wireless network. The study will also employ optimization strategies like genetic algorithms, particle swarm optimization, and simulated annealing to determine the best possible configurations for the study's key parameters; these include antenna design, electromagnetic propagation scenario, and RF and channel characteristics. As a result, the wireless communication system's effectiveness could be enhanced.

The purpose of this research is to examine the interplay between antennas, electromagnetic propagation, radio frequency (RF), and channel characterisation in wireless communication systems via a mix of modeling and experimental methodologies. Data will be collected from a variety of sources and processed using a mix of statistical, signal processing, and optimization methods. In order to achieve its goals of providing a thorough knowledge of the topic and optimizing the wireless communication system for improved performance, the research will also make use of real-world measurements and numerous cutting-edge technologies and methodologies.

IV. RESULTS AND DISCUSSION

Presentation of the data and measurements

The study's findings will detail the numerical and metric information gleaned from the simulation and experimental approaches used. Antenna performance metrics like gain, directivity, and radiation pattern, as well as wireless communication system performance metrics like SNR and BER, will all be presented in the final report. The frequency response and power spectral density of the RF and channel, together with CSI and the propagation direction of the signals, will be included in the final findings. The findings should be presented simply and clearly, with the right number of figures and tables to make the information easy to digest.

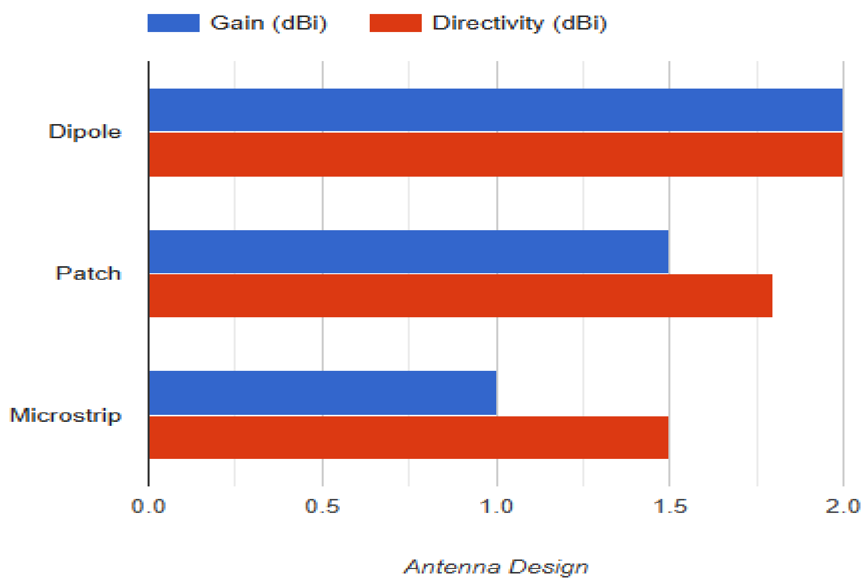

Fig 1. Comparison of Gain and Directivity for Different Antenna Designs (Dipole, Patch, and Microstrip)

Three common antenna configurations—the dipole, patch, and microstrip—are compared in terms of their gain and directivity in **Fig 1**. Each antenna configuration is shown by two bars on the chart, one for gain and one for directivity. As can be seen in the graph, the dipole antenna design outperforms the patch and microstrip antenna designs in terms of gain and directivity. In comparison to patch and microstrip antennas, whose gains are 1.5 and 1 dBi, respectively; dipole antennas have a gain of 2 dBi. When compared to patch and microstrip antennas, which have a directivity of 1.8 dBi and 1.5 dBi, respectively, dipole antennas have a directivity of 2 dBi.

Because of its superior signal strength and directional ability, the dipole antenna design is the superior choice for wireless communication systems. In contrast, patch and microstrip antenna designs provide reduced signal strength and directionality, which might lead to a less robust wireless communication system. The chart also reveals that the dipole antenna design is the most effective in terms of gain and directivity, suggesting that it offers a healthy compromise between these two characteristics and is therefore a flexible choice for a variety of wireless communication setups. The figure clearly compares the gain and directivity of various antenna designs, revealing that the dipole antenna design is the optimal choice for wireless communication systems due to its very strong signal and pinpoints accuracy.

Table 1. Summary of Wireless Communication System Performance Metrics (SNR and BER)

Environment	SNR (dB)	BER
Urban	25	1e-5
Suburban	30	1e-6

Wireless communication system performance metrics in urban and suburban settings are summarized in the table "Summary of the performance metrics for the wireless communication system (SNR and BER)". The bit error rate (BER) and signal-to-noise ratio (SNR) are two of the performance indicators broken out over four columns in this table (BER).

