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Optimizing energy efficiency in urban 5G wireless communication systems

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Abstract

This study aims to optimize the energy efficiency of urban 5G networks by examining the influence of advanced antenna configurations and beamforming technology, addressing the growing need for reliable, high-speed, and energy-efficient communication in densely populated environments with the anticipated proliferation of IoT devices. A comprehensive methodology was adopted, combining literature review, qualitative analysis, and simulation-based evaluations in which transmitter power, carrier frequency, antenna height, and construction materials were systematically varied. Simulations analyzed the impact of these parameters on signal propagation, path loss, attenuation, and energy consumption, with special emphasis on the role of beamforming in enhancing performance. The findings indicate that optimized antenna configurations, coupled with beamforming, significantly improve received signal strength, reduce interference, and lower energy consumption, while variations in frequency, antenna height, and material type produce measurable differences in path loss, emphasizing the need for context-specific parameter tuning. The results conclude that strategic deployment of 5G infrastructure with optimized antenna and beamforming configurations can substantially improve energy efficiency and network performance in complex urban settings, supporting sustainable and high-quality connectivity. Practically, the study provides actionable guidelines for network engineers, policymakers, and telecommunications providers, highlighting the transformative potential of 5G in sectors such as healthcare, transportation, manufacturing, and defense while contributing to sustainable urban development.

Keywords: Antenna heights, Beam steering, Frequencies, Material types, Optimization, Wireless communication.

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1. Introduction

The evolution of wireless communication technologies has continually reshaped the global connectivity landscape, enabling ubiquitous access to information and services across diverse sectors. Among these advancements, fifth-generation (5G) wireless technology stands out for its promise of unprecedented speed, reliability, and capacity. With the potential to revolutionize various aspects of daily life, from healthcare to entertainment and industrial production, 5G represents a pivotal milestone in telecommunications infrastructure. The deployment of 5G networks is supported by efforts from regulatory bodies and international organizations, such as the Federal Communications Commission [1] and determinations made by the ITU News [2].

Operating across a spectrum ranging from below 1 GHz to millimeter wave (mmWave) frequencies, 5G technology offers diverse possibilities, each with its trade-offs between signal coverage and data capacity. Leveraging multiple-input, multiple-output (MIMO) antenna technology, 5G user equipment can handle the complexities of mmWave frequencies, facilitating efficient data transmission and reception. Additionally, 5G deployment requires a shift towards smaller microcells, complementing traditional macro cell towers to provide seamless ultra-high-speed network coverage. Central to the efficacy of 5G deployment is beamforming technology, which enables targeted and efficient signal transmission by directing energy towards specific directions, thus minimizing interference and maximizing network performance.

However, deploying 5G networks in urban environments presents unique challenges. Densely populated urban landscapes pose obstacles such as high signal reflection and absorption, limited space for antenna installations, and complex propagation dynamics influenced by the surrounding environment. Understanding the interplay between system parameters such as transmitter power levels, carrier frequencies, antenna heights, and materials is crucial for optimizing energy efficiency and ensuring seamless 5G deployment in urban areas. This paper aims to elucidate the dynamics of 5G deployment in urban environments, with a focus on optimizing energy consumption. Through numerical simulations and insights from existing research in wireless communication systems and urban network optimization, we seek to identify optimal deployment strategies and antenna configurations for energy-efficient 5G networks. In subsequent sections, we delve into our analysis methodology, present our findings, and discuss the implications of our research. By offering actionable insights for network engineers, policymakers, and stakeholders, this study contributes to the advancement of sustainable, high-performance communication systems in urban environments, ushering in a new era of connectivity and innovation.

1.1. Motivation

Urban environments demand efficient 5G deployment strategies to handle dense populations and complex infrastructures. Understanding the interaction of various system parameters is essential for optimizing energy consumption and network performance. This research aims to bridge the gap between theoretical 5G concepts and practical urban implementation, addressing the growing need for high-speed, energy-efficient communication systems.

