FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 8 No. 5, October, 2024, pp 379 - 393
DOI: https://doi.org/10.33003/fjs-2024-0805-2761

ANALYSIS AND OPTIMIZATION OF URBAN-SUBURBAN 5G COVERAGE PREDICTIONS

***Osuolale Abdramon Tiamiyu, Hakeem Babalola Akande and Fatima Olamide Abass**

Department of Telecommunication Science, University of Ilorin

*Corresponding authors' email: tiamiyu.oa@unilorin.edu.ng; ozutiams@yahoo.com

ABSTRACT

In today's world, the demand for robust and faster network connectivity and data speeds has become paramount. Though the transition to 5G technology is a significant advancement that promises unparalleled speeds, reduced latency, and enhanced connectivity crucial for modern applications, the current situation reveals persistent challenges in achieving these ideals across diverse environments. There are disparities between predicted and actual network performance metrics such as throughput, latency, coverage gaps, and inconsistencies in QoS (quality of service). The study aims to analyze the existing 5G coverage predictions and model a similar network scenario on MATLAB for optimization of the 5G network.

Keywords: 5G, Beamforming technology, SINR, KPI, 5G throughput

INTRODUCTION

In today's rapidly evolving digital landscape, the demand for faster and more reliable network connectivity has become paramount, shaping industries, economies, and daily lives across the globe. The transition from the fourth generation of wireless technology (4G) to the fifth generation of wireless technology (5G) technology represents a monumental leap in telecommunications, promising unprecedented data speeds, ultra-low latency, and robust connectivity to support a vast array of applications (Sani & Baba, 2024). This evolution is not just about faster internet for individual users but also about enabling transformative technologies that drive economic growth and societal advancement (Tiamiyu, 2019). In Nigeria, as in many other parts of the world, the adoption of 5G technology holds immense promise. The Nigerian economy, known for its resilience and innovation in sectors like fintech and e-commerce, stands to benefit significantly from the enhanced capabilities of 5G (Bakare et al. (2021)). Faster data speeds and lower latency will empower businesses to innovate more efficiently, offering seamless online transactions, real-time data analytics, and enhanced customer experiences (Khalifa, 2024). For instance, Nigerian businesses could leverage 5G to improve logistics and supply chain management, enable remote work capabilities with reliable video conferencing, and enhance digital marketing strategies with augmented reality (AR) and virtual reality (VR) applications (Pahalson et al. (2023)).

The impact of 5G extends beyond business efficiencies to include transformative changes in healthcare, education, and public services. In healthcare, 5G's ultra-reliable low-latency communication (URLLC) can support remote surgery and telemedicine, enabling healthcare professionals to provide critical services even in remote areas with limited access to medical facilities. In education, 5G can revolutionize learning experiences with immersive VR classrooms and real-time collaboration among students and educators across different locations (Elendu et al. (2024)). On a global scale, the deployment of 5G networks is set to redefine connectivity standards, facilitating innovations such as smart cities, autonomous vehicles, and industrial Internet of Things (IoT). These advancements rely on the seamless integration of massive device connectivity and efficient data transmission enabled by 5G technology. For instance, smart city initiatives can leverage 5G to improve traffic management systems, enhance public safety with real-time surveillance, and optimize energy consumption through smart grids (Abir et al. (2023)). Accurate coverage predictions play a pivotal role in the efficient deployment of 5G networks, particularly given the unique challenges posed by this technology. Unlike previous generations, 5G utilizes high-frequency bands and advanced technologies like beamforming to deliver targeted coverage. Predicting coverage patterns involves understanding signal propagation characteristics, the influence of obstacles in urban environments, and the need for dense small-cell deployments in high-demand areas (Sousa et al. (2021)).

In Nigeria, the advent of 5G technology represents a pivotal advancement poised to revolutionize connectivity across industries, enhance operational efficiencies, and elevate user experiences to unprecedented levels. As the demand for faster and more reliable network capabilities continues to grow, the need for optimal coverage predictions becomes increasingly crucial. These predictions not only ensure strategic deployment of network infrastructure but also play a vital role in minimizing signal interference, improving network reliability, and delivering seamless connectivity across diverse applications (Asianuba, 2021).

One of the key technologies driving the promise of 5G in Nigeria is beamforming. This advanced feature of 5G networks enables precise directional coverage by focusing radio frequency signals exactly where they are needed. In practical terms, beamforming allows operators to target specific areas with high demand for connectivity, such as urban centres or crowded events, while minimizing signal dispersion and interference (Avnet Abacus, 2023). For example, in Lagos, Nigeria's bustling economic hub, beamforming can be deployed to enhance coverage in densely populated areas like business districts, where traditional network signals may struggle due to high-rise buildings and heavy user traffic. Mitigating signal blockages is another critical benefit of beamforming in 5G networks, particularly in urban environments characterized by complex layouts and structural impediments. By dynamically adjusting the transmission direction of signals, beamforming helps circumvent obstacles like buildings or terrain features that could otherwise degrade signal strength or cause dead zones. This capability is essential for ensuring reliable connectivity in areas with obstructed line-ofsight, such as city centres where tall buildings often hinder signal propagation. Moreover, the enhanced network efficiency offered by beamforming translates into tangible improvements in spectral efficiency and overall performance.

In Nigeria, where spectrum resources are valuable and finite, optimizing their usage is paramount. Beamforming reduces unnecessary signal dispersion by directing RF signals precisely to targeted users or devices, thereby maximizing spectral efficiency. This efficiency not only supports higher data speeds and lower latency but also enables the seamless operation of bandwidth-intensive applications like video streaming, online gaming, and augmented reality experiences. The adaptability of beamforming to varying user demands is particularly advantageous in Nigeria's dynamic market landscape. As consumer behaviours and business requirements evolve, 5G networks equipped with beamforming can dynamically adjust to meet changing demands (Ashraf et al. (2024)). For instance, during major events such as concerts or festivals in cities like Lagos, Ibadan, Abuja, Kaduna, Kano or Port Harcourt, where large crowds gather, beamforming can allocate resources efficiently to ensure uninterrupted connectivity for attendees relying on mobile data services. Similarly, in rural areas where population densities are lower but connectivity remains essential for agricultural IoT applications or remote healthcare services, beamforming can optimize coverage and performance tailored to specific local needs. Integrating beamforming technology into 5G networks holds immense promise for Nigeria, offering a pathway to enhanced connectivity, improved operational efficiencies, and enriched user experiences across various sectors (Pons et al. (2023)). By leveraging beamforming's capabilities to deliver precise directional coverage, mitigate signal blockages, improve network efficiency, and adapt to diverse user demands, Nigeria can unlock the full potential of 5G technology. As the country continues to embrace digital transformation, accurate coverage predictions facilitated by technologies like beamforming will be instrumental in maximizing the benefits of 5G and driving sustainable growth in the digital economy.

In an ideal scenario, 5G networks would seamlessly deliver high throughput, low latency, reliable connectivity, extensive coverage, robust capacity handling, smooth mobility support, energy and spectrum efficiency, superior quality of service, and seamless handover between cells. However, the current situation reveals persistent challenges in achieving these ideals across diverse environments. Real-world measurements from drive tests indicate disparities between predicted and actual network performance metrics such as throughput, latency, coverage gaps, and inconsistencies in quality of service (Pahalson et al. (2023)). Despite ongoing efforts and investments in network infrastructure and optimization strategies, including beamforming and Massive Multiple Input Multiple Output (MIMO) technologies, these challenges persist, affecting user experience and limiting the full realization of 5G's transformative potential.

These issues persistently impact both individual users and businesses reliant on 5G technology. Users experience frustration due to unreliable connections, delayed data transfer, and inadequate coverage in certain locations, hindering productivity and impeding the adoption of emerging applications like IoT. Businesses face operational inefficiencies and potential revenue loss from service disruptions and degraded network performance (Tiamiyu, 2020). Despite advancements, the existing solutions have not effectively addressed the root causes of these performance gaps, necessitating a deeper investigation into the factors influencing network performance variability. Understanding these complexities is crucial to developing targeted interventions that enhance network reliability, optimize resource allocation, and improve overall user satisfaction. This research aims to bridge the gap in current knowledge by analyzing real drive test measurements to uncover insights into the discrepancies between predicted and actual 5G network performance. By identifying these discrepancies and their underlying causes, this study seeks to propose evidence-based recommendations for optimizing 5G coverage predictions. Ultimately, addressing these challenges will pave the way for more efficient network deployments, improved user experiences, and the realization of 5G's transformative potential in Nigeria and beyond. It is with these goals in mind that this research endeavours to provide a comprehensive understanding of 5G network performance dynamics and propose effective strategies for mitigating the identified issues.

Related Works

An empirical study carried out by Sousa et al. (2021) investigated the accuracy of 5G coverage predictions by analyzing a new beamforming antenna model and different path loss models. This study utilized 3D synthetic and real scenarios for both outdoor and indoor environments. The researchers also used real 5G drive tests to evaluate the 3GPP path loss model's accuracy in urban macro (UMa) scenarios.