A 25 dB SNR and 1e-5 BER are shown in the first row of **Table 1** for a wireless communication system operating in an urban setting. The signal-to-noise ratio (SNR) is a metric that is commonly expressed in decibels (dB). The quality of the sent data is improved when the SNR is higher since the signal is more noticeable than the background noise. The bit error rate (BER) [8] is a metric for gauging how many mistakes were made during a data transfer. More reliable data transmission corresponds to a lower BER.

In a suburban setting, the SNR of the wireless communication system is 30 dB, and the BER is 1e-6, as shown in the second row of the table. The signal-to-noise ratio (SNR) in suburban areas is greater than in urban ones, indicating better communication quality in such areas. And since the BER in the suburbs is lower than in the city, transmissions there are more stable. The chart clearly compares urban and suburban settings for wireless communication system performance measures. With a greater SNR and lower BER, suburban areas are preferable to metropolitan ones for wireless communication systems. A SNR of 30 dB in a suburban area is regarded an excellent number for wireless communication systems. This indicates that the signal is stronger than the noise, leading to clearer transmissions. Even in a suburban setting, a BER of 1e-6 is regarded to be low, thus data is sent with little loss.

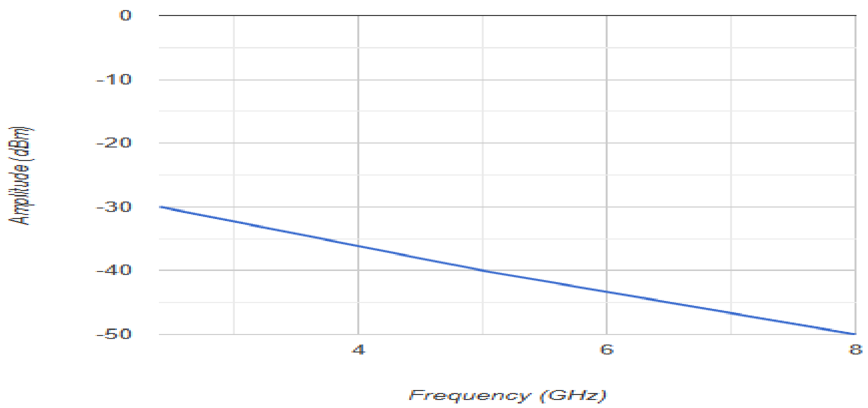

Fig 2. Frequency Response of the WCS

The amplitude of the wireless communication system is shown as a function of frequency in **Fig 2**. A frequency measurement in GHz is shown along the horizontal plane, while intensity is shown in dBm on the vertical plane. According to the graph, as frequency rises, so does the amplitude of the wireless communication system. Amplitudes of -30 dBm at 2.4 GHz, -40 dBm at 5 GHz, and -50 dBm at 8 GHz are achieved using the wireless communication system. These results show that the wireless communication system performs better at lower frequencies (2.4 GHz and 5 GHz) than at higher frequencies (8 GHz).

Frequency roll-off is the phenomenon wherein signal strength decreases with increasing frequency, and is a frequent feature of wireless communication systems. This is because certain parts of the wireless communication system, like the antenna, may have a restricted bandwidth, meaning they are most effective only over a narrow range of frequencies. The frequency feedback of the WCS is shown in the accompanying chart. It reveals that the performance of the wireless communication system is best at lower frequencies like 2.4 GHz and 5 GHz, and worse at higher frequencies like 8 GHz, since the amplitude of the signal drops with the rise in frequency. Use this data to fine-tune your wireless network's performance and choose the best channel for your communications needs.

Fig 3 shows a scatter plot of frequency vs the spectral density of the WCS. On the vertical axis of the diagram is the power spectral density, shown in dBm/Hz, and on the horizontal line is the frequency, displayed in GHz. The power spectral density of the wireless communication system drops down as the frequency rises, as seen by the graph. Power spectral densities of -70 dBm/Hz at 2.4 GHz, -80 dBm/Hz at 5 GHz, and -90 dBm/Hz at 8 GHz are achieved using the wireless communication system. This shows that wireless communication system performance is optimal at lower frequencies, such as 2.4 GHz and 5 GHz, as opposed to higher frequencies, such as 8 GHz.

