

Assessing capacity and coverage planning: 5G NR performance using 2300 MHz in urban area

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Article Info

Article history:

Received Apr 26, 2025

Revised Apr 21, 2026

Accepted Aug 20, 2026

Keywords:

2300 MHz

5G

Capacity planning

Coverage planning

Network performance

Simulation

ABSTRACT

The rapid evolution of mobile communications technology and increasing data traffic demands have necessitated fifth generation (5G) network development, especially in urban environments. While previous studies examined 3.5 GHz and 700 MHz bands, the 2300 MHz mid-band frequency remains unexplored despite offering optimal balance between coverage and capacity. This research analyzes capacity and coverage planning for 5G implementation at 2300 MHz in Bandung City's urban area (167.31 km²), employing the urban macro (UMa) propagation model for line of sight (LoS) and non-line of sight (NLoS) conditions, validated through network planning simulations. Capacity planning projects user growth from 421,758 (2024) to 479,453 (2028), with traffic demand increasing from 1.92 to 2.37 Gbps/km². Coverage analysis identifies 86 sites required for optimal deployment, driven by downlink requirements. Performance simulations demonstrate "Excellent" signal strength synchronization signal-reference signal received power (SS-RSRP: -75 to -70 dBm), "Good" signal quality synchronization signal-signal-to-interference-plus-noise ratio (SS-SINR: 10-15 dB), and average throughput of 137.42 Mbps, exceeding IMT-2020 requirements by 37%. The deployment achieves 72.5% user connectivity (132,071 users). While simulation results confirm successful urban 5G deployment balancing coverage and capacity, real-world pilot validation would strengthen practical applicability for network planners implementing similar urban networks.

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1. INTRODUCTION

The rapid advancement of mobile communications has significantly reshaped the telecommunications landscape, leading to the development of fifth generation (5G) networks [1], [2]. This transformation is largely driven by the surge in data traffic and the growing demand for applications that require high reliability and low latency [3], [4]. As the latest global standard, 5G introduces a unified air interface aligned with the International Mobile Telecommunications 2020 (IMT-2020) framework, providing technical capabilities that extend the potential of mobile communication systems [5]–[7].

5G supports peak data rates of up to 20 Gbps for downlink and 10 Gbps for uplink. Latency targets are set at 1 ms for the user plane and 10 ms for the control plane. The system is also designed to connect up to 1 million devices per square kilometer (km²) [1]. With user-experienced data rates reaching 100 Mbps for downlink and 50 Mbps for uplink, 5G ensures consistent performance in high-density scenarios. It

accommodates mobility at speeds up to 500 km/h and offers energy efficiency improvements of up to 100 times compared to 4G, along with a threefold increase in spectral efficiency.

These technological features enable new real-time applications, ranging from intelligent automation in industry 4.0 [7] to large-scale deployments of the internet of things (IoT) [6]. The flexible 5G architecture is tailored to support a range of service types, including enhanced mobile broadband (eMBB), ultra-reliable low-latency communication (URLLC), and massive machine-type communication (mMTC). Despite its potential, deploying 5G in urban settings such as those in Indonesia presents significant technical and logistical challenges. These include planning infrastructure that can meet the increasing demand for capacity, as well as managing frequency spectrum efficiently. Indonesia, in particular, continues to face difficulties in scaling its telecommunications infrastructure to support the country's digital transformation objectives while addressing rising bandwidth needs.

Related work and scientific positioning: previous studies have explored 5G network deployment across a range of scenarios and frequency bands. At the global level, research has addressed challenges such as network densification in urban areas to accommodate rising capacity demands, as illustrated by the case of Taiz City, Yemen [8]. In parallel, other studies have focused on enabling technologies, including the use of multi-gNodeB simulators to support ultra-reliable communications in indoor industry 4.0 environments [9], as well as the deployment of networked flying platforms to enhance coverage [6].

Building on this global perspective, several studies have investigated 5G network planning across different deployment scenarios and frequency bands. A recent study evaluated 5G fixed wireless access at 3.5 GHz and 26 GHz using a link- and flow-level planning approach, demonstrating the influence of propagation conditions, interference, and traffic load on network performance [10]. These findings highlight the importance of frequency-specific planning in balancing coverage and capacity requirements. Recent research on next-generation wireless networks further identifies artificial intelligence/machine learning (AI/ML) integration, integrated communication-sensing, immersive virtual environments, and spectrum advancements as important directions for future mobile network development [11].

Further investigations in Indonesia have examined the low-frequency 700 MHz band for wide-area coverage, where one study found that 27 gNodeB sites were required to ensure adequate uplink performance in an urban area [12]. The main contributors' simulations confirmed the viability of this setup, achieving an average synchronization signal-reference signal received power (SS-RSRP) of -94.15 dBm and a synchronization signal-signal-to-interference-plus-noise ratio (SS-SINR) of 13.32 dB, indicating good signal performance. Meanwhile, trials involving the high-frequency 28 GHz band assessed its suitability for eMBB use cases [13]. The key finding was a direct correlation between wider bandwidth and higher throughput, with the authors reporting that mmWave signal performance is highly sensitive to physical obstructions and power settings. Although these efforts contribute valuable insights into individual frequency bands, a focused assessment of the 2300 MHz mid-band remains absent from the current literature. This band, in particular, presents a compelling balance of coverage and capacity, making it especially well-suited for urban deployments in Indonesia.