The previous study by Sousa et al. (2021) adopted an experimental approach by testing different path loss models and beamforming antenna configurations in both synthetic and real-world environments. In contrast, the present study adopts a more descriptive approach, focusing on the analysis and optimization of existing coverage predictions using real drive test measurements. Moreover, while the previous study was conducted using a combination of 3D synthetic scenarios and real data from urban areas, the present study focuses specifically on data collected from drive tests in various environments.

Sousa et al. (2021) found that using beamforming with multiple vertical beams is particularly advantageous when base stations are placed below the surrounding buildings. In regular UMa surroundings, a single vertical beam provided adequate indoor coverage and maximized outdoor coverage after antenna tilt optimization. The study highlighted significant discrepancies in the 3GPP path loss model's initial predictions, with a Mean Absolute Error (MAE) of 21.05 dB for Line-of-Sight (LoS) and 14.48 dB for Non-Line-of-Sight (NLoS). Calibration of the model substantially improved its accuracy, reducing the MAE to 5.45 dB for LoS and 7.51 dB for NLoS. Additionally, the study demonstrated that machine learning algorithms, particularly the Random Forest algorithm, could further refine path loss predictions, achieving MAEs within the range of 4.58 dB to 5.38 dB for LoS and 3.70 dB to 5.96 dB for NLoS.

The current study aligns with Sousa et al. (2021) findings by emphasizing the need for accurate 5G coverage predictions in various environments. However, it builds on this by focusing on empirical data collected directly from drive tests, which provides a more practical perspective on real-world 5G deployment challenges.

Polak et al. (2024), in their study, investigated the performance of 4G and 5G mobile signal coverage in a heavy industry environment. In their study, they focused on the stability and reliability of data transmission within complex factory settings, which are critical for the integration of advanced wireless technologies in Industry 4.0. The researchers conducted long-term measurement campaigns using a costeffective and portable setup, recording several key performance indicators (KPI) for both 4G and 5G downlink and upload to analyze the impact of the industrial environment and network load over time.

Their study is similar to the present study in the sense that both studies aim to analyze and optimize network coverage and performance using real-world measurements. However, the previous study by Polak et al. (2024) adopted a comprehensive analytical approach, focusing on the industrial environment's impact on 4G and 5G networks. In contrast, the present study adopts a more focused approach, specifically targeting the optimization of 5G coverage predictions using drive test measurements. Additionally, while the previous study was conducted in a heavy industry environment, the present study focuses on urban and suburban environments, emphasizing the adaptability and generalizability of the research findings.

Polak et al. (2024) found that the performance of 4G and 5G networks in a heavy industry environment is significantly influenced by factors such as the presence of large machinery, metal structures, and network load variations throughout the day. The study highlighted that during peak working hours, the network load increased, leading to fluctuations in signal strength and data transmission rates. The researchers also noted that the portable measurement setup was effective in capturing real-time data and providing valuable insights into the network's performance under different conditions.

Polak et al. (2024) also highlighted the importance of continuous monitoring and evaluation of network performance to meet the increasing demands of mobile users. This is a key area of agreement with the present study, which also underscores the necessity of regular drive tests and empirical data collection to keep up with the dynamic nature of 5G networks. Both studies recognize the critical role of real-world measurements in identifying performance gaps and implementing effective optimization techniques to improve network quality and user satisfaction.

An empirical study carried out by Abbas and Curry (2020) investigated the accuracy of 5G coverage predictions and compared them with real trial measurements. The study was on the initial link budget for data services, providing coverage predictions and measurements for a 5G NR NSA (Non-Stand Alone) trial operating at 3.5GHz with 60 MHz bandwidth. The study by Abbas and Curry (2020) adopted an experimental approach by conducting a trial measurement and comparing the results with predictions generated by an RF planning tool. They found that the initial link budget and coverage predictions generated by the Atoll tool provided a reasonable estimate of the actual 5G coverage. However, there were discrepancies between the predicted and measured coverage, particularly in areas with complex environmental factors such as tall buildings and dense urban infrastructure. The study highlighted the importance of beamforming gain, less down tilting, and increased gNodeB transmit power in compensating for coverage differences. These findings underscore the need for accurate and reliable coverage predictions to ensure optimal network performance during the initial rollout of 5G networks. The current study aligns with Abbas and Curry's (2020) findings by emphasizing the need for accurate and reliable network performance evaluations to ensure optimal service delivery. However, it builds on this by focusing specifically on the optimization of 5G coverage predictions using real drive test measurements. Both studies underscore the significance of integrating theoretical models with real-world measurements to understand the complexities of wireless signal propagation in different environments and the necessity of adaptive solutions to address these challenges.

In addition, Abbas and Curry's (2020) findings on the impact of environmental factors and network load on signal performance are echoed in the present study's focus on optimizing 5G coverage predictions. The present study aims to build on these insights by specifically analyzing how beamforming and other advanced technologies can be leveraged to improve 5G signal quality and coverage in urban and suburban settings. By integrating real drive test measurements with advanced modelling techniques, the present study seeks to offer practical solutions for enhancing 5G network performance in diverse environments.

An empirical study carried out by Obiefuna and Omijeh (2024) investigated the prediction and detection of coverage holes in 5G networks using machine learning techniques. The study focused on identifying areas within 5G networks where the signal is either nonexistent or too weak to be detected, referred to as coverage holes (CH). The researchers utilized pre-collected measured report data from a live 5G network monitoring system and applied various machine learning classification techniques, including Artificial Neural Networks (ANN), Random Forest (RF), Naive Bayes (NB), and Logistic Regression (LR), to predict and detect these coverage gaps. They concluded that machine learning techniques such as ANN, RF, NB, and LR could effectively predict and detect coverage holes in 5G networks.

Another empirical study carried out by El-Saleh et al. (2022) investigated the performance of mobile broadband cellular networks in a densely populated city. The study focused on evaluating the QoS provided by various mobile network operators (MNO) in Cyberjaya City, Malaysia. The researchers collected data through drive tests, analyzing multiple performance metrics such as signal quality, throughput (downlink and uplink), ping, and handover in both outdoor and indoor environments.

The previous study is similar to the present study in the sense that both studies aim to analyze and optimize network coverage and performance using real-world measurements. However, the previous study by El-Saleh et al. (2022) adopted a comprehensive analytical approach, focusing on mobile broadband (MBB) services in 3G and 4G networks across various implementation scenarios and performance metrics. In contrast, the present study adopts a more focused approach, specifically targeting the optimization of 5G coverage predictions using drive test measurements.

El-Saleh et al. (2022) found that the maximum average throughput for outdoor drive tests was 14.3 Mbps for downlink and 7.1 Mbps for uplink, while the minimum average ping and packet loss was 36.5 ms and 0.14, respectively, for all MNO. The in-building measurements, however, showed a significant drop in performance, with an overall average data rate of only 2 Mbps. The study highlighted several recommendations for MBB providers to enhance their network performance and quality of experience (QoE) for users.

The current study aligns with El-Saleh et al. (2022) findings by emphasizing the need for accurate and reliable network performance evaluations to ensure optimal service delivery. However, it builds on this by focusing specifically on the 5G network and its unique challenges, such as higher frequency bands and beamforming technologies. The present study aims to utilize real drive test measurements to refine 5G coverage predictions, thereby providing a more accurate representation of network performance in various environments. By comparing the performance of an optimized network model in MATLAB with real-world data, the current study seeks to validate the effectiveness of its optimization strategies in enhancing 5G coverage.

System Model

The study set out to achieve several key objectives, beginning with conducting a Single Site Verification (SSV) drive test to gather empirical data on the 5G signal behaviour. Thus, the study considered an urban environment, recognizing the challenges posed by complex terrains, high user density, and varying user demands. Specific parameters include signal propagation characteristics, interference patterns, and the adaptability of coverage models to dynamic conditions.

The research adopted a hybrid approach combining simulation-based analysis and real-world drive test measurements. The simulation toolbox in MATLAB was utilized for indepth exploration of the beamforming antenna model's impact on 5G coverage predictions. MATLAB, developed by MathWorks, is widely used in both academia and industry for various applications due to its powerful and versatile capabilities (Xu, 2014). The MATLAB has, as its part, the 5G Communication Toolbox, specifically designed for the design, simulation, analysis, and verification of 5G systems. This toolbox provides standard-compliant functions and tools for the end-to-end development of 5G NR communication systems; and it is essential for researchers, engineers, and network operators who aim to optimize the performance of 5G networks (Moayyed et al. (2020)). As a high-performance software environment for technical computing, MATLAB integrates computation, visualization, and programming in an easy-touse interface where problems and solutions are expressed in familiar mathematical notation. Its comprehensive toolset and ease of use make it an invaluable resource for researchers and engineers working on network optimization projects.

In this study, for 5G network optimization, MATLAB was used to simulate network conditions, analyze performance, develop optimization algorithms, and visualize the impact of various changes on network efficiency. The simulations complemented the real drive tests, providing empirical data to validate the model's effectiveness in practical scenarios.