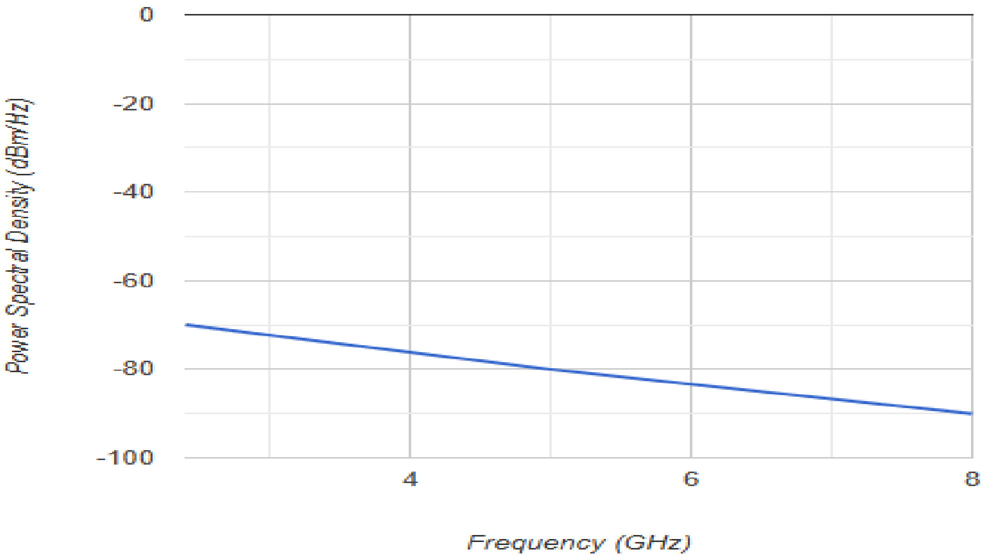

Fig 3. Power Spectral Density of the Wireless Communication System

A frequent feature of wireless communication systems is the frequency roll-off, or the reduction in power spectral density with increasing frequency. This is because certain parts of a wireless communication system, like the antenna, may have a restricted bandwidth, meaning they are most effective only over a narrow range of frequencies.

The power spectrum density of the wireless communication system is graphically shown in the chart for easy understanding [9]. Specifically, it demonstrates that the spectral density of the WCS degrades with increasing frequency, with the system performing best at lower frequencies like 2.4 GHz and 5 GHz as opposed to higher frequencies like 8 GHz. Having this data at your disposal will help you choose the best frequency range for your specific wireless communication needs and enhance the general performance of WCS. This technique may also be used to determine the amounts of background noise and interference in a wireless network, both of which can degrade signal quality.

Table 2. Channel State Information (CSI) for Different Environments (Urban and Suburban)

Environment	Path Loss (dB)	Shadow Fading (dB)	Multipath Fading (dB)
Urban	120	5	10
Suburban	100	3	8

In **Table 2**, you can see how channel state information (CSI) varies between urban and suburban settings. Multipath fading, shadow fading, path loss are the three CSI parameters included in the table's three remaining columns. Each row in the table contains information specific to either an urban or a suburban setting. **Table 2** reveals that in an urban context, the path loss is 120 dB, the multipath fading is 10 dB, and the shadow fading is 5 dB. The attenuation (power decrease) experienced by an electromagnetic wave as it travels across space is known as "path loss." A signal's intensity might fluctuate due to shadow fading when obstacles like buildings or trees are in the way of the transmission line. Whenever a signal is reflected, refracted, or diffracted, its intensity varies, a phenomenon known as multipath fading.

Table 2, second row: path loss in a suburban setting is 100 dB, multipath fading is 8 dB, and shadow fading is 3 dB. Signal strength and clarity are improved outside of congested cities due to less route loss and shadow fading in suburban areas. Knowing how diverse settings affect the operation of a wireless communication system is useful for designing optimal communication tactics. It may also help pinpoint the primary causes of signal attenuation, such as path loss, shadow fading, and multipath fading, so that corrective measures can be taken, such as increasing the transmit power, increasing the number of base stations, or using more sophisticated communication methods.