Contribution and paper structure: to address the identified gap, this study presents a detailed investigation into 5G network implementation using the 2300 MHz mid-band frequency in an Indonesian urban setting. The primary contribution of this work is a practical evaluation of this specific frequency band, focusing on achieving an optimal balance between broad coverage and high capacity. This balance is essential for efficient and cost-effective urban deployment. The study complements existing research and technology assessments across different spectrum bands and deployment contexts [10]–[13] by proposing a structured planning methodology and performance benchmarks to support network planners facing similar deployment challenges.

The remainder of this paper is organized as follows. Section 2 outlines the research methodology, including planning concepts and technical parameter selection. Section 3 presents the results and discussion, covering user projection, traffic demand estimation, and network performance simulation. Section 4 concludes by summarizing the key findings and providing recommendations for future 5G deployments in urban environments.

2. METHOD

In this section, it is explained the methodology employed for 5G network planning in Bandung City's urban environment, covering both theoretical calculations and simulation-based validation approaches. The research methodology involves four components: research framework, capacity planning, coverage planning, and simulation environment setup for performance evaluation using Forsk Atoll software, an industry-standard network planning tool.

2.1. Research framework

The research methodology employs a structured approach beginning with parameter identification and collection of essential capacity and coverage metrics, as depicted in Figure 1. Network planning calculations are categorized into two complementary strategies: capacity planning and coverage planning. Both planning outcomes are subsequently implemented in the Atoll simulation environment for comprehensive network performance evaluation according to the research workflow. Performance analysis examines key KPIs including signal strength, quality, throughput, and user connectivity parameters. The study concludes with detailed results and specific recommendations for optimal 5G network deployment.

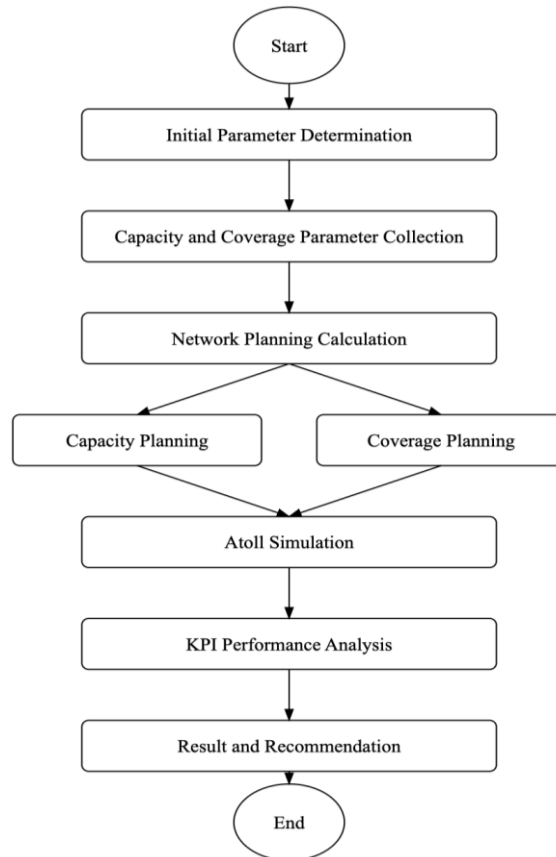


Figure 1. Flowchart of the 5G network planning process

2.2. Capacity planning

Capacity planning is a foundational aspect of 5G network design, intended to ensure that the infrastructure can sustain anticipated increases in user density and accommodate peak data demand. This process involves the analysis of subscriber growth forecasts and the estimation of traffic loads to determine the appropriate network dimensioning. This sub-section details the methodology employed for user population projection and traffic demand estimation, which collectively inform the capacity requirements of the network. The capacity planning calculation is conducted systematically as follows:

2.2.1. Projection of user population

This step considers the projected number of users and traffic requirements to ensure the network infrastructure can meet demand with the desired quality of service (QoS) [14]. The user projection calculation is expressed in (1):

$$U_{(t)} = U_0 \times (1 + GF)^t \quad (1)$$

where $U_{(t)}$ represents the user population in year t , U_0 is the baseline user population in the reference year, t denotes the time period in years, and GF represents the annual user growth factor [7].

2.2.2. Projection of traffic demand

Beyond user projections, the expected traffic demand serves as a critical factor influencing network design considerations [15]. The traffic demand requirements are determined using (2):

$$D_{(t)} = \rho \times H_b \times D_m \times \varphi(t) \times A_m \quad (2)$$

where $D_{(t)}$ represents the projected traffic demand, ρ denotes the user density, H_b is the number of busy hours per day, D_m represents the number of days per month, $\varphi(t)$ indicates the percentage of active users at a given time (used to calculate peak traffic demand), and A_m represents the average traffic demand per user per month. The active user ratio and per-user traffic parameters are derived from 5G NR traffic modeling guidelines [14], [15].