The datasets for this 5G network analysis were collected through a cluster site drive-test conducted in Eti-osa Cluster covering the area of Victoria Island (VI), and Ikoyi in Lagos State, Nigeria. These locations are illustrated in Figure 1. Key performance metrics assessed included data throughput, latency, reliability, network capacity, coverage, energy efficiency, QoS, call attempts, call setup success rate, blocked calls, dropped calls, retainability rate, accessibility (CSSR), and handover success rate. These tests provided a comprehensive evaluation of 5G network performance in the specified areas.

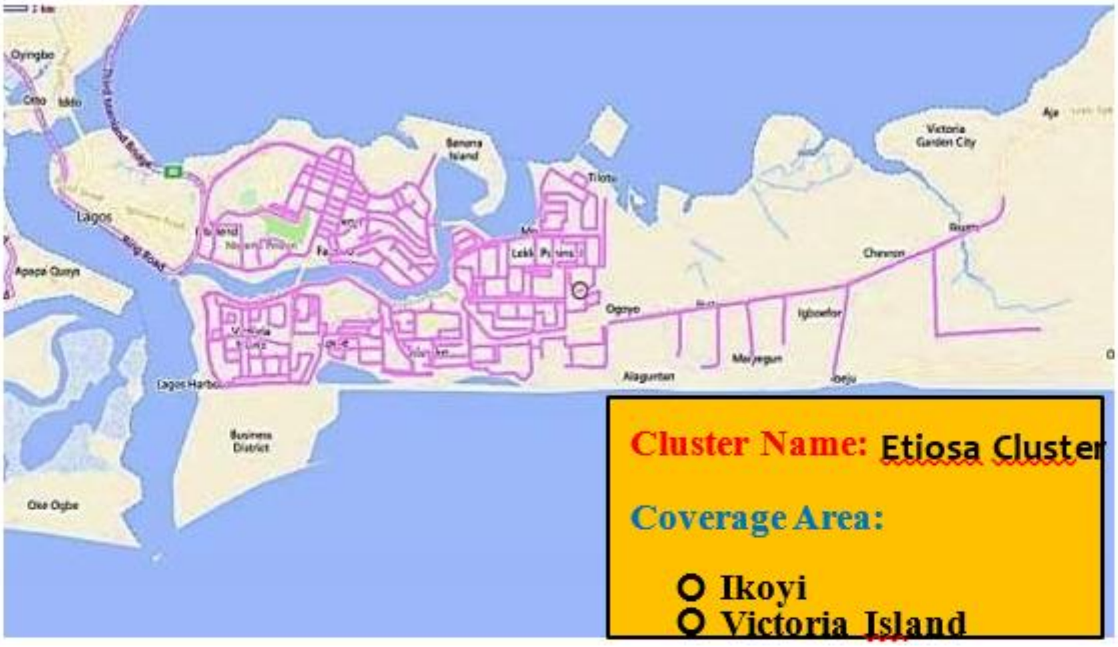


Figure 1: The Coverage Area

For the drive test for 5G network analysis, a comprehensive set of tools and equipment to ensure accurate data collection and analysis was utilized. These include the TEMS Investigation and TEMS Discovery software tools, which are industry-standard for capturing and analyzing network data during drive-tests (Figure 2,3). All the necessary software was installed on a suitable Laptop. The laptop computer provided the necessary processing power and storage for real-time data handling. The mobile station tool, typically a smartphone or mobile device, was equipped with the required software to perform the drive test, and a GPS antenna ensured precise geo-tagging of the collected network data. Together, these tools and equipment facilitated a thorough and reliable assessment of network performance.

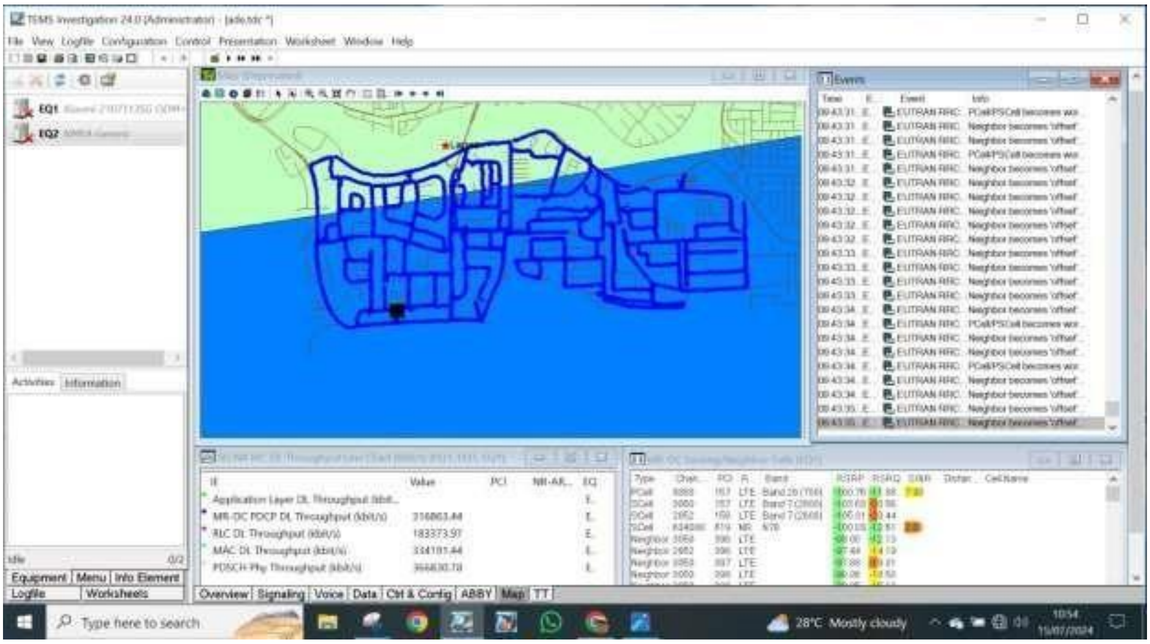


Figure 2: The TEMS Investigation Interface

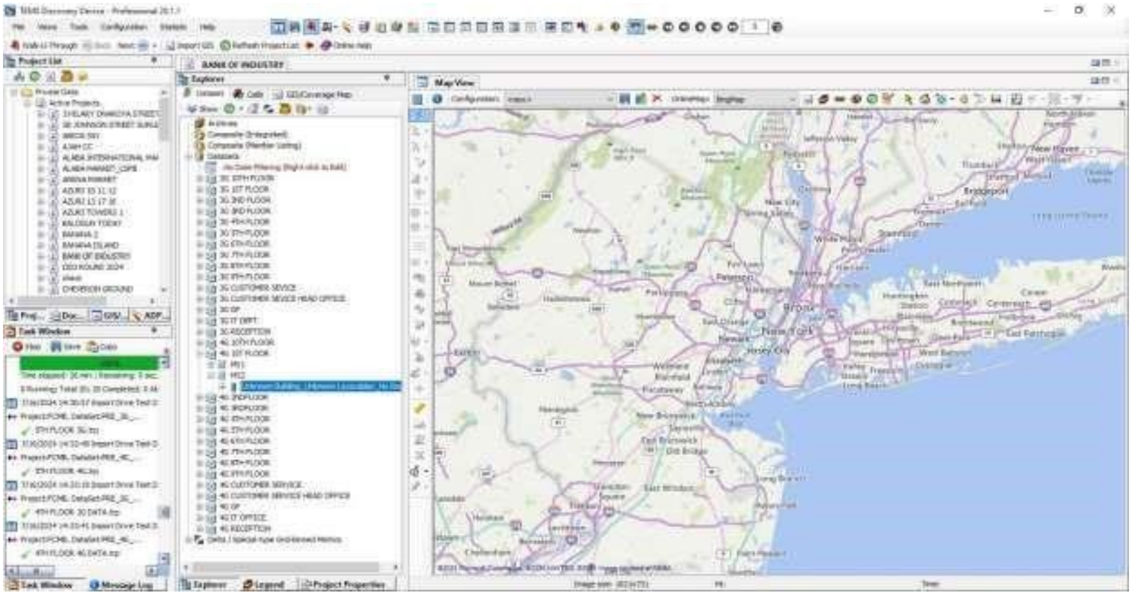
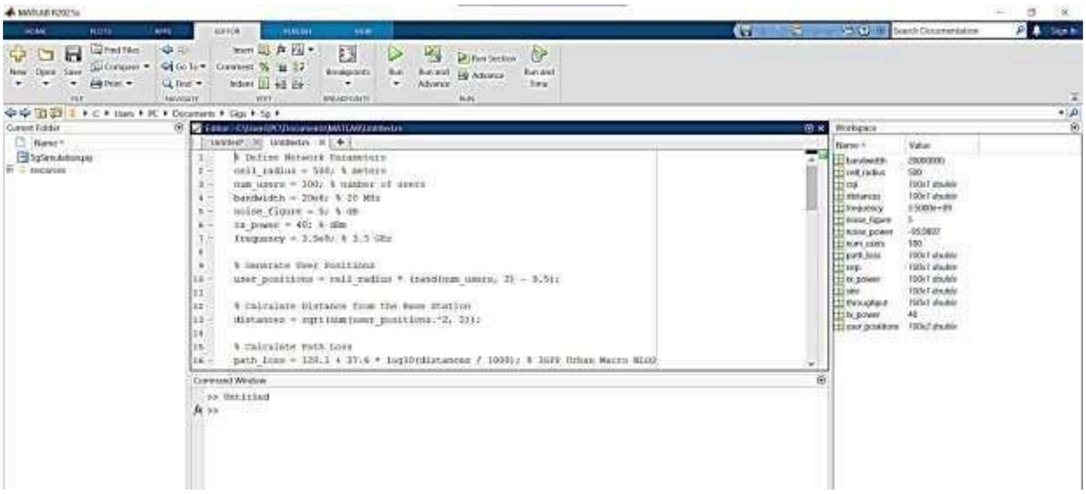