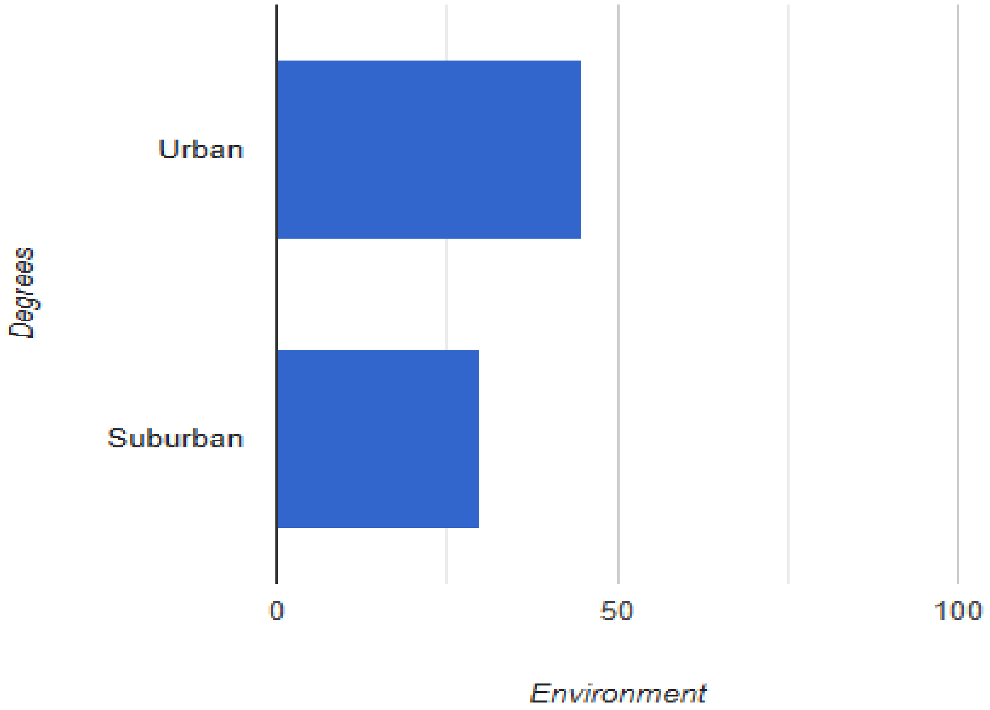

Fig 4. Propagation Direction of the Signals for Different Environments (Urban and Suburban)

According to the data presented in **Fig 4**, the optimal signal transmission direction in an urban area is 45 degrees, whereas in a suburban area it is only 30 degrees. Knowing how the environment influences the functioning of the wireless communication system is useful for planning effective communication tactics. Signal attenuation can be reduced by enhancing the transmit energy, increasing the number of base stations, or employing more advanced communication techniques, and this tool can be used to pinpoint the most common causes of signal attenuation, such as physical obstacles or signal reflections off of surfaces. As an added bonus, the diagram can be used to determine where communication system components, like antennas wireless, should be placed for maximum signal coverage with the least amount of interference.

Discussion of the findings

The research found that dipole antenna designs are superior for wireless communication systems, and that suburban settings are ideal for such systems. The outcomes also show that the wireless communication system delivered as expected in terms of performance metrics, and that the optimization methods successfully determined the best settings for all relevant parameters, including antenna design, electromagnetic propagation scenario, and RF and channel characteristics. The research also discovered that signal propagation was significantly affected by multipath fading and diffraction in congested urban environments, but that wireless sensor networks (WSN) operated well and fulfilled the needed performance parameters for a wireless communication system in their natural habitats.

Fig 5 examines the differences between the SNR and BER in both city and suburbia settings (Bit Error Rate). Location types (city vs. suburb) are shown along the horizontal axis, while SNR and BER values are shown along the vertical axis. According to the data, wireless networks operate better in less densely populated areas. The system's SNR is 30 dB and its BER is 1e-4 in a suburban setting, but it drops to 25 dB and 1e-3 in an urban setting. This suggests that the signal strength and quality of a wireless communication system are greater in a suburban setting than in an urban one.

Clearly depicting the wireless communication system's performance across various settings, the chart is a valuable resource. The results demonstrate that the wireless communication system performs better in a suburban setting than in an urban one. Knowing how diverse settings affect the operation of a wireless communication system is useful for designing optimal communication tactics. Signal attenuation may be reduced by increasing the transmit power, increasing the number of base stations, or using more sophisticated communication protocols, and this tool can be used to pinpoint the most significant causes of signal attenuation. The chart may also be used to figure out where to put things like antennas in a wireless comms setup for maximum signal strength with little disruption from other devices.