2.3. Coverage planning

Once the capacity dimensioning has been completed, coverage planning becomes the subsequent critical phase to ensure uniform signal quality across the entire service area. This stage involves detailed technical analysis, including link budget computations and path loss modeling, to estimate the effective cell radius and determine the total number of required sites. The methodology described in this sub-section forms the analytical basis for quantifying site requirements and defining their spatial distribution within the network simulation framework. The coverage planning calculation is conducted systematically as follows:

2.3.1. Link budget

Coverage planning in cellular networks represents a complex technical process centered on the calculation of maximum allowable path loss (MAPL). Accurate path loss estimation is essential in coverage planning because it directly influences the predicted service range and reliability of the network [16]. MAPL serves as a critical parameter that determines the maximum achievable cell coverage radius while maintaining adequate signal quality. MAPL calculation contains multiple parameters including effective isotropic radiated power (EIRP), receiver gain, receiver sensitivity, and various margins necessary to compensate for additional losses in the radio environment. Table 1 presents the key parameters required for effective link budget calculations.

Table 1. Key parameters for coverage planning

Parameter	Value
Subcarriers spacing	30 kHz
Bandwidth	30 MHz
Number of resource blocks	78

2.3.2. Path loss propagation model

The UMa propagation model is designed for high population density areas and considers for both line-of-sight (LoS) and non-line-of-sight (NLoS) scenarios [17]. This model effectively characterizes environments where the received signal comprises a combination of direct and indirect components. The UMa model defines distinct path loss calculations [18]–[20], similar to the urban micro (UMi) model, with specific formulations for different propagation scenarios. The UMa propagation model was selected for this study based on its alignment with Bandung's urban characteristics. With a population density of 14,979 people/km² and typical building heights ranging from 5-50 meters, the deployment environment matches UMa scenario specifications defined in 3GPP TR 38.901 [21]. This model is validated for the 2300 MHz frequency range and provides industry-standard predictions for macro-cell deployments in high-density urban areas. Alternative models such as UMi are optimized for small-cell scenarios with lower antenna heights, while rural macro models apply to lower-density environments, neither of which accurately represents the planned macro-cell deployment in Bandung's urban core. However, it should be acknowledged that the UMa model parameters defined in 3GPP TR 38.901 [21] were derived from measurements conducted in temperate-climate dense urban environments with building material compositions that may differ from those in tropical Indonesian cities. Factors such as tropical humidity, local vegetation density, and Bandung's specific building materials (predominantly brick and lightweight concrete) could introduce propagation variations not captured by the standard model. Validating these parameters through field measurements in Bandung remains a limitation of this study and a recommended direction for future research.

For LoS conditions, with cell radii distances (d_{2D}) ranging from 10 meters to the breakpoint distance (d'_{BP}), the path loss is calculated using (3):

$$PL_{LoS} = 28.0 + 22\log_{10}(d_{3D}) + 20\log_{10}(f_c) \quad (3)$$

For NLoS conditions, applicable for cell radii distances (d_{2D}) between the breakpoint distance (d'_{BP}) and 5 km, the path loss is calculated using (4):

$$PL_{NLoS} = 28.0 + 40\log_{10}(d_{3D}) + 20\log_{10}(f_c) - 9\log_{10}((d'_{BP})^2 + (h_{BS} - h_{UT})^2) \quad (4)$$

where d_{3D} represents the three-dimensional distance between transmitter and receiver in meters, f_c is the carrier frequency in GHz, h_{BS} is the base station height in meters, and h_{UT} is the user terminal height in meters.

2.3.3. Calculation of cell coverage area and site requirements

In 5G network implementation, a 3-sector antenna configuration provides an optimized service coverage area [22]. The coverage area served by one cell with a 3-sector antenna configuration can be calculated using (5):

$$L_{cell} = 1.95 \times 2.6 \times d^2 \quad (5)$$

where L_{cell} represents the area that can be served by one cell in km², and d represents the cell radius in km.

2.4. Simulation environment and performance metrics

The 5G network simulation in this study was conducted using the Atoll application, an industry-standard software platform designed for wireless network planning and optimization. This software facilitates precise propagation modeling, scenario creation, parameter configuration, and detailed 5G network performance analysis [23], [24]. The network key performance indicators (KPIs) evaluation focuses on four critical parameters: signal strength (SS-RSRP), signal quality (SS-SINR), throughput, and the traffic of users connected as detailed in Table 2.

Table 2. 5G network KPIs

Parameter	Category	Range	Unit
SS-RSRP	Excellent	≥ -85	dBm
	Good	-100 to -85	dBm
	Fair	-115 to -100	dBm
	Poor	< -115	dBm
SS-SINR	Excellent	≥ 15	dB
	Good	10 to 15	dB
	Fair	5 to 10	dB
	Poor	< 5	dB
Throughput	Peak DL	> 100	Mbps
	Peak UL	> 50	Mbps
User connected	Coverage	> 95	%
	Density	1	Million/km ²

3. RESULTS AND DISCUSSION

In this section, it presents the findings from our 5G network planning study for Bandung City. The analysis reveals critical insights into infrastructure requirements, network performance, and optimization opportunities specific to this urban environment.

3.1. Capacity planning results analysis

3.1.1. Projection of user population and demand traffic analysis

Based on the analysis of user projections and traffic demand in Bandung City for 5G network planning, results indicate a significant increase in traffic demand from 2024 to 2028. This analysis incorporates Bandung City's population density of 14,979 people/km², derived from a total population of 2,506,203 residents distributed across an area of 167.31 km² [24]. The 5G user projection demonstrates consistent growth, beginning with 421,758 users in 2024 and increasing steadily to 479,453 users by 2028. Concurrently, the generated traffic demand exhibits upward trajectory, starting at 1.92 Gbps/km² in 2024, and progressively increasing to 1.99 Gbps/km² (2025), 2.09 Gbps/km² (2026), 2.22 Gbps/km² (2027), eventually reaching 2.37 Gbps/km² in 2028. This traffic density trajectory is consistent with demand projections reported for comparable Indonesian urban deployments [24].