Figure 3: The TEMS Discovery Interface



```
% Define Network Parameters
cell_radius = 500; % meters
num_users = 100; % number of users
bandwidth = 20e6; % 20 MHz
noise_figure = 5; % dB
tx_power = 40; % dBm
frequency = 3.5e9; % 3.5 GHz

% Generate User Positions
user_positions = cell_radius * (rand(num_users, 2) - 0.5);

% Calculate Distance from the Base Station
distances = sqrt(sum(user_positions.^2, 2));

% Calculate Path Loss
path_loss = 128.1 + 37.6 * log10(distances / 1000); % 3GPP Urban Macro NLOS
```

```
>> Untitled
>>
```

Figure 4: Simulation on the MATLAB

Table 1 shows the drive test data for the 5G network in the selected areas of Lagos, revealing several KPI.

Table 1: Important Drive Test Indicators

Network	KPI	Source	%
5G	SS-RSRP >=-105	Drive Test	94.14%
	SS-SINR >= 5db	Drive Test	46.37%
	Data >=50mbs	Drive Test	75.19%
	CQI >=6	Drive Test	97.74%

5G Network Simulation Scenario at 3.5 GHZ WITH 3000 Users

Based on the issues identified and the proposed recommendations for optimization, the simulation models a single-site 5G network scenario operating at full traffic capacity with 1000 users per sector, 3 sectors in all. KPI such as download data throughput, signal quality, SINR, RSRP, CQI, and others are measured. The carrier frequency is set to 3.5 GHz, and the simulation incorporates sectorization and dynamic resource allocation to reduce interference and enhance performance.

The table 2 and 3 show how the network parameters were defined to reflect a typical urban macrocell environment.

Table 2: Network Parameters

Parameters	Value	Description
Cell-radius	500m	Radius of the cell
Num-users	3000	Number of users in the cell
Bandwidth	100MHz	Bandwidth allocated per user
Noise_figure	5dB	Noise figure of the receiver
Tx_power	46dBm	Transmit power of the base station
Frequency	3.5GHz	Carrier frequency
Path_loss	$PL=69.55+26.16\log10(f)-13.82\log10(hb)-a(hm)+(44.9-6.55\log10(h_b))\log10(d)$ Assuming the Base station height(h_b) is 30 meters and the Mobile station antenna height (h_m) is 1.5 meters	Path loss model based on Extended Hata Model

As obvious in the table 2:

i. Cell Radius: The radius of the cell is set to 500 meters, representing the coverage area of a single 5G base station.
ii. Number of Users: The simulation includes 1000 users randomly distributed within the cell.
iii. Bandwidth: Each user is allocated a bandwidth of 100 MHz. iv. Noise Figure: The noise figure of the receiver is assumed to be 5 dB.
iv. Transmit Power: The base station transmits at a power of 46 dBm (40 watts).
v. Frequency: The carrier frequency is set to 3.5 GHz.
vi. Number of Sectors: The cell is divided into 3 sectors to reduce interference and improve resource allocation.

Table 3: Calculated Parameters

Parameters	Unit	Description
Distance	Meters	Distance of each user from the base station
Rx_Power	dBm	Received Signal Power
SINR	dB	Signal-to-Interference-plus-Noise Ratio
Throughput	bps	Data throughput per user
RSRP	dBm	Reference Signal Received Power
CQI	-	Channel Quality Indicator

User Distribution and Path Loss Calculation

User positions are randomly generated within the cell radius, ensuring a realistic distribution of users. The cell is divided into 3 sectors, and users are assigned to sectors based on their positions, calculated using angular division.

Path Loss (PL) Calculation

The Extended Hata (eHata) model is used to calculate the path loss:

$$PL = 69.55 + 26.16\log_{10}(f) - 13.82\log_{10}(h_b) - a(h_m) + (44.9 - 6.55\log_{10}(h_b))\log_{10}(d)... \quad (1)$$

where f is the frequency in MHz, h_b is the base station antenna height (30 meters), h_m is the mobile station antenna height (1.5 meters), and d is the distance in kilometres. The correction factor for the mobile antenna height, a(h_m) is calculated as:

$$a(h_m) = (1.1\log10(f) - 0.7)h_m - (1.56\log10(f) - 0.8) \ \dots \quad (2)$$

Received Signal Power and SINR Calculation

The received signal power is determined by subtracting the path loss from the transmit power. The SINR is then calculated by considering the noise power, which includes thermal noise and the noise figure:

$noise\_power = -174 + 10\ \log_{10}(bandwidth\_per\_user) + noise\_figure\ldots$ (3)

$Interference\_power = 10\ \log_{10}(num\_sector\_users)\ \ldots$ (4)

$SINR = rx_{power} - (noise_{power} + interference_{power})\ \ldots$ (5)

Throughput and KPI Calculation

User throughput is calculated using Shannon's formula:

$$throughput = bandwidth \times \log_2\left(1 + 10^{\left(\frac{SINR}{10}\right)}\right) \quad (6)$$

Other KPIs, such as RSRP and CQI, are calculated based on simplified models. RSRP is determined by adjusting the received power for the bandwidth, and CQI as a function of the SINR. Figure 8 show the visualized simulation results.

RESULTS AND DISCUSSION

Analysis and Optimization

Utilizing a combination of drive-testing and advanced analytical tools, KPIs to evaluate network accessibility, retainability, integrity, mobility, availability, and utilization were examined to have a comprehensive analysis of the 5G network performance within the selected coverage areas of Lagos, Nigeria—Ikoyi, Victoria Island, and Lekki. By analyzing real-world data collected during drive tests to identify performance bottlenecks, optimize network parameters, and enhance user experience, the findings presented provide valuable insights into the current state of the 5G network and offer recommendations for future improvements.

The drive test data for the 5G network in the selected areas of Lagos reveals several KPI s (Table 1). The SS-RSRP (SS Reference Signal Received Power) is above -105 dBm in 94.14% of the measurements, indicating strong signal strength. The SS-SINR (SS Signal-toInterference-plus-Noise Ratio) exceeds 5 dB in 46.37% of the tests, reflecting moderate signal quality amidst interference. Data speeds are above 50 Mbps in 75.19% of the cases, showcasing robust data throughput. Additionally, the CQI (Channel Quality Indicator) is above 6 in 97.74% of the tests, signifying excellent channel quality. These metrics highlight the overall strong performance of the 5G network in the studied areas.

In Figure 5 is shown the frequency and band plot to visually depict the availability of the 5G network in the Etiosa cluster observed by 96.65%. It is concluded that the 5G availability is 100%.

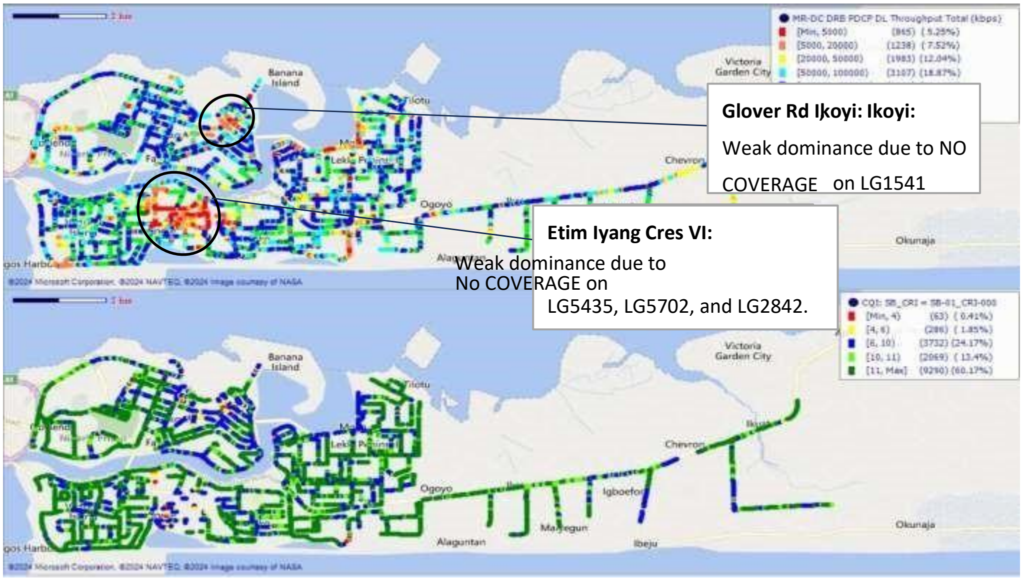
Figure 5: 5G DL plot: frequency & band

The two plots illustrate the coverage and availability of the 5G network within the Etiosa cluster. The top plot (green) and the bottom plot (blue) indicate different frequency bands used in the region. The data shows that the dominant frequency band used is n78 (3500 MHz), covering 96.65% of the area, while the n28 (700 MHz) band covers the remaining 3.35%. The widespread coverage indicated by the green and blue lines signifies robust 5G network availability throughout the mapped regions, including key areas such as Ikoyi, Victoria Island, and Lekki. The observation of 96.65% coverage leads to the conclusion that overall 5G network availability in the Etiosa cluster is nearly complete. This visual representation underscores the extensive reach of the 5G network deployment in the area, ensuring consistent and high-quality network access for users.