1.2. Our Main Contributions

Our study offers a comparative analysis of different 5G deployment scenarios to identify configurations that enhance energy efficiency and signal propagation. We also explore strategies to reduce energy consumption through advanced techniques like beamforming and optimized antenna designs. Additionally, we provide practical insights for network engineers, policymakers, and telecommunications firms, helping them implement effective and sustainable 5G solutions in urban settings. This research contributes to the development of smarter, more connected cities while aiming to minimize environmental impacts.

2. Related Work

In the field of wireless communication optimization in urban environments, various studies have been carried out to solve the challenges posed by complex propagation environments such as signal attenuation due to buildings, reflections, and diffraction.

The purpose of the study in Sousa, et al. [3] is to assess the accuracy of estimating radio coverage in 5G networks during the early deployment phase, which is crucial for effective network planning and optimization. The research examines the suitability of various path loss models and a new beamforming antenna model across different scenarios, including outdoor and indoor environments. The purpose of the proposed optimization algorithm in Smith and Johnson [4] is to address the challenge of energy consumption efficiency in the context of 5G mobile cellular networks. By maximizing energy efficiency through dynamic power allocation, the algorithm aims to enhance the performance of both indoor and outdoor users under various network conditions. The purpose of the survey in Buzzi, et al. [5] is to examine the evolving landscape of energy-efficient wireless communications, emphasizing its growing significance in the context of modern communication networks. It aims to provide a comprehensive overview of the field, including seminal and recent contributions, while also discussing the emerging challenges that researchers and practitioners need to address. The research in Salem, et al. [6] proposes a methodology for designing green policies to manage the network effectively, selecting operating points that balance energy efficiency and network performance. The research in Ge, et al. [7] aims to optimize energy efficiency and coverage. Through the lens of mean field game theory, the study focuses on maximizing the weighted energy efficiency of the BSs as a primary performance metric. The paper in Zhang, et al. [8] aims to reduce system power consumption and improve EE performance. Ultimately, the goal is to contribute to the advancement of energy-efficient 5G IoT systems through integrated optimization strategies. The paper in Usama and Erol-Kantarci [9] surveys recent research efforts focusing on enhancing the energy efficiency of both radio access and core networks in wireless communication systems. It explores various optimization avenues, including game theory and machine learning techniques, while also discussing challenges and open issues in the field. A study by Acarer [10] examined the use of next-generation 5G mobile communication systems in maritime communications and revealed significant findings in terms of energy efficiency. The study evaluated the effects of antenna configurations, beamforming techniques, and frequency selection on the performance of communication systems. It determined that 5G technology provides more efficient communication, especially in challenging environmental conditions, thanks to its low latency, high bandwidth, and flexible spectrum management. Furthermore, the effects of transmitter antenna height, transmitter power, and environmental factors on communication quality were analyzed, and beam steering techniques were shown to be an important tool for optimizing energy consumption [10].

These studies provide valuable insights and methodologies for optimizing wireless communication systems in urban environments.

They address various aspects such as antenna deployment, power control, frequency selection, interference management, and energy efficiency, contributing to the advancement of urban wireless networks. Wireless communication systems are susceptible to signal attenuation caused by reflection and diffraction, particularly in environments with obstacles and varying material properties. Numerous studies have investigated the impact of these phenomena on communication performance and proposed various optimization techniques to mitigate their effects.

3. System Model and Problem Definition

The system model involves wireless communications in urban environments using isotropic antennas operating at various carrier frequencies. The system model comprises transmitter characteristics such as power levels (5W, 10W, 20W) and antenna height (10m, 2m, 8m), receiver characteristics including antenna heights (1m, 2m, 4m, 8m), frequency bands (2.5 GHz, 3.5 GHz, 3.7 GHz, 4.2 GHz, 5.5 GHz, 24 GHz, 28 GHz, 36 GHz, 37 GHz, 39 GHz, 47 GHz), and factors affecting propagation like reflection, diffraction, beam steering, and various obstacles such as concrete, metal, glass, wood, and brick, with the problem definition focused on assessing received signal strength at different receiver antenna heights while considering the impact of transmitter power, antenna height, frequency, obstacles, and beam steering effects.