As illustrated in Figure 2, the graph effectively visualizes the correlation between user population growth and escalating data traffic demands. The blue line represents the steady increase in 5G user adoption, while the orange line demonstrates the more pronounced rise in generated demand traffic, particularly evident during the 2027-2028 period. This captures the 5G technology adoption and utilization patterns in Bandung City throughout the five-year forecast period.

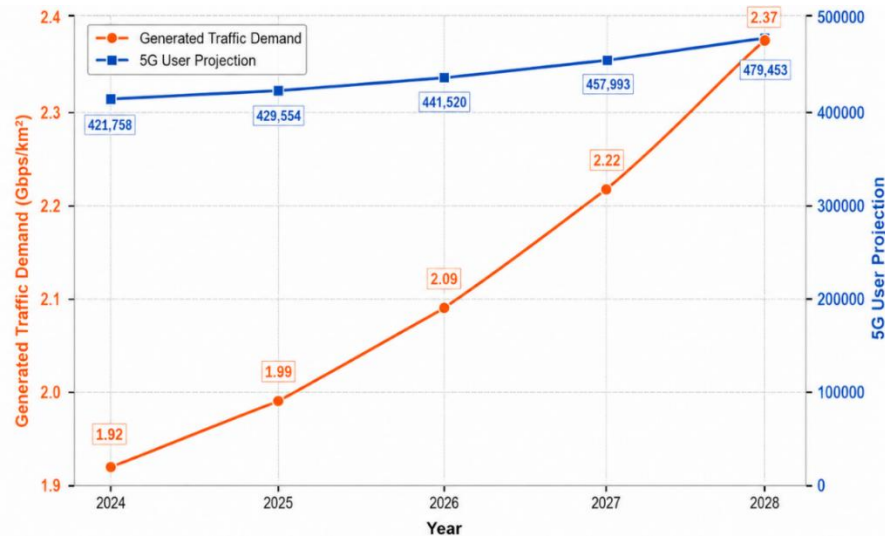


Figure 2. Projected 5G user growth and generated traffic demand over time

3.1.2. Site requirements analysis

Based on capacity planning calculations containing projected traffic demand and network throughput analysis, Table 3 presents the site requirements for 5G network implementation in Bandung City. The analysis indicates that 64 sites are necessary to support the projected 2028 traffic density of 2.37 Gbps/km² across Bandung City's 167.31 km² area. Each site must accommodate approximately 7,491 users while maintaining optimal service quality. The calculated cell radius of 0.73 km reflects the balance between coverage requirements and capacity demands in this urban deployment scenario.

Table 3. Site requirements calculation results

Parameter	Results
Network throughput	2.37 Gbps/km ²
Total users (2028)	479,453
Surface area	167.31 km ²
Number of sites required	64
Users per site	7,491
Cell radius	0.73 km

3.2. Coverage planning results analysis

3.2.1. Link budget analysis

The link budget calculation focuses on determining the MAPL using the components detailed in Table 4 [21]. Based on the analysis of link budget calculations for 5G network planning in the 2300 MHz frequency band, distinct parameters emerge for both uplink and downlink transmission scenarios. These parameters are critical in determining the MAPL between the base station and user equipment, ensuring optimal signal transmission and reception throughout the network.

The link budget parameters in Table 4 are consistent with commonly used 5G radio network planning approaches for urban deployments [14], [18], [21], [25]. Body loss accounts for signal attenuation from user device positioning during typical handheld usage. Interference margin compensates for co-channel interference from neighboring cells, with higher downlink values reflecting multi-cell interference patterns characteristic of macro deployments. Penetration loss values represent signal attenuation through typical urban building materials (concrete and brick) at 2300 MHz, based on ITU-R propagation models for indoor coverage scenarios [21].

Table 4. Link budget calculation results

Parameter	Uplink value	Downlink value
TX power	23 dBm	53 dBm
Antenna gain	5 dB	15 dB
Body loss	2 dB	5 dB
EIRP	-5.833 dBm	34.169 dBm
SINR	5 dB	5.53 dB
Interference margin	2 dB	15 dB
Penetration loss	10.84 dB	22 dB
MAPL	81.886 dB	80.696 dB

3.2.2. Path loss analysis

The path loss analysis for 5G network deployment employs the UMa model for both LoS and NLoS scenarios in the urban environment. For the LoS scenario, calculations yield a path loss value of 100 dB with a three-dimensional distance coverage of 600 meters and corresponding cell radius (d_{2D}) of 600 meters. In contrast, the NLoS scenario demonstrates significantly reduced coverage capabilities with a three-dimensional distance of 85.9 meters and cell radius of 85.9 meters. This LoS-to-NLoS coverage reduction is consistent with UMa propagation behavior at mid-band frequencies documented in [21] and observed in similar planning study [20].