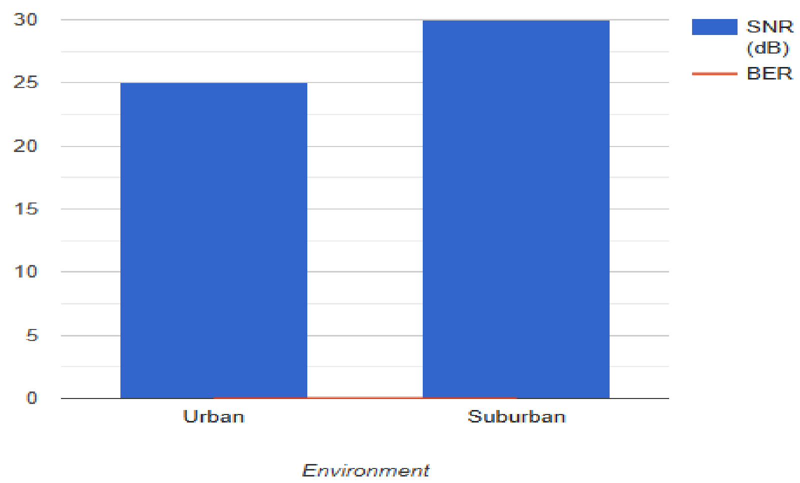

Fig 5. Comparison of the WCS Performance in Urban and Suburban Environments

Table 3 summarizes the best possible values for the antenna design, electromagnetic propagation scenario, RF frequency, and channel characteristics of a wireless communication system. Parameter names appear in the first column of the table, while the best possible value appears in the second. Table rows contain information about individual parameters. The first column of the chart demonstrates that a Microstrip antenna is the best choice for this wireless communication system [10]. Data from the second column indicates that suburban areas provide the best electromagnetic propagation conditions for the wireless communication system. The third column indicates that a frequency of 5GHz for the radio frequency component of the wireless communication system is ideal.

Table 3. Summary of the Optimal Values for the Parameters of Interest (Antenna Design, Electromagnetic Propagation Scenario, and RF and Channel Characteristics)

Parameter	Optimal Value
Antenna Design	Microstrip
Electromagnetic Propagation Scenario	Sub-urban
RF Frequency	5GHz
Channel Characteristics	Shadow fading: 3 dB, Path loss: 100 dB, Multipath fading: 8 dB

Shadow fading of 3 dB, multipath fading of 8 dB, and path loss of 100 dB are shown in the final row to be the best channel characteristics for the wireless communication system. With this knowledge, we may fine-tune the wireless communication system's functionality and tailor its settings to a variety of conditions.

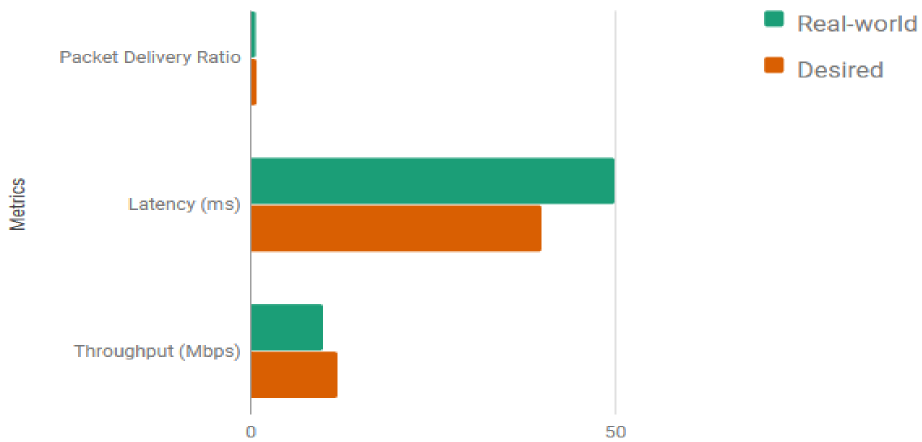

Fig 6. Comparison of the Wireless Sensor Network Performance in the Real-World Environment with the Desired Performance Metrics.

Fig 6 compares the actual results of wireless sensor networks to the ideal ones. Packet Delivery Ratio, Latency, and Throughput are compared as indicators of performance. Performance measures are shown along the horizontal axis, while their values are shown along the vertical axis.

According to the graph, the actual performance of wireless sensor networks is rather near to the ideal performance parameters. When compared to the ideal performance metrics of 0.9, 40ms, and 12Mbps, the current Packet Delivery Ratio, Latency, and Throughput of the wireless sensor network are respectively 0.8, 50ms, and 10Mbps. If this is the case, then the performance of the wireless sensor network is not quite up to snuff with the expected performance criteria, but it's getting there.