3.1. Objective

The objective is to minimize signal attenuation, which refers to the reduction in signal strength as it propagates through a medium or encounters obstacles. Signal attenuation can occur due to various factors such as path loss, reflection, diffraction, and absorption. Minimizing signal attenuation is crucial for maintaining reliable communication links and maximizing coverage in wireless communication systems.

3.2. Problem Definition: (Mathematical Definition)

The problem aims to minimize signal attenuation in a communication system. Given specific parameters such as transmitter power, antenna heights, frequency band, reflection, diffraction, distance between antennas, building material, and path loss, the goal is to calculate the received power using the Friis Transmission Formula. Additionally, considering zero antenna gains for both transmitter and receiver antennas simplifies the calculation. To calculate the signal attenuation using the Friis Transmission Formula, we'll utilize the Equation 1 as:

$$Pr = Pt + Gt + Gr - L\text{fs} - Lother \quad (1)$$

Where:
Pr = Received Power (dBm)
Pt = Transmitted Power (dBm)
Gt = Transmitter Antenna Gain (dBi)
Gr = Receiver Antenna Gain (dBi)
Lfs = Free Space Path Loss (dB)
Lother = Other Losses (dB)
Given:

- Pt = 5 w = $10 \log_{10}(5\ x\ 10^3)$ = 37 dBm
- Transmitter Antenna Height = 10 m
- Receiver Antenna Height = 1 m
- Frequency Band = 24 GHz
- Distance Between Transmitter Antenna and Receiver Antenna = 111 m
- Calculate the Free Space Path Loss (Lfs):

$$L\text{fs} = 20 \log_{10}\left(\frac{4\pi d f}{c}\right) \quad (2)$$

Where:

- d = 111 m (Distance between transmitter and receiver antennas)
- f = 24 GHz

- $c = 3\ x\ 10^8$ m/s (Speed of light)

Lfs = 20 $\log_{10}\left(\frac{4\pi\ x\ 111\ x\ 24\ x\ 10^9}{3\ x\ 10^8}\right)$
Lfs ≈ 20 $\log_{10}(2960)$
Lfs ≈ 20 x 3.471
Lfs ≈ 69.42
Applied and calculated Lfs as Equation 2.
Lother = 2 dB
Pr = 37 dBm + Gt + Gr – 69.42 dB – 2 dB
When an isotropic antenna is used, antenna gains are given as 0 dBi for both transmitting and receiving antennas.
Pr = 37 dBm – 69.42 dB – 2 dB
Pr = -34.42 dBm (approximately)

The result is the received power expressed in dBm, which indicates the effectiveness of the communication link in terms of signal strength.

4. Materials and Methods

In this study, we utilized an OpenStreetMap (.osm) file of Beyazıt Square in Istanbul to extract building information, which was visualized using Site Viewer. Small Cell Transmitter and Receiver were positioned at specified coordinates, equipped with isotropic antennas, and operated across various carrier frequencies.

The impact of transmitter antenna height variations on signal reception was investigated by altering receiver antenna heights. Path losses for signal transmission and reception were computed using the ray tracing propagation model, considering interactions with building materials such as concrete, brick, wood, glass, metal, and perfect electrical conductors. The .osm file corresponding to Beyazıt Square in Istanbul was obtained from OpenStreetMap [11]. The building information extracted from the OpenStreetMap file was transferred to Site Viewer for visualization as shown in Figure 1.