3.2.3. Coverage area and site requirements analysis

Based on the coverage planning approach incorporating site calculation results and network coverage requirements, Table 5 presents the key parameters for 5G network implementation in Bandung City. The analysis reveals that each site can effectively cover 2.25 km² for uplink and 1.97 km² for downlink transmission. This coverage differential necessitates additional sites for downlink requirements, resulting in the final determination of 86 sites to ensure comprehensive network performance throughout the target area, aligning with infrastructure dimensioning strategies for urban 5G deployments [22].

Table 5. Coverage planning key parameters results

Parameter	Results
Total coverage area	167.31 km ²
Uplink coverage per site	2.25 km ²
Downlink coverage per site	1.97 km ²
Uplink sites required	75
Downlink sites required	86
Uplink reuse distance	3.23 km
Downlink reuse distance	3.1261 km

3.3. Simulation and network performance result analysis

To validate the theoretical findings, a network deployment simulation was conducted using the Forsk Atoll network planning tool. The simulation implemented 86 sites derived from downlink coverage planning calculations across the 167.31 km² target area. Figure 3 visualizes the simulation results for network coverage and performance. Figure 3(a) shows the coverage distribution simulation, Figure 3(b) presents the SS-RSRP level distribution, Figure 3(c) presents the SS-SINR level distribution, and Figure 3(d) shows the throughput level distribution. These results are used to evaluate the network performance in terms of signal strength, signal quality, and data throughput.

3.3.1. Analysis of synchronization signal–reference signal received power distribution

SS-RSRP measures the signal strength emitted by the sites. Based on simulation results presented in Figure 3(b), the SS-RSRP coverage analysis demonstrates distinct signal strength distributions across the covered area. The histogram analysis shown in the yellow region between -75 and -70 dBm, falls within the “Excellent” category (SS-RSRP $\geq$ -85 dBm). This distribution pattern indicates effective site placement strategy with significant portions of the coverage area experiencing optimal signal strength. Previous 3.5 GHz measurement studies have similarly demonstrated that propagation conditions and path loss characteristics significantly influence received signal performance in urban environments [16]. The SS-RSRP performance obtained in this study also exceeds the -94.15 dBm (“Good”) value reported for the 700 MHz deployment [12].

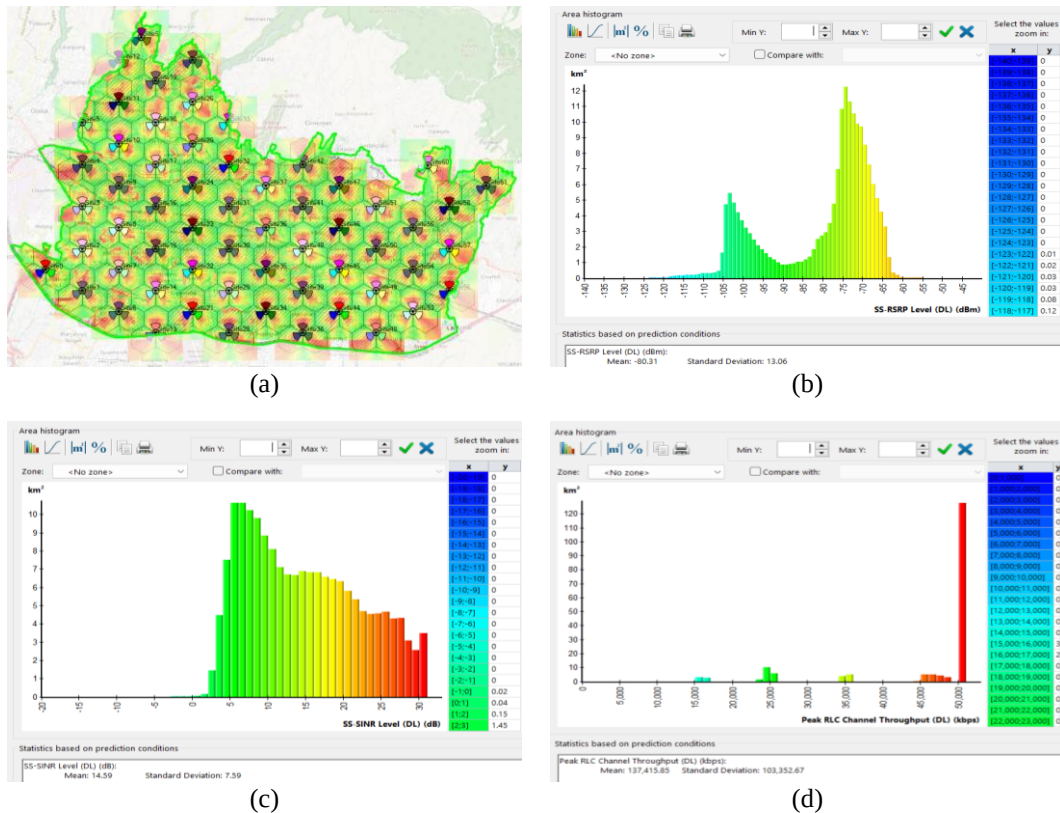


Figure 3. Simulation results of the 5G network performance in; (a) coverage distribution, (b) SS-RSRP level distribution histogram, (c) SS-SINR level distribution histogram, and (d) throughput level distribution histogram