5G Dedicated KPI Plot: Throughput & CQI

The two plots in Figure 6 illustrate the 5G downlink performance in the Etiosa cluster, focusing on PDCP (packet data convergence protocol) DL (downlink) Throughput and CQI.

Weak dominance due to



Glover Rd Ikoyi: Ikoyi:
Weak dominance due to NO
COVERAGE on LG1541

Etim Iyang Cres VI:
Weak dominance due to
No COVERAGE on
LG5435, LG5702, and LG2842.

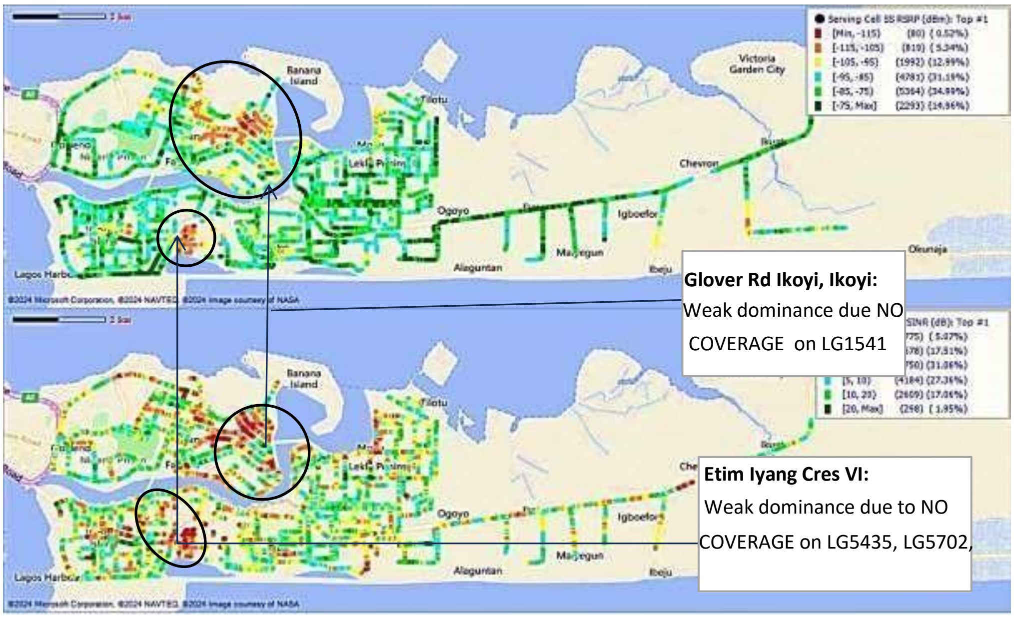
Figure 6: 5G DL plot: throughput & CQI

In figure 6, the upper plot represents the PDCP DL Throughput distribution across different areas. The colors indicate varying throughput levels, with red and orange showing lower throughput, while green and blue indicate higher throughput. rom the data, 75.19% of the areas observed a throughput above 50 Mbps. This indicates that the majority of the Etiosa cluster enjoys high-speed data connectivity, though there are pockets of lower performance, particularly visible in red and orange areas.

The bottom plot in figure 6 shows the CQI distribution. Higher CQI values (indicated by green and blue) correspond to better signal quality and potentially higher data rates. The data shows that 97.74% of the CQI samples are 6 and above, suggesting good overall network quality in the Etiosa cluster. While the Etiosa cluster demonstrates strong 5G performance with high throughput and good CQI in most areas, specific regions such as Glover Road and Etim Iyang Crescent exhibit weak coverage, highlighting areas for potential network improvement.

5G Dedicated KPI Plot: SS-RSRP & SS-SINR

In Figure 7 is illustrated the 5G SS-RSRP and SS-SINR metrics within the Etiosa cluster.



Glover Rd Ikoyi, Ikoyi:
Weak dominance due NO
COVERAGE on LG1541

Etim Iyang Cres VI:
Weak dominance due to NO
COVERAGE on LG5435, LG5702,

Figure 7: 5G DL PLOT: SS-RSRP & SS-SINR

In figure 7, the top plot shows the SS-RSRP distribution across different areas, with the colors indicating signal strength. Red and orange represent lower signal strength, while green and blue indicate stronger signal strength. In Figure 7 is revealed that 94.14% of the areas have an SS-RSRP value of -105 dBm or better, indicating that the majority of the Etiosa cluster has strong signal reception. However, there are some areas with weaker signals, particularly in red and orange. The bottom plot illustrates the SS-SINR distribution. Higher SS-SINR values, shown in green and blue, correspond to better signal quality and reduced interference. The data shows that 46.37% of the SS-SINR samples are 5 dB or better. This suggests that while nearly half of the Etiosa cluster experiences good signal quality, the other half encounters significant interference, as indicated by the presence of red and orange areas.

Overall, while the Etiosa cluster exhibits strong SS-RSRP values in most areas, the SS-SINR data indicates that nearly half of the region suffers from signal quality issues due to interference. Specific locations, such as Glover Road and Etim Iyang Crescent, have notable gaps in coverage, highlighting areas for potential network improvements.

Table 2 shows several network performance issues and proposed action plans for various sites. Site LG4164 suffers from poor 4G coverage, SINR, and throughput due to building obstructions affecting logical server T0005. The recommendation is to explore dominance improvement with LG4164 and T0011. LG2910 faces poor 4G and 5G coverage due to the decommissioning of site LG48409 and high-rise building obstructions, suggesting an azimuth redesign for LG2910. Sites T0190 and LG4025 experience poor 4G and 5G SINR due to mode 3 interference caused by sector swaps, recommending an investigation and correction of the sector swaps. LG5427 has weak 4G and 5G coverage due to an ongoing outage at LG2842, proposing an azimuth redesign for LG5427. Additionally, LG2858 and LG2653 have coverage and SINR issues due to weak dominance from logical servers LG2653 and T0069, both needing an azimuth redesign. These targeted actions aim to enhance network performance and user experience across the identified sites.

Table 4: Issues Identified and Proposed Recommendations

Site	Issue	Action Plan
LG4164	Poor 4G coverage/SINR/throughput due to weak dominance caused by building an obstruction of logical server T0005	Explore Dominance improvement with LG4164 and T0011
LG2910	Poor 4G5G coverage due to decommissioned site LG48409 and multiple high-rise building obstructions	Explore azimuth redesign on LG2910
T0190	Poor 4G5G SINR due to mode 3 interference caused by sector swap	Investigate & correct sector swap on T0190
LG4025	Poor 4G5G SINR due to mode 3 interference caused by sector swap	Investigate & correct sector swap on LG4025
LG5427	Weak 4G5G coverage due to ongoing outage on LG2842 as a result of access issues	Explore azimuth redesign on LG5427
LG2858	Poor coverage and SINR due weak dominance of logical server LG2653 & T0069	Explore azimuth redesign on LG2858
LG2653		Explore azimuth redesign on LG2653
T0069		Explore azimuth redesign on T0069