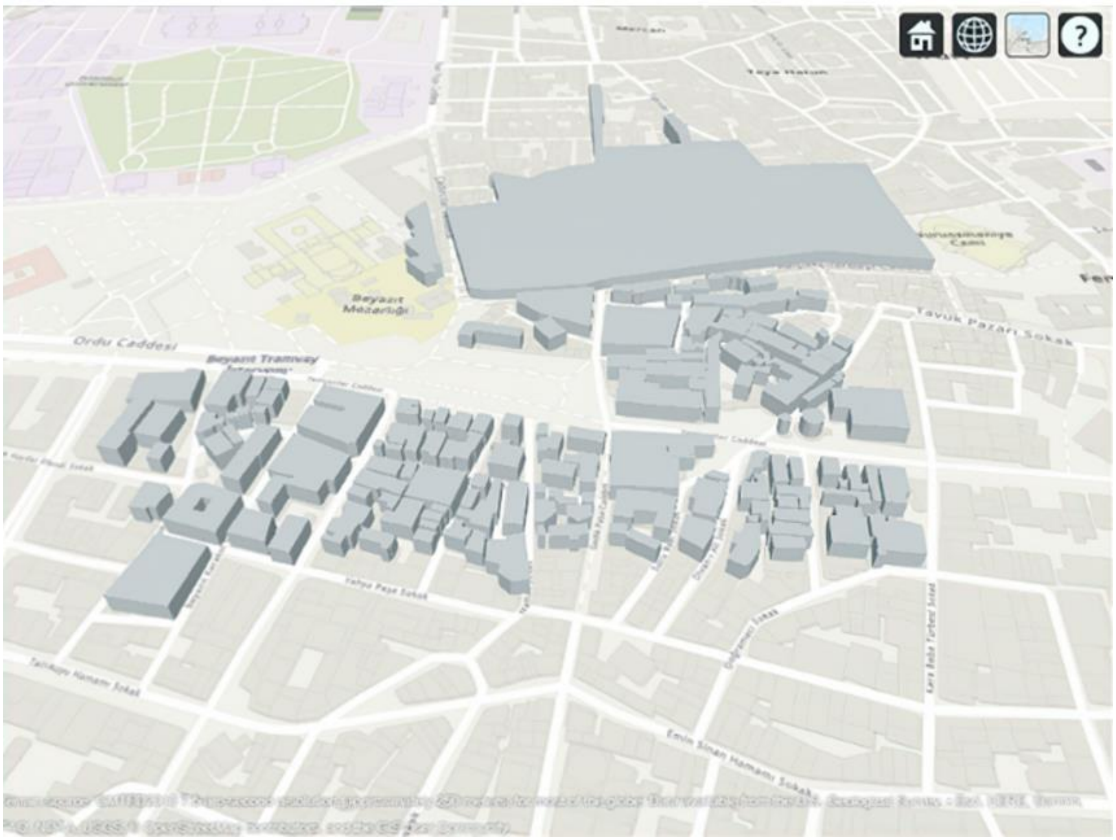

Figure 1.
Three-dimensional building model of Beyazıt Square, Istanbul, generated from OpenStreetMap (.osm) data.

4.1. Configuration

The Small Cell Transmitter is equipped with isotropic antennas. It operates across various carrier frequencies: 2.5 GHz, 3.5 GHz, 3.7 GHz, 4.2 GHz, 5.5 GHz, 24 GHz, 28 GHz, 36 GHz, 37 GHz, 39 GHz, and 47 GHz. Transmitter power levels of 5 W, 10 W, and 20 W are considered. Different transmitter antenna heights are evaluated for their impact on signal propagation. Small Cell Transmitter is located at a latitude 41.00920 and Longitude 28.96668 is given by Table 1.

Table 1.
Sample Output Parameters for Small Cell Transmitter and Location Details of the Small Cell Receiver (Latitude: 41.008871, Longitude: 28.967746) with Variable Antenna Heights to Assess Impact on Signal Reception.

Key	**Value**
Name	Small Cell Transmitter
Latitude	41.0092
Longitude	28.9667
Antenna	isotropic
Antenna Angle	0
Antenna Height	10
System Loss	0
Transmitter Frequency	4.70E+10
Transmitter Power	10

Ray tracing propagation model using the shooting and bouncing rays (SBR) method is employed. The SBR propagation model uses ray tracing analysis to compute propagation paths and their corresponding path losses. Path losses are calculated considering free-space loss, reflection, diffraction, and antenna polarization loss.

Buildings in the area are characterized by surface materials, including concrete, brick, wood, glass, metal, and perfect electrical conductor. The influence of these materials on signal propagation is taken into account.

Beam steering and the Phased Array System Toolbox™ along with MathWorks [12] Academic use are employed for optimizing a non-line-of-sight link. The optimization process aims to enhance signal quality and reliability under various environmental conditions and constraints. The Received signal strength method in the MathWorks [12] application was used for the calculation. This method returns the signal strength at receiver site RX due to transmitter site TX with the Propagation Model argument.