3.3.2. Analysis of synchronization signal–signal-to-interference-plus-noise ratio distribution

SS-SINR serves as a critical parameter that quantifies signal quality by measuring the ratio of desired signal strength relative to interference and noise levels, expressed in decibels (dB). The histogram analysis in Figure 3(c) reveals that the majority of the coverage area experiences signal quality ranging from 5 dB to 30 dB. The highest concentration appears in the green region (approximately 5-10 dB), corresponding to the “Fair” category according to standardized SS-SINR classifications. A significant portion extends into the yellow and orange regions (10-20 dB), indicating “Good” signal quality. The mean SS-SINR value of 14.59 dB with a standard deviation of 7.59 dB confirms overall “Good” signal quality throughout the deployment area, with most locations experiencing interference levels that support reliable data transmission consistent with IMT-2020 performance expectations [1]. The mean SS-SINR of 14.59 dB is comparable to the 13.32 dB reported for the 700 MHz deployment [12], with the slight improvement attributable to higher site density compensating for increased mid-band propagation loss [21]. It should be noted that this simulation assumes a single-operator scenario. In a multi-operator environment where service providers operate simultaneously in the 2300 MHz frequency band, co-channel interference will reduce the SS-SINR value, particularly at the cell edges, depending on the channel association policy implemented. Orthogonal sub-band allocation minimizes inter-operator interference but reduces bandwidth per operator, whereas full-band sharing maintains capacity at the cost of increased interference [21].

3.3.3. Analysis of throughput distribution

The throughput analysis evaluates network performance against established 5G network key performance indicators, which specify minimum thresholds of 100 Mbps for downlink and 50 Mbps for uplink transmission. The histogram analysis in Figure 3(d) reveals a highly asymmetric distribution with a pronounced concentration in the highest throughput range, represented by the tall red bar at the right side of the graph. The mean peak RLC channel throughput of 137,415.85 kbps (137.42 Mbps) significantly exceeds the minimum downlink requirement of 100 Mbps established in the IMT-2020 performance criteria [1]. This performance metric indicates that the network design provides substantial value above minimum requirements, ensuring reliable service delivery even during peak demand periods. The substantial standard deviation of 103,352.67 kbps (103.35 Mbps) reflects the significant variability in throughput across different

coverage zones, which is expected in a complex urban environment with varying signal conditions. Despite this variability, the concentration of results in higher throughput ranges confirms that the vast majority of the coverage area achieves optimal performance levels that comfortably meet or exceed target specifications.

3.3.4. Analysis of traffic parameter (user connected)

Beyond network performance metrics, analyzing the simulation's traffic parameters is essential to evaluate the network's capacity to effectively serve its user base. This analysis includes assessing the total number of connected users and their distribution across different service types. Figure 4 provides a detailed overview of these traffic parameters, presenting the total number of successfully connected users and their traffic coverage distribution on the simulation map.

As shown in Figure 4(a), the simulation indicates that the network successfully connects 132,071 users, accounting for 72.5% of the potential user base. Among these active connections, the majority utilize downlink services (71,849 users), while 58,552 users access uplink services, and 1,669 users engage in simultaneous data transmission. The cumulative application throughput reached 95,113.19 Mbps for downlink and 96,920.37 Mbps for uplink, demonstrating the network's capability to deliver high-performance service. The corresponding simulation map in Figure 4(b) visually confirms the effective spatial distribution of user connectivity across the region, highlighting that the 86-site deployment sufficiently covers the target area.

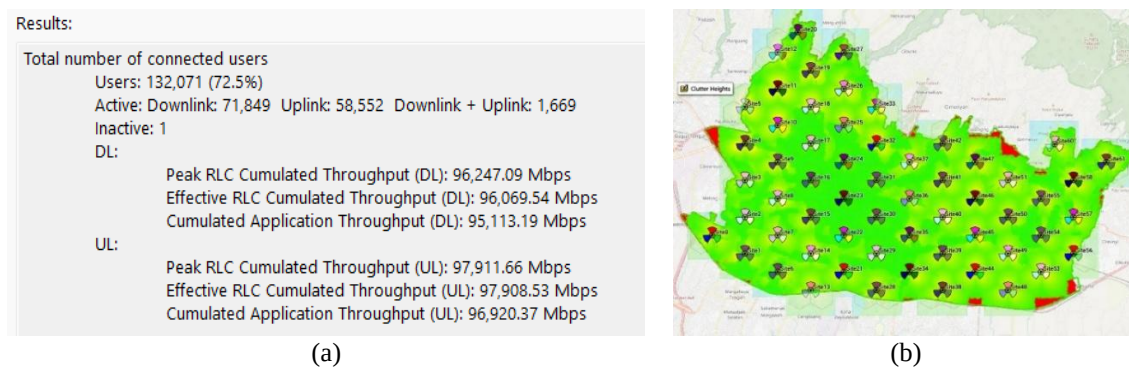


Figure 4. Traffic performance simulation results in; (a) analysis of connected users and (b) spatial distribution of traffic coverage across the simulated area