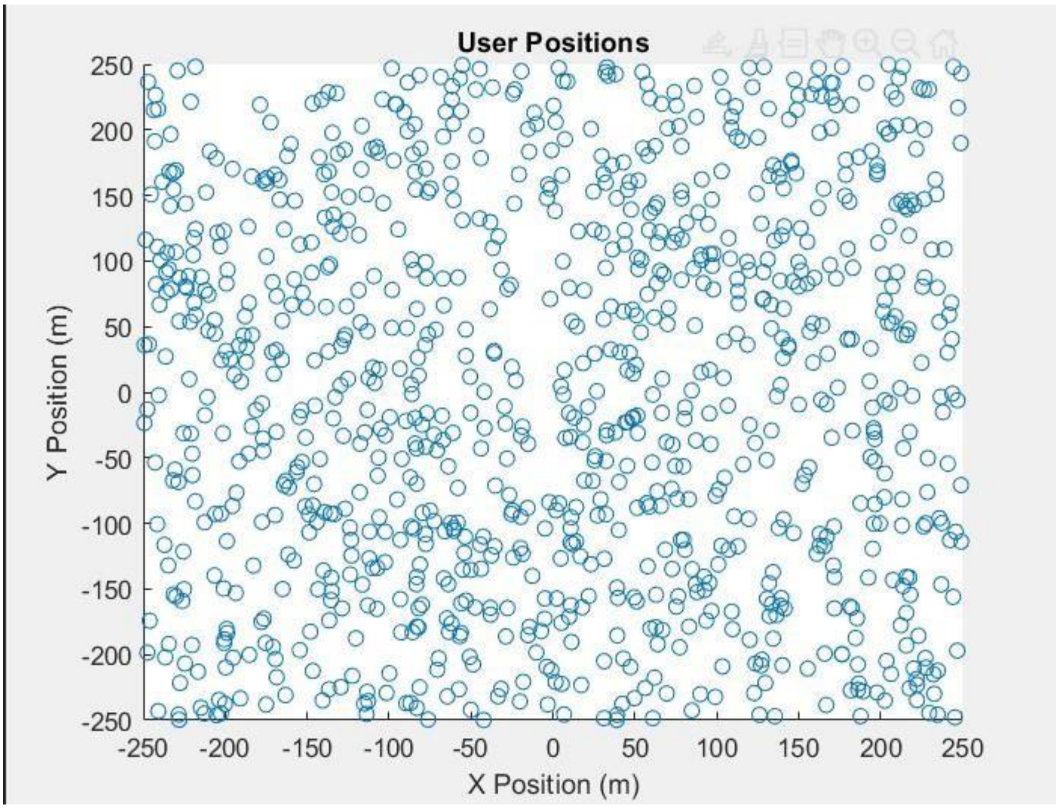


Figure 8: Users Positions

Figure 8 shows the distribution of users within the cell. Each blue circle represents the position of a user in the cell, with coordinates plotted along the X and Y axes in meters. The plot illustrates a random yet fairly even spread of users across the cell area, indicating no significant clustering or gaps in user distribution. This visualization helps in understanding the spatial distribution of users, which is crucial for analyzing network coverage, capacity, and performance within the cell. Distances of users from the base station are illustrated in Figure 9A and B.

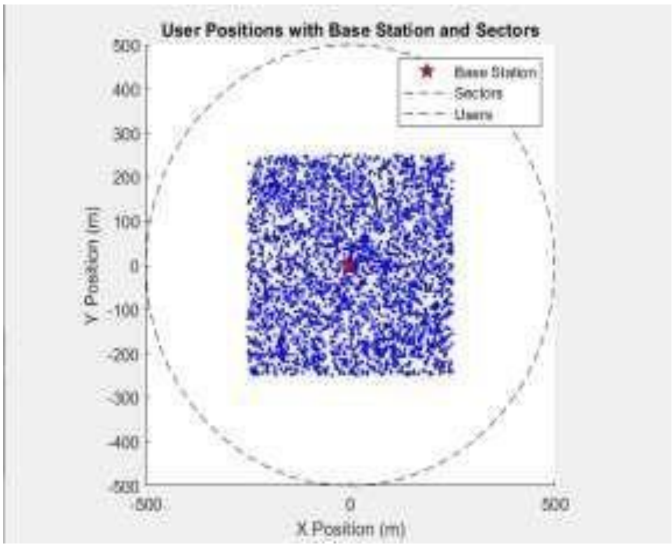


Figure 9A: Users' Distances from the Base Station

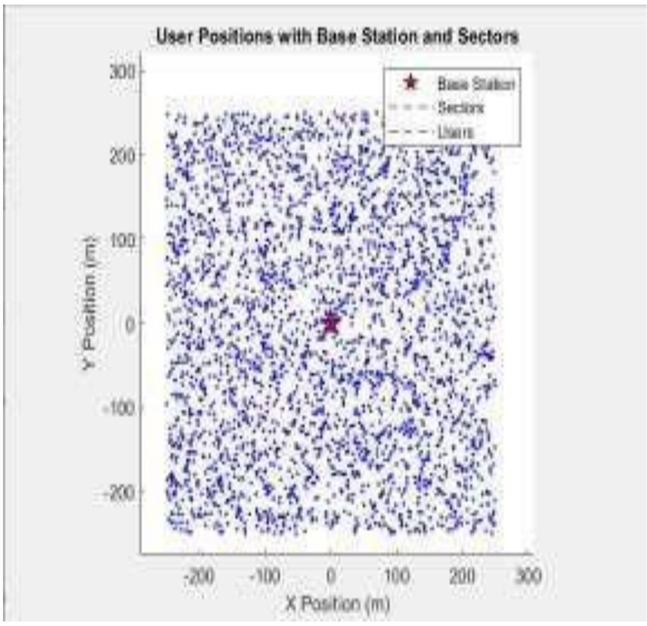


Figure 9B: Users' Distances from the Base Station

Figure 10 illustrates SINR Distribution, a line plot depicting the SINR values experienced by the users.

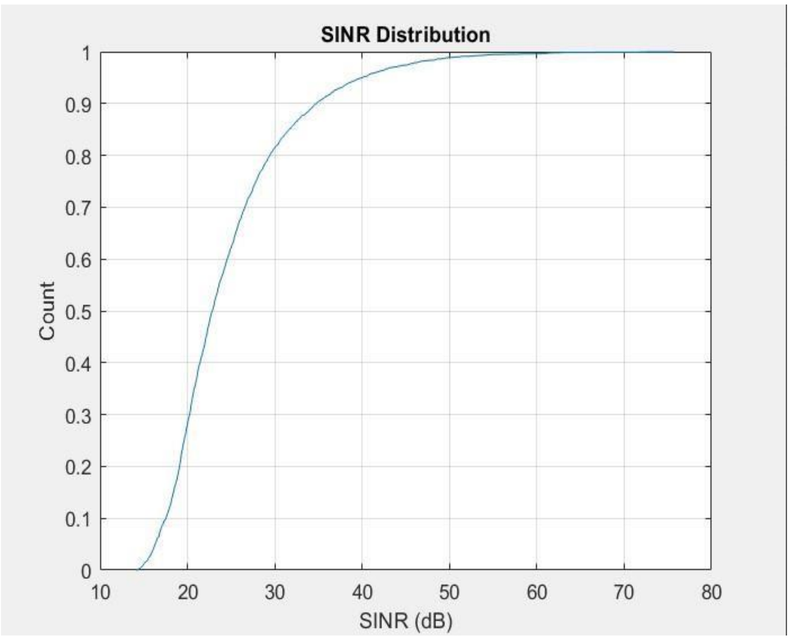


Figure 10: SINR Distribution

The SINR values range from approximately 10 dB to 80 dB. The curve indicates a cumulative distribution, showing that most users experience SINR values between 20 dB and 40 dB, with the distribution becoming flatter as SINR values increase. The majority of users achieve SINR values around 30 dB, which implies that network conditions are generally favourable, leading to better signal quality and potentially higher data rates.

A Line graph illustrating the throughput distribution among users is shown in Figure 11.

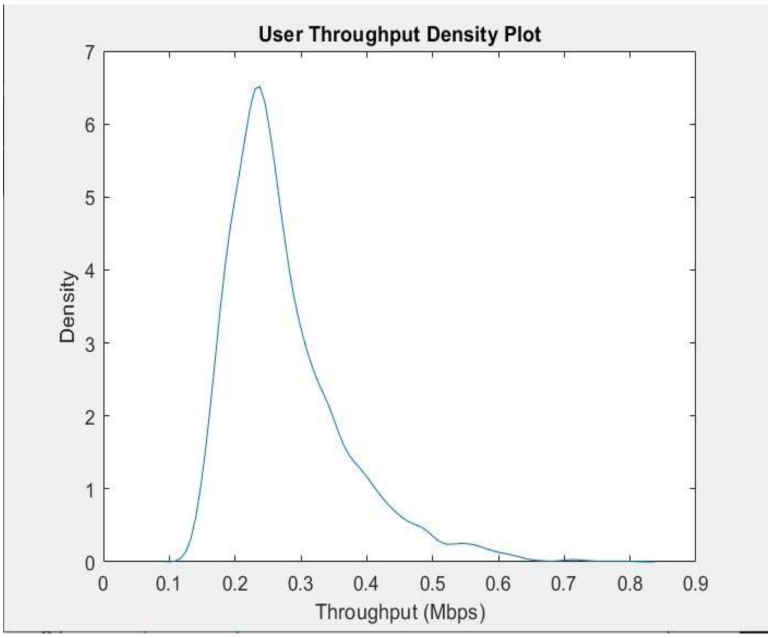


Figure 11: User Throughput Density

The user throughput density plot (Figure 11) illustrates the distribution of user throughput, measured in Mbps. It highlights that the majority of users have a throughput of around 0.2 to 0.3 Mbps, with a sharp peak indicating that this is the most common throughput experienced by users. The density decreases significantly for higher throughput values, with very few users achieving throughput above 0.7 Mbps. This distribution suggests that while most users have moderate data rates, there are few instances of very high throughput, possibly due to network congestion or limitations in network resources.

A histogram showing the RSRP values for the users is illustrated in Figure 12.