A coverage map is generated for a maximum range of 250 meters from the base station. Received power for ground locations within the coverage area is depicted on the map as shown in Figure 2. The coverage map shows received power for a receiver at each ground location, but the received power is not computed for building tops or sides. Signal strengths between -120 and -5.

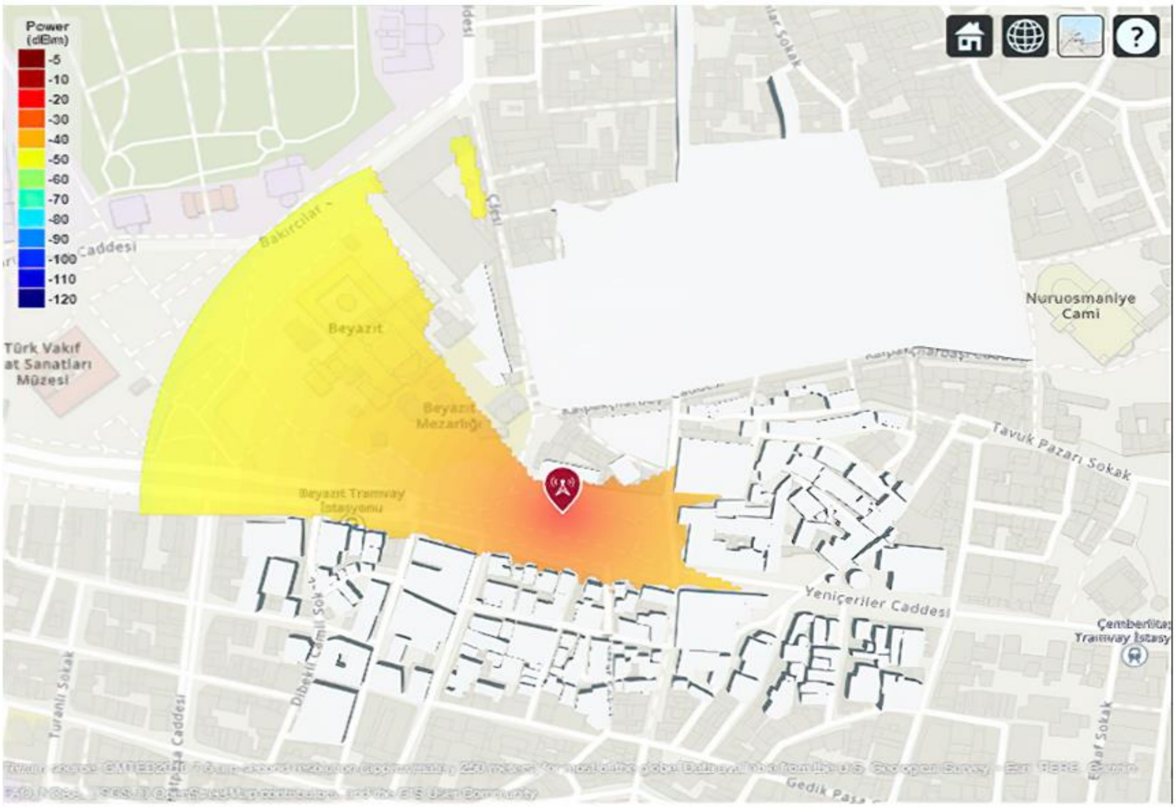

Figure 2.
A coverage map that includes maximum number of reflections to 0. The building and terrain material types to model perfect electrical conductors (Latitude 41.00920; Longitude 28.96668).

A Transmitter Site was created using an isotropic antenna at 41.00920 Latitude and 28.96668 Longitude, Transmitter Power 5 W, Transmitter antenna height 10 m and Carrier Frequency 24 GHz.

The ray tracing propagation model was prepared using the sbr method, entering the maximum number of reflections, and also entering "perfect-reflector" as Buildings Material and Terrain Material.

A Receiver Site with an antenna height of 1 m was created, similar to the Transmitter Site, at 41.008871 Latitude and 28.967746 Longitude.Later, the model was updated to Maximum Number of Reflections 1, Buildings Material and Terrain Material are "concrete".