The 72.5% user connection rate, while substantial, indicates opportunities for optimization. This level falls below the 95% IMT-2020 coverage target [1], a gap also observed in other simulation-based macro-cell planning studies [8], [22] largely attributable to static site placement without iterative optimization or small-cell augmentation. From a QoS perspective, the 27.5% unconnected user share would experience service denial during peak periods, potentially resulting in increased call setup failures and degraded perceived network reliability. Analysis of the spatial distribution in Figure 4(b) indicates that unconnected users are concentrated primarily at cell-edge boundaries where SS-RSRP falls below the connection threshold identified in subsection 3.3.1 targeted antenna adjustment and transmit power optimization at sites adjacent to these coverage gaps could improve cell-edge SS-SINR by 3–5 dB [21], shifting a portion of these users above the attachment threshold without requiring additional infrastructure investment. The unconnected 27.5% of users likely fall into two categories: those at cell edges experiencing signal degradation below connection thresholds, and those in high-density areas during peak traffic periods where capacity limitations prevent additional connections. Strategies to improve connectivity include targeted site densification in identified coverage gaps, deployment of small cells in high-traffic zones, and implementation of advanced features such as carrier aggregation and coordinated multipoint transmission to enhance cell-edge performance. These optimization approaches would not only increase the connection success rate but also improve the user-perceived QoS, particularly in edge-of-coverage scenarios and during network congestion periods.

4. CONCLUSION

The primary contributions of this study to the field include: i) a systematic evaluation of the previously unexplored 2300 MHz mid-band frequency for Indonesian urban deployments, complementing existing research on other spectrum bands; ii) a validated methodology combining capacity and coverage

planning that network operators can adapt for similar urban environments; and iii) empirical evidence demonstrating that this mid-band frequency provides an optimal balance between coverage reach and capacity requirements for dense urban areas. The present analysis relies on simulation-based modeling using the UMa propagation model and Atoll planning tool. While these industry-standard approaches provide reliable predictions, real-world deployments may encounter additional factors such as specific building geometries, local interference sources, and variable user behavior patterns that could affect performance. Future research should prioritize: i) pilot deployments with drive-testing to validate simulation findings against measured data; ii) investigation of dynamic spectrum sharing techniques to improve spectral efficiency; iii) exploration of advanced antenna configurations including massive MIMO and beamforming to optimize user experience in high-density areas; iv) quantitative assessment of the impact of multi-operator coexistence; and v) comparative techno-economic analysis across multiple frequency bands (700 MHz, 2300 MHz, and 3.5 GHz) to guide spectrum allocation decisions for Indonesian operators.

ACKNOWLEDGMENTS

The authors extend their gratitude to researchers from Telkom University and the Digital Strategy, Planning, and Architecture Division of PERURI for their valuable contributions to this research. This work was carried out without any specific research grant or contract from external funding agencies.

FUNDING INFORMATION

This research was conducted without any specific research grant or contract from funding agencies in the public, commercial, or not-for-profit sectors.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization

M : **M**ethodology

So : **S**oftware

Va : **V**alidation

Fo : **F**ormal analysis

I : **I**nterpretation

R : **R**esources

D : **D**ata Curation

O : **O**riginal Draft

E : **E**xperimentation

Vi : **V**isualization

Su : **S**upervision

P : **P**roject administration

Fu : **F**unding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available on request from the corresponding author, PR. The data could compromise the privacy of research participants which are not included due to restrictions.

REFERENCES

- [1] S. Henry, A. Alsahily, and E. S. Sousa, "5G is Real: Evaluating the Compliance of the 3GPP 5G New Radio System with the ITU IMT-2020 Requirements," *IEEE Access*, vol. 8, pp. 42828–42840, 2020, doi: 10.1109/ACCESS.2020.2977406.
- [2] K. Liolis *et al.*, "Use cases and scenarios of 5G integrated satellite-terrestrial networks for enhanced mobile broadband: The SaT5G approach," *International Journal of Satellite Communications and Networking*, vol. 37, no. 2, pp. 91–112, Mar. 2019, doi: 10.1002/sat.1245.
- [3] A. P. K. Reddy, N. Kumar, S. S. A. Tirumalasetty, S. Srinivasan, and J. V. B. James, "Latency Analysis for IMT-2020 Radio Interface Technology Evaluation," in *2020 IEEE 3rd 5G World Forum, 5GWF 2020 - Conference Proceedings*, Sep. 2020, pp. 613–618, doi: 10.1109/5GWF49715.2020.9221093.