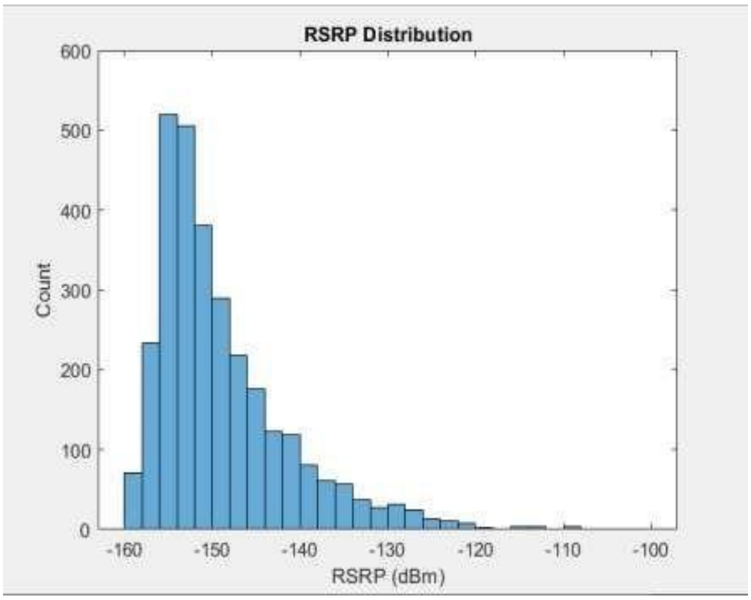


Figure 12: RSRP Distribution

The RSRP distribution is presented as a histogram (Figure 12). It shows the signal strength received by users, measured in dBm. The histogram shows a skewed distribution with a peak around -150 dBm, indicating that most users receive weak signal strength. There is a gradual decline as the RSRP values increase, with very few users experiencing stronger signals around -110 dBm. This suggests that the majority of users are operating in areas with lower signal strength.

CQI Distribution: A histogram of the CQI values assigned to the users.

The CQI distribution is shown as a line plot (Figure 13) and a histogram (Figure 14).

i. Line Plot: The line plot depicts the CQI values assigned to users in a sequential manner based on their index. The plot starts from CQI 7 and steps up, indicating a variation in channel quality among users. Higher CQI values indicate better channel quality.

ii. Histogram: The histogram provides a detailed distribution of CQI values across users. It shows that most users have CQI values ranging from 9 to 15, with notable peaks at CQI values of 10. This indicates that a significant portion of users experience moderate to good channel quality.

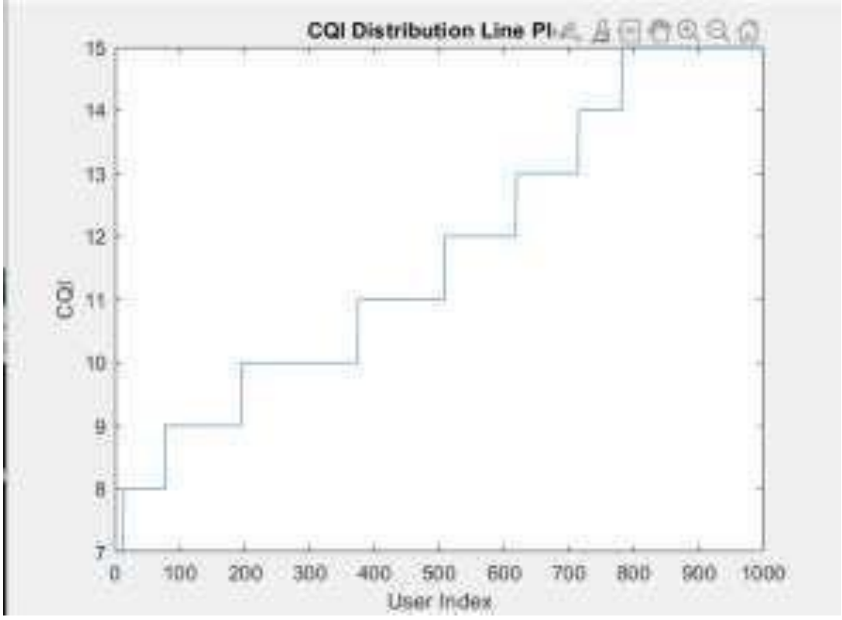


Figure 13: CQI Distribution (Line Plot)

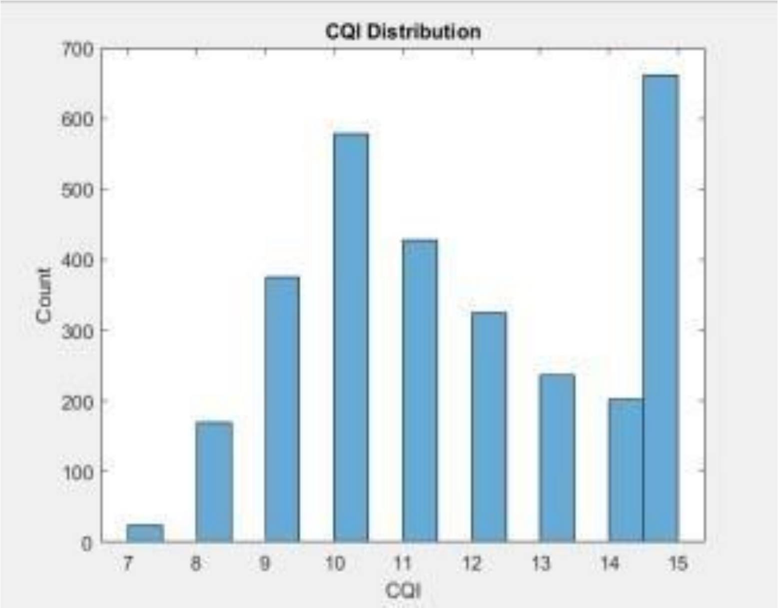


Figure 14: CQI Distribution (Histogram)

Summary

Analyzing existing 5G coverage predictions while factoring in signal propagation, interference, and obstacles in diverse environments, it was confirmed that while the network's overall coverage is extensive, environmental factors such as buildings and natural obstructions significantly impact signal propagation and quality. The network parameters were set to reflect realistic user distribution and path loss calculations.

The path loss was computed to determine the attenuation of the signal as it travels through space, impacting the received signal power and SINR. Throughput and KPI calculations followed, providing a complete view of the network performance under simulated conditions. In the visualization section, user positions were depicted in a scatter plot, showing a welldistributed user base within the cell. This even distribution indicated a balanced load on the network infrastructure. User distance from the base station is another crucial factor, the users that were closer to the base station typically experienced better connectivity and signal quality, emphasizing the importance of strategically placing base stations to optimize coverage. The SINR distribution plot shows the range of SINR values experienced by users, with most values falling between 20 dB and 40 dB. The majority of users achieved SINR values around 30 dB, indicating favourable network conditions, which lead to better signal quality and higher data rates. This distribution suggests that the network can generally provide good service quality to its users.

User throughput is illustrated in a density plot, highlighting the distribution of data transfer rates among users. The density decreases for higher throughput values, suggesting that while moderate data rates are common, very high throughput instances are rare, possibly due to network congestion or resource limitations. The skewed distribution as obvious in the RSRP distribution histogram indicates that users are often in areas with lower signal strength, highlighting the need for improved network infrastructure to boost signal reception. The CQI distribution is presented through a line plot and a histogram, showing that most users have CQI values ranging from 9 to 15, with notable peaks at 10 and 15. This indicates that a significant portion of users experience moderate to good channel quality, essential for maintaining a robust and efficient network.

The signal strength, as depicted by SS-RSRP values, was predominantly strong, with 94.14% of samples greater than or equal to -105 dBm. However, the SS-SINR values indicated that only 46.37% of the samples had an SINR greater than or equal to 5 dB, highlighting areas where interference and obstacles degrade signal quality.

The evaluation of beamforming coverage patterns, using various KPIs, provided a comprehensive understanding of the network's performance. Throughput analysis showed that 75.19% of the region had throughput over 50 Mbps, indicating strong data transfer capabilities. CQI values, which reflect signal quality, showed that 97.74% of the samples had a CQI of 6 or higher which ensured reliable and high-quality connections for users. However, areas with weak dominance, due to lack of coverage in specific cells, revealed gaps in the network's geographical availability. The study also noted moderate success in other KPIs such as latency, mobility support, and energy efficiency, but highlighted the need for improved coverage and handover success rates to enhance user experience. Thus, these findings underscore the importance of considering environmental factors in network planning and optimization. The drive test revealed that the 5G network within the Etiosa cluster demonstrated generally robust performance, with high throughput and good signal quality across most areas. However, weak coverage spots were identified on Glover Road in Ikoyi and Etim Iyang Crescent in Victoria Island, where certain cells provided no coverage. This initial data collection laid a solid foundation for further analysis, offering critical insights into real-world signal behaviour and areas needing improvement.

In addressing the objective of identifying improvements, the study pinpointed several areas for enhancement, including better coverage and signal quality in identified weak spots. Optimization included improvement in cell placement and coverage to mitigate signal dropoffs and overall network performance. Furthermore, the study emphasized the importance of adaptive interference management to handle dynamic user demands, ensuring that the network remains resilient and capable of delivering consistent service quality. These improvements are vital for maintaining a competitive edge in providing high-speed, reliable 5G connectivity.