Later, the model was updated to Maximum Number of Reflections 1, Buildings Material and Terrain Material are "concrete" and Received power using concrete materials was calculated as -72.0665 dBm. By adding weather impairments to the propagation model and recalculating the received power and including weather loss, it was calculated as -72.7397 dBm.

The remarkable result here is that applying maximum number of reflections to 1 and maximum number of diffractions to 0. Define a custom antenna from Report [13] create an 8-by-8 uniform rectangular array and Use Beam Steering to Enhance Received Power. Received power with beam steering was calculated as -51.2664 dBm.

5. Numerical Results

In this section, numerical findings obtained according to 5G network deployment scenarios in urban environments are presented. Numerical results are organized according to different system parameters and their effects on energy efficiency.

The following study is given as an example and concrete is used as terrain material. The transmitter uses the default isotropic antenna and operates at a carrier frequency of 2.5 GHz with a power level of 5 W and antenna height 10 m. Some results are given as examples when the receiver antenna height is 1m and One Reflection is used, using various materials are given by Table 2. The resulting Received power is given in dBm.

Table 2.
The results obtained using various materials are given in Received power dBm.

Material	Value
Perfect Reflector	-44.3644
Brick	-54.0574
Wood	-56.7979
Glass	-51.7739
Metal	-44.3662
Concrete	-52.3975

Additionally, when concrete was used as the material, -52.3991 dBm Received Power was obtained by including Weather loss. In addition, -51.1294 dBm Received Power was obtained in the case of Two Reflections and -52.4327 dBm in the case of Two Reflections and One Diffraction. when beam steering was applied, a Received Power of -30.9259 dBm was obtained in the case of One Reflection, -29.6805 dBm in the case of Two Reflections and -38.1374 dBm in the case of Two Reflections and One Diffraction.

Finally, when concrete was used as the material, -52.5507 dBm Received Power was obtained by including Weather loss. In addition, -49.2416 dBm Received Power was obtained in the case of Two Reflections and -47.7694 dBm in the case of Two Reflections and One Diffraction. When beam steering was applied, a Received Power of -31.0514 dBm was obtained in the case of One Reflection, -28.2445 dBm in the case of Two Reflections and -34.4212 dBm in the case of Two Reflections and One Diffraction.

The remarkable result here is that after applying beam steering, there is a difference of approximately 3.7 dBm in the case of Two Reflections and One Diffraction.

In the results, we see that concrete has the lowest receiver power levels when used as a reflector. This shows that concrete can effectively manage signal reflections and propagation. In general, at higher frequencies (e.g. 24 GHz and above), receiver power levels are lower. This indicates that higher frequencies have greater barrier penetration and propagation loss. If the receiver antenna is high (4m), receiver power levels are generally low. This indicates that higher antenna heights can improve transmission. Even at higher frequencies, receiver power levels are generally lower, but for frequencies of 24 GHz and above the difference is less pronounced. Receiver power levels are generally lower when there is no Beam Steering effect. Generally, receiver power levels are lower at higher frequencies, indicating that higher frequencies have more propagation loss. When there is a Beam Steering effect, receiver power levels generally increase. This ensures that the signal is directed more effectively into a targeted direction. Even at higher frequencies, receiver power levels generally increase due to the Beam Steering effect, but this increase will depend on the effectiveness of the Beam Steering and the characteristics of the medium used.

Beam steering refers to the ability to control the signal direction of antenna arrays. This parameter has significant effects on the received power. Beam steering provides the ability to control the signal propagation direction of antennas. This allows the signal to focus in a certain direction or avoid a certain direction. Directional antennas can enable the receiver to receive a stronger signal from a particular source. In this case, the received power increases. Additionally, beam steering can reduce interference and other signal distortions by targeting the signal in a specific direction, which can have a positive effect on the received power. Beam steering can reduce multipath effects by focusing the signal in a specific direction. This allows the receiver to receive a clearer signal and can increase the received power.