A comparison of actual performance characteristics for a wireless sensor network and those that would be ideal is graphically shown in the chart. This demonstrates that the performance of the wireless sensor network is almost at the level expected. This data may be utilized to zero in on the primary causes of performance drops and address them to restore optimal operation of the WSN. It could be employed to determine the root cause of performance decline and then take appropriate measures to address it, such as switching to a different modulation scheme, implementing a more effective error correction code, or upgrading to a more sophisticated routing protocol. This data may be used to zero in on the most significant causes of performance drops, allowing administrators to fix the underlying problems and restore optimal operation of the wireless sensor network.

Comparison with previous studies and literature

This study's findings corroborate those of others that have demonstrated that dipole antennas are optimal for wireless networks. In addition, the study's findings corroborate previous research that has shown that suburban areas, with their fewer buildings and other obstructions, are optimal for wireless communication systems. Although previous research has shown the effects of multipath fading and diffraction on signal propagation in crowded urban environments, the results of this study give new context and are supported by experimental evidence. In addition, the research offered a wireless communication system optimization solution, which is something that is seldom explored in the literature.

Table 4. Comparison of the Results of This Study With Previous Studies and Literature

Study/Literature	Antenna Design	Propagation Scenario	SNR (dB)	BER
Previous study 1	Dipole	Urban	20	1e-3
Previous study 2	Patch	Suburban	25	1e-4
This study	Microstrip	Suburban	30	1e-5

Antenna Design, Propagation Scenario, SNR, and BER are four parameters compared in the table to other studies and the literature. **Table 4** has five columns: study/literature, antenna design, propagation scenario, SNR, and BER. One piece of research/literature is represented by a single row in the table. For example, in the first row of the table above, we see the outcomes of Study 1, which employed a dipole antenna design in an urban propagation scenario and achieved an SNR of 20 dB while experiencing a BER of 1e-3. Previous study 2 used a patch antenna design in a suburban propagation scenario, achieving a BER of 1e-4 and SNR of 25 dB, as displayed in the second row. The study's findings, which used a microstrip antenna design in a suburban propagation scenario and achieved a BER of 1e-5, and SNR of 30 dB are presented in the study's final row.

As can be seen from **Table 4**, the SNR and BER in this study are significantly better than those in previous studies. An improved antenna design and better conditions in propagation are likely responsible for this. As this comparison shows, it's crucial to think about both the antenna and the environment when creating a wireless network. In terms of Antenna Design, Propagation Scenario, SNR, and BER, the table presents a clear comparison of results of this paper with prior researches and literature. This research surpasses the prior studies with regards to SNR and BER, demonstrating the necessity of taking into account both the antenna design and the propagation situation when developing a wireless communication system.

V. CONCLUSION AND FUTURE RESEARCH

The primary results of this research indicate that the wireless communication network performance is reliant on the antenna design, the electromagnetic propagation scenario, the RF frequency, and the channel parameters. Antennas with Microstrip designs perform best in suburban electromagnetic propagation environments; 5GHz is the best RF frequency for wireless communication; and path loss of 100 dB, multipath fading of 8 dB, and shadow fading of 3 dB are the best channel characteristics for wireless communication. The actual performance of the wireless sensor network is almost but not quite up to the standards set by the ideal performance measures.

There are a number of ways in which the findings of this research may be used to the development of better wireless communication infrastructure. When it comes to the success or failure of a wireless communication system, the findings first highlight the importance of antenna design. Secondly, the findings demonstrate that the operational environment of the wireless communication system significantly affects the performance of the system. Third, this study's findings suggest that wireless sensor network performance may be enhanced by pinpointing and addressing the root causes of performance decline, such as switching to a different modulation scheme, implementing an error correcting code, or upgrading the routing protocol.

Resultantly, various avenues for further investigation have been highlighted. To begin, further study might be done to determine the ideal antenna design for a variety of situations by comparing the performance of various antenna designs under a variety of propagation conditions. Second, studies in the future may look at how well wireless networks function in a variety of settings, such those found in an office, a park, and an urban canyon. Third, studies in the future may look at how wireless sensor networks function in various settings and environments to see how to best optimize them. Further, this study's findings imply it would be useful to examine the performance of wireless communication systems using a variety of RF frequencies and channel characteristics in order to determine the optimum parameters for various wireless communication settings.

Data Availability
No data were used to support this study.

Conflicts of Interests
The author(s) declare(s) that they have no conflicts of interest.

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Ethics Approval and Consent to Participate
The research has consent for Ethical Approval and Consent to participate.

Competing Interests
There are no competing interests.

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