Finally, modelling a similar network scenario on MATLAB to explore potential optimizations, the simulated network scenario aimed to mirror the real-world conditions of the Etiosa cluster, allowing for a direct comparison of performance metrics. The results from the simulated network showed notable improvements in throughput, signal strength, and overall network efficiency compared to the existing network. The optimized model demonstrated enhanced adaptability to interference and better handling of multiple connections, showcasing the potential benefits of strategic adjustments to network infrastructure. This comparative analysis underscores the value of simulation tools in network planning and optimization, providing actionable insights for future network deployments.

The study achieved its objectives by providing a detailed analysis of the 5G network's current state, identifying critical areas for improvement, and demonstrating the potential benefits of optimization through simulation. The findings highlight the importance of continuous monitoring and adaptation to ensure high-quality 5G service, addressing both current performance gaps and future user demands.

CONCLUSION

The primary aim of this research project was to analyze existing 5G coverage predictions and model a similar network scenario on MATLAB to optimize 5G beamforming antenna coverage. The comprehensive analysis of the 5G network within the Etiosa cluster revealed generally robust performance with high throughput and good signal quality, though certain areas exhibited weak coverage. Incorporating factors such as signal propagation, interference, and environmental obstacles, the study provided critical insights into real-world signal behaviour. Optimizing beamforming antenna coverage, the MATLAB simulations, designed to mirror these conditions, demonstrated significant improvements in network performance metrics, including throughput and signal strength. These findings underscore the importance of adaptive network planning and optimization, highlighting the potential of simulation tools to enhance 5G network performance and ensure reliable, high-quality connectivity in diverse environments. Integrating empirical data, comprehensive analysis, and advanced modelling, the study offers a robust framework for enhancing 5G network performance and user experience in diverse environments. This research not only addresses current performance gaps but also lays the groundwork for future advancements in 5G technology.

RECOMMENDATIONS

Based on the findings of this research from the drive tests and the simulations, recommendations to have better coverage and optimal performance, providing users with more reliable and higher-quality connectivity of the 5G network within the Etiosa cluster of Lagos are:

i. Enhance Coverage in Weak Signal Areas: Address the identified weak coverage areas, such as Glover Road in Ikoyi and Etim Iyang Crescent in Victoria Island. This can be achieved by deploying additional small cells or repeaters to ensure comprehensive coverage and mitigate signal dead zones.
ii. Optimize Beamforming Techniques: Utilize advanced beamforming techniques to dynamically adjust signal direction and strength based on user density and movement patterns. This will enhance signal quality and throughput, especially in high-demand areas, thereby improving overall user experience.
iii. Regular Network Performance Monitoring: Implement continuous network performance monitoring using KPIs like throughput, latency, and SINR. This proactive approach will help in quickly identifying and rectifying any performance issues, ensuring consistent network quality.
iv. Interference Management: Deploy advanced interference mitigation strategies, such as coordinated multipoint (CoMP) and interference cancellation techniques. This will help in reducing signal interference from neighbouring cells, leading to improved signal quality and network reliability.
v. User-Centric Network Optimization via Machine Learning: Consider user behaviour and movement patterns in network optimization plans. Utilize machine learning algorithms to predict user demand and optimize network resources accordingly to ensure efficient handling of high-traffic scenarios and seamless connectivity.
vi. Adopt techniques like carrier aggregation and dynamic spectrum sharing to maximize spectrum utilization. This will increase the network's capacity to handle multiple connections simultaneously, enhancing overall network performance.

Future Studies

Based on the recommendations, future studies could explore, among others, the following:

i. Investigate the development and implementation of more sophisticated beamforming algorithms that can adapt in real time to user mobility and density patterns.
ii. Explore innovative interference mitigation strategies, such as coordinated multipoint (CoMP) transmission and reception, to further enhance signal quality and reliability.
iii. Conduct detailed studies on user behaviour and movement patterns to develop predictive models that can optimize network resource allocation dynamically.
iv. Investigate the application of machine learning and artificial intelligence in real-time network performance monitoring and optimization to proactively manage network resources and improve user experience.
v. Assess the impact of emerging 5G applications, such as augmented reality (AR) and autonomous vehicles, on network performance and infrastructure requirements.

REFERENCES

Abbas, R., & Curry, T. (2020). 5G coverage, prediction, and trial measurements. *www.academia.edu*. https://www.academia.edu/114825764/5G_Coverage_Prediction_and_Trial_Measurements

Abir, S. M. a. A., Abuibaid, M., Huang, J. S., & Hong, Y. (2023). Harnessing 5G Networks for Health Care: Challenges and Potential Applications. *International Conference on Smart Applications, Communications and Networking (SmartNets)at Istanbul, Turkey*. https://doi.org/10.1109/smartnets58706.2023.10215757

Ashraf, A., Gunawan, T. S., Kartiwi, M., Nur, L. O., Nugroho, B. S., & Astuti, R. P. (2024). Advancements and challenges in scalable modular antenna arrays for 5G massive MIMO networks. *IEEE Access*, 1. https://doi.org/10.1109/access.2024.3391945

Asianuba, I. B. (2021). CHALLENGES OF 5G DEPLOYMENT IN NIGERIA. *ResearchGate*. https://www.researchgate.net/publication/365408478_CHALLENGES_OF_5G_DEPLOYMENT_IN_NIGERIA

Avnet Abacus. (2023). *5G Beamforming: An Engineer's Overview | Avnet Abacus*. https://my.avnet.com/abacus/solutions/markets/communications/5g-solutions/5gbeamforming/

Bakare, K. A., Bagiwa, L. I., Nafisa, M. M., & Abdulsalam, A. (2021). A review on 5G wireless network implementation strategies in Nigeria. FUDMA Journal of Sciences, 5(2), 419-427. https://fjs.fudutsinma.edu.ng/index.php/fjs/article/download/633/494

El-Saleh, A. A., Alhammadi, A., Shayea, I., Hassan, W. H., Honnurvali, M. S., & Daradkeh, Y. I. (2022). Measurement analysis and performance evaluation of mobile broadband cellular networks in a populated city. *Alexandria Engineering Journal /Alexandria Engineering Journal*, *66*, 927–946. https://doi.org/10.1016/j.aej.2022.10.052

Elendu, C., Elendu, T. C., & Elendu, I. D. (2024). 5G-enabled smart hospitals: Innovations in patient care and facility management. *Medicine*, *103*(20), e38239. https://doi.org/10.1097/md.0000000000038239

Khalifa, D. (2024, April 4). How Nigeria can leverage the rise of fintech for economic progress. *The World Bank Working for a World Free of Poverty*. https://blogs.worldbank.org/en/psd/how-nigeria-can-leverage-the-rise-of-fintech-foreconomicprogre

Obiefuna, T. C., & Omijeh, B. O. (2024). 5G network coverage hole prediction and detection using machine learning. *European Journal of Engineering and Technology Research*, *9*(1), 1–9. https://doi.org/10.24018/ejeng.2024.9.1.3102

Pahalson, P. C. A., Gyang, D. D., & Zungkat, B. A. (2023). 5G Technology: An assessment of the opportunities and challenges in an emerging Nigerian society. *International Journal of Next-generation Networks*, *15*(2/3/4), 01–14. https://doi.org/10.5121/ijngn.2023.15401

Polak, L., Kufa, J., Sotner, R., & Fryza, T. (2024). Measurement and analysis of 4G/5G mobile signal coverage in a heavy industry environment. *Sensors*, *24*(8), 2538. https://doi.org/10.3390/s24082538

Pons, M., Valenzuela, E., Rodríguez, B., Nolazco-Flores, J. A., & Del-Valle-Soto, C. (2023). Utilization of 5G Technologies in IoT Applications: Current Limitations by Interference and Network Optimization Difficulties—A Review. *Sensors*, *23*(8), 3876. https://doi.org/10.3390/s23083876

Sani, H., & Baba, M. D. (2024). 5G NETWORKS AND THEIR IMPACT ON THE TELECOMMUNICATIONS INDUSTRY IN NIGERIA. *ResearchGate*. https://www.researchgate.net/publication/378680318_5G_NETWORKS_AND_THEIR_IMPACT_ON_THE_TELECOMMUNICATIONS_INDUSTRY_IN_NIGERIA

Sousa, M., Alves, A., Vieira, P., Queluz, M. P., & Rodrigues, A. (2021). Analysis and optimization of 5G coverage predictions using a beamforming antenna model and real drive test measurements. *IEEE Access*, *9*, 101787–101808. https://doi.org/10.1109/access.2021.3097633

Tiamiyu, O. A. (2019). Analysis of QOS Delivered to Users of WCDMA Band in Different Locations: Case Study of University of Ilorin, Nigeria. Труды учебных заведений связи, 5(3), 45-56.

Tiamiyu, O. A. (2020). QoS IN MIMO USING UNLICENSED WIRELESS SPECTRUM Nigeria. Journal of the Nigerian Association of Mathematical Physics, 55(179-186).

©2024 This is an Open Access article distributed under the terms of the Creative Commons Attribution 4.0 International license viewed via https://creativecommons.org/licenses/by/4.0/ which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is cited appropriately.