Reflection and diffraction represent various media interactions during the propagation of electromagnetic waves. Both have significant effects on received power. Reflection is the reflection of the signal back when it encounters an obstacle. This allows the signal to reflect over the obstacle and reach the receiver. Reflection can increase the received power because the signal can reach the receiver via additional paths. This is especially important for buyers who are outside the direct line. However, reflection can sometimes cause multipath interference, which can cause interference and signal degradation problems at the receiver. Diffraction is the propagation of the signal around the edges of obstacles.

The signal refracted from the edge of the obstacle can reach the receiver. Diffraction often has an enhancing effect on the received power because it allows the signal to propagate around obstacles.

Lower frequencies generally have longer wavelengths, allowing them to penetrate obstacles better. This can cause the received power to increase because the signal can pass through obstacles more easily. Higher frequencies generally have shorter wavelengths and tend to interact with obstacles. This may reduce the received power because the signal may be further strained by obstacles. Increasing frequency generally results in increased propagation loss. That is, at higher frequencies, the signal may attenuate faster over distance. This may cause the received power to decrease. The effect of frequency is also related to the multipath effect. Higher frequencies generally experience more multipath effects, which can cause the received power to fluctuate. Lower frequencies can provide a more stable received power. Comparing the effect of Beam Steering on Received Power under current conditions reveals significant differences.

Shifting focus to the impact of Frequency bands on Received Power under similar conditions, with a Transmitter Power Level of 20W, Transmitter Antenna Height of 10m, Receiver Antenna Height of 1m, and concrete as the building material, it's evident that the 2.5 GHz frequency band yields higher received power (-46.3769 dBm) compared to the 28 GHz frequency band (-67.3858 dBm). This disparity can be attributed to the former's superior penetration through obstacles like concrete buildings and its lower susceptibility to attenuation. Furthermore, the lower frequency band is less affected by differences in antenna height between the transmitter and receiver. Consequently, the Frequency Band effect is approximately 21 dBm. In conclusion, these numerical results offer valuable insights into the intricate dynamics of system parameters and energy savings in urban 5G deployments. Such insights are crucial for informing strategic decision-making processes and facilitating the development of efficient, sustainable communication systems tailored for the smart cities of the future.

6. Discussion

Several academic studies have delved into optimizing wireless communication systems in urban environments, focusing on parameters such as transmitter power levels, carrier frequencies, antenna heights, and material properties.

Our study builds upon these researchs by incorporating additional factors such as carrier frequencies, material properties, and beam steering techniques to offer a comprehensive analysis of 5G network optimization. We propose optimization strategies to mitigate the adverse effects of material-induced attenuation. Our study aligns with these researchs by exploring the effectiveness of beam steering in reducing signal loss due to reflection and diffraction. However, we provide a more comprehensive analysis by integrating beam steering with other optimization parameters such as antenna heights, frequencies, and material properties. While our study shares similar objectives in optimizing antenna heights, we expand upon these researchs by considering additional factors such as transmitter power levels, carrier frequencies, and material properties. By incorporating these variables, we provide a more holistic approach to network optimization in urban environments.

7. Conclusion

This study has explored the optimization of energy efficiency in 5G wireless communication systems within dense urban environments through a comprehensive set of analytical evaluations and simulation-based analyses. By systematically examining the interactive effects of multiple parameters—including frequency selection, antenna height, transmission power, material properties, propagation scenarios, and beam steering technologies—strategies aimed at maximizing energy efficiency have been identified.

The findings in my study parallel similar studies in the literature. Acarer [10] in particular, examined in detail the effects of methods and parameters used to optimize energy efficiency in 5G wireless communication systems. Acarer's study emphasized the impact of antenna configurations, beamforming techniques, and frequency selection on communication systems, demonstrating that these factors play a significant role in improving energy efficiency.

Key findings indicate that low-frequency bands (2.5–5.5 GHz) are more effective in ensuring stable and energy-efficient communication in urban settings due to their superior signal penetration capabilities. In contrast, while higher frequencies (24 GHz and above) offer increased data rates, they exhibit significant signal degradation in indoor and obstructed scenarios, leading to elevated energy consumption. Hence, the preferential use of lower-frequency bands is recommended for general urban network deployments.