- [4] ITU-R, "IMT Vision–Framework and overall objectives of the future development of IMT for 2020 and beyond," *Mobile, Radiotermination, Amateur and Related Satellite Services*, vol. 0, pp. 1–21, 2015.
- [5] J. Isabona, C. C. Ugochukwu, A. L. Imoize, and N. Faruk, "An Empirical Comparative Analysis of 4G LTE Network and 5G New Radio," in *Proceedings of the 5th International Conference on Information Technology for Education and Development: Changing the Narratives Through Building a Secure Society with Disruptive Technologies, ITED 2022*, Nov. 2022, pp. 1–5, doi: 10.1109/ITED56637.2022.10051243.
- [6] S. A. W. Shah, T. Khattab, M. Z. Shakir, and M. O. Hasna, "A Distributed Approach for Networked Flying Platform Association with Small Cells in 5G+ Networks," in *Proceedings - IEEE Global Communications Conference, GLOBECOM*, Dec. 2017, vol. 2018, pp. 1–7, doi: 10.1109/GLOCOM.2017.8254852.
- [7] M. Attaran, "The impact of 5G on the evolution of intelligent automation and industry digitization," *Journal of Ambient Intelligence and Humanized Computing*, vol. 14, no. 5, pp. 5977–5993, May 2023, doi: 10.1007/s12652-020-02521-x.
- [8] R. Q. Shaddad *et al.*, "Densification of 5G wireless access network for urban area at Taiz city, Yemen," in *Advances in Intelligent Systems and Computing*, 2019, vol. 843, pp. 417–426, doi: 10.1007/978-3-319-99007-1_40.
- [9] R. Bolla, R. Bruschi, C. Lombardo, A. Mohammadpour, R. Trivisonno, and W. Y. Poe, "A 5G multi-gNodeB simulator for ultra-reliable 0.5–100 GHz communication in indoor Industry 4.0 environments," *Computer Networks*, vol. 237, p. 110103, Dec. 2023, doi: 10.1016/j.comnet.2023.110103.
- [10] N. Saba, P. Lassila, K. Ruttik, R. Jäntti, and J. Salo, "Radio network planning for 5G FWA at 3.5 GHz and 26 GHz: A link- and flow-level approach," in *IEEE Access*, vol. 13, pp. 152782–152799, 2025, doi: 10.1109/ACCESS.2025.3603906.
- [11] S. P. Tera, R. Chinthaginjala, G. Pau, and T. H. Kim, "Toward 6G: An Overview of the Next Generation of Intelligent Network Connectivity," *IEEE Access*, vol. 13, pp. 925–961, 2025, doi: 10.1109/ACCESS.2024.3523327.
- [12] P. Rahmawati, M. I. Nashiruddin, and M. A. Nugraha, "Simulation of 700 MHz Spectrum Deployment in Indonesia's Urban Area for 5G New Radio Network," in *2022 10th International Conference on Information and Communication Technology, ICoICT 2022*, Aug. 2022, pp. 293–298, doi: 10.1109/ICoICT55009.2022.9914873.
- [13] A. C. Situmorang, D. Gunawan, and V. G. Anggraini, "5G trials on 28 GHz Band in Indonesia," in *2019 28th Wireless and Optical Communications Conference, WOCC 2019-Proceedings*, May 2019, pp. 1–5, doi: 10.1109/WOCC.2019.8770687.
- [14] A. R. Mishra, "5G Network Planning," in *Fundamentals of Network Planning and Optimisation 2G/3G/4G*, Wiley, 2018, pp. 295–313, doi: 10.1002/9781119331797.ch10.
- [15] C. Naik, S. Patil, M. Mali, S. Kumbhar, and S. Patil, "Study of 5G NR Network Against Mixed Traffic," in *International Conference on Communication Systems and Networks, COMSNETS*, Jan. 2025, no. 2025, pp. 19–24, doi: 10.1109/COMSNETS63942.2025.10885598.
- [16] A. Schumacher, R. Merz, and A. Burg, "3.5 GHz coverage assessment with a 5G testbed," in *2019 IEEE 89th Vehicular Technology Conference (VTC2019-Spring)*, Kuala Lumpur, Malaysia, 2019, pp. 1–6, doi: 10.1109/VTCSpring.2019.8746551.
- [17] NG-RAN, "Architecture Description," *3GPP TS 38.401, Rel. 15, V15.3.0*, 2018.
- [18] Huawei Technologies Co., "5G Link Budget: Best Partner for Innovation." White Paper, Shenzhen, China, 2018.
- [19] NR; Study on channel model for frequencies from 0.5 to 100 GHz, "Physical layer procedures for control," *3GPP TS 38.213, Rel. 18, V18.2.0*, 2025.
- [20] R. N. Esa, A. Hikmaturokhman, and A. R. Danisya, "5G NR Planning at Frequency 3.5 GHz: Study Case in Indonesia Industrial Area," in *Proceeding - 2020 2nd International Conference on Industrial Electrical and Electronics, ICIEE 2020*, Oct. 2020, pp. 187–193, doi: 10.1109/ICIEE49813.2020.9277427.
- [21] Study on Channel Model for Frequencies from 0.5 to 100 GHz, *3GPP TR 38.901, Rel. 18, V18.0.0*, May 2024.
- [22] E. J. Oughton, Z. Frias, S. van der Gaast, and R. van der Berg, "Assessing the capacity, coverage and cost of 5G infrastructure strategies: Analysis of the Netherlands," *Telematics and Informatics*, vol. 37, pp. 50–69, Apr. 2019, doi: 10.1016/j.tele.2019.01.003.
- [23] Nidhi, B. Khan, A. Mihovska, R. Prasad, and F. J. Velez, "A Study on Cross-Carrier Scheduler for Carrier Aggregation in Beyond 5G Networks," in *2022 3rd URSI Atlantic and Asia Pacific Radio Science Meeting, AT-AP-RASC 2022*, May 2022, pp. 1–4, doi: 10.23919/AT-AP-RASC54737.2022.9814320.
- [24] Statistical Agency of Bandung City, "Bandung City in Figures," *BPS Indonesia*, [Online]. Available: <https://bandungkota.bps.go.id/publication/2024/02/28/991b8451fddb9bdd7d374894/kota-bandung-dalam-angka-2024.html>. (Accessed: Apr. 13, 2025).
- [25] V. Farré, J. D. V. Sánchez, and H. C. Mora, "5G NR radio network planning at 3.5 GHz and 28 GHz in a business/dense urban area from the north zone in Quito City," *Engineering Proceedings*, vol. 47, no. 1, Dec. 2023, doi: 10.3390/engproc2023047024.

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