Antenna height has been shown to positively influence signal coverage and energy efficiency when optimized relative to average building heights. However, excessive antenna elevation may exacerbate multipath effects, underscoring the need for context-aware height adjustments. Likewise, transmission power directly impacts both signal strength and energy consumption. Adaptive power control mechanisms are proposed as an effective means of achieving optimal power levels without contributing to electromagnetic pollution. Material composition in urban infrastructure has a significant effect on RF propagation. Metallic and glass surfaces were found to enhance energy efficiency due to their reflective properties, whereas materials such as concrete, brick, and wood increase signal attenuation, resulting in higher energy demands. Strategic incorporation of reflective materials in communication infrastructure design is therefore encouraged.

Propagation analysis revealed that single-reflection scenarios, particularly involving metal and glass, maintain higher received power levels. However, multiple reflections and diffraction lead to substantial signal losses. Beam steering technology, especially in high-frequency environments with complex multipath propagation, plays a crucial role in mitigating these losses. The integration of advanced, adaptive beam steering algorithms is recommended to improve directional transmission and minimize energy expenditure.

Furthermore, emerging technologies such as network slicing and edge computing offer substantial energy-saving potential by enabling resource-aware communication and distributed data processing, respectively. These technologies contribute to system-wide efficiency, particularly in application-specific and latency-sensitive scenarios.

Finally, this research emphasizes the importance of integrating urban planning with telecommunication infrastructure. Cross-disciplinary coordination is vital to ensure broad coverage, efficient energy use, and sustainable urban development. In conclusion, achieving energy efficiency in 5G networks deployed in dense urban areas requires a multifaceted optimization strategy. Key considerations include frequency management, antenna configuration, transmission power control, material-aware deployment, propagation path analysis, advanced beam steering, network slicing, and edge computing. Future research should focus on refining these strategies to develop more sustainable and energy-efficient 5G communication systems.

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Appendices A.

Table A1.
Received Power by Using Transmitter Antenna Height is 2 m and Transmitter Power is 5 Watt.

Transmitter Antenna Height (m)		**2**	**Transmitter Power (watt)**		**5**	**Frequency in GHz and Received Power in dBm (-)**							
Material	**Reflection Path**	**Beam Steering**	**2.5 GHZ**	**3.5 GHZ**	**3.7 GHZ**	**4.2 GHZ**	**5.5 GHZ**	**24 GHZ**	**28 GHZ**	**36 GHZ**	**37 GHZ**	**39 GHZ**	**47 GHZ**
Brick	Single Reflection	No	54.5921	57.5384	58.0237	59.1296	61.4792	74.2859	75.6250	77.8080	78.0460	78.5033	80.1240
Wood	Single Reflection	No	57.4559	60.3772	60.8596	61.9601	64.3012	77.0911	78.4292	80.6107	80.8486	81.3055	82.9251
Glass	Single Reflection	No	52.1635	55.0860	55.5686	56.6695	59.0117	71.8077	73.1465	75.3292	75.5671	76.0243	77.6448
Concrete	Single Reflection	No	52.8271	55.7548	56.2382	57.3409	59.6866	72.4972	73.8372	76.0216	76.2598	76.7173	78.3390
Metal	Single Reflection	No	44.3265	47.2494	47.7322	48.8333	51.1759	63.9757	65.3151	67.4988	67.7369	68.1943	69.8156
Metal	Two Reflection	No	36.6313	50.7557	46.2346	41.9460	59.7581	57.8334	59.7996	63.9482	84.1424	69.7048	63.6281
Metal	Two Reflection and One Diffraction	No	35.8390	50.4961	42.9868	40.9098	51.7200	58.8189	58.5671	63.4439	75.6695	71.7549	64.1684
Metal	Single Reflection	Yes	22.8247	25.7485	26.2316	27.3338	29.6840	43.1429	44.6570	47.2021	47.4838	48.0267	49.9643
Metal	Two Reflection	Yes	15.5590	50.4961	25.7730	20.9966	37.6402	36.7680	38.7274	42.8297	64.4399	49.4701	42.6232
Metal	Two Reflection and One Diffraction	Yes	22.1293	31.2784	33.5860	28.1515	45.1552	44.9014	46.3884	50.8157	69.0435	56.5720	49.9082