5G Open RAN Network Planning for Indonesia's New Capital City: A Capacity and Coverage Analysis

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***Abstract*—The development of *Ibu Kota Nusantara* (Nusantara Capital City, IKN), Indonesia's new capital, necessitates a robust telecommunication infrastructure to support government initiatives and operations. This study presents a 5G network planning framework utilizing Open Radio Access Network (Open RAN) architecture for the *Kawasan Inti Pusat Pemerintahan* (Core Government Administrative Area, KIPP-1A) region of IKN. Through systematic capacity and coverage dimensioning, optimal infrastructure requirements were determined to support the immediate government needs. The implementation utilized a 2300 MHz frequency with 30 MHz bandwidth, with analysis forecasting user growth from 76,695 in 2024 to 94,644 by 2028. Capacity planning calculations indicated a requirement for 17 sites to accommodate the projected traffic demand of 83,667.97 Mbps, while coverage planning determined 12 sites would suffice from a signal propagation perspective. Network simulation results demonstrated excellent performance metrics: a mean Reference Signal Received Power (SS-RSRP) of −73.13 dBm with 96% optimal coverage, a mean Signal-to-Interference-plus-Noise Ratio (SS-SINR) of 15.55 dB within a satisfactory range, and a mean throughput of 138.58 Mbps, exceeding the requirements of fifth-generation mobile networks. The proposed architecture comprises 1 Centralized Unit (CU) and 6 Distributed Units (DUs), supporting 17 radio sites. This research presents a strategic and technical plan for efficient telecommunications deployment in the IKN environment, striking a balance between coverage, capacity, and implementation complexity.**

***Keywords*—5G network planning, network dimensioning, Open RAN, telecommunication infrastructure**

I. Introduction

The deployment of Fifth-Generation (5G) technology marks a significant step forward in cellular communication infrastructure, offering unmatched capabilities across various communication models [1]. 5G technology delivers significant improvements in Massive Machine-Type Communications (mMTC), Ultra-Reliable Low-Latency Communications (URLLC), and enhanced mobile broadband (eMBB). From a technical standpoint, 5G networks provide higher data rates than 4G Long-Term Evolution (LTE) systems, enabling faster mobility, broader Internet of Things (IoT) connectivity, and ultra-low latency performance [2, 3]. However, deploying 5G infrastructure involves numerous technical challenges, especially regarding spectrum efficiency. The technology operates at higher frequency bands than 4G, which requires the development and deployment of Multiple Input Multiple Output (MIMO) technology to improve spectrum capacity and efficiency [4]. These technical demands lead to more complex and potentially more resource-intensive infrastructure, particularly in backhaul networks and fiber optic deployment [5].

The Open Radio Access Network (Open RAN) architecture is a crucial solution for addressing infrastructure challenges. Unlike traditional Radio Access Network (RAN) setups, Open RAN adopts a transformative approach by establishing open interfaces between network components, software, and hardware elements. The primary technical innovation is the combination of RAN virtualization with Software-Defined Network (SDN) technology, enabling advanced configuration, optimization, and control through the Radio Intelligent Controller (RIC) [6, 7]. The key difference between Open RAN and traditional RAN is in its vendor-agnostic implementation approach. Open RAN's standardized interfaces enable multi-vendor integration and can potentially cut Capital Expenses (CAPEX). The architecture typically comprises a Remote Radio Unit (RRU), a Centralized Unit (CU), and a Distributed Unit (DU), with the unique capability to separate the CU and DU up to 5 km, resulting in notable operational improvements over traditional Baseband Unit (BBU) setups [8].

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Previous research has identified Open RAN as particularly suitable for 5G implementation because of its ability to address ultra-low latency requirements through the integration of RAN virtualization and SDN [9, 10]. Studies on 5G New Radio (NR) deployment in high-density urban environments have highlighted the importance of strategic site location planning and frequency allocation to maximize coverage and capacity efficiency [11, 12]. While previous studies have focused on 5G deployment in established urban settings, the planning methods and capacity planning principles still apply to greenfield urban developments. However, IKN presents a unique greenfield urban environment where, despite having similar urban morphology and population density, the network planning benefits from the lack of legacy infrastructure constraints, greater site selection flexibility, and coordinated infrastructure deployment. This sets the study apart from traditional network planning in established urban areas, which usually involves retrofitting infrastructure and integrating legacy systems. Existing research has not thoroughly addressed the capacity and coverage dimensioning needs for 5G Open RAN network planning in greenfield developments, such as Indonesia's new capital city, *Ibu Kota Nusantara* (Nusantara Capital City, IKN). This research aims to conduct an explicit, systematic analysis of capacity and coverage to determine the optimal infrastructure requirements for effective 5G Open RAN deployment in IKN. It provides a technical framework that capitalizes on both the advantages of greenfield deployment and the benefits of Open RAN architecture for next-generation telecommunications infrastructure.

This research analyzes the design of 5G Open RAN networks for IKN, with a specific focus on the *Kawasan Inti Pusat Pemerintahan* (Core Government Administrative Area, KIPP-1A) region. It uses a technical analysis approach that covers both capacity and coverage dimensioning. The implementation utilizes a frequency of 2300 MHz with a bandwidth allocation of 30 MHz. Predictive modeling calculations span from 2024 to 2028, determining the optimal number of sites, user growth projections, 5G data rate requirements, network performance metrics derived from simulation analyses, and architectural needs for Open RAN components (CU and DU) in the new capital city environment.

The structure of this research is organized as follows: Section II examines 5G RAN and Open RAN technologies; Section III presents the research methodology; Section IV discusses the results and analysis used to determine network site requirements; and Section V offers the conclusions and implications of the research.

II. Basic Theory

A. 5G New Radio (NR) Technology

5G NR represents the next generation of mobile technology, designed as a unified air interface to fulfill the IMT-2020 requirements established by the International Telecommunication Union Radiocommunication Sector (ITU-R). This technology introduces revolutionary capabilities and innovations that significantly enhance mobile communications performance. The 5G NR architecture has been specifically designed to support a wide range of use cases, spanning from eMBB to URLLC [13, 14].

The IMT-2020 specification defines eight key performance metrics that set the operational targets for 5G networks, as shown in Fig. 1. These metrics include peak data rates of 20 Gbps for downlink and 10 Gbps for uplink, establishing high standards for data transmission speeds. User-experienced data rates are aimed at 100 Mbps downlink and 50 Mbps uplink, ensuring consistent, high-quality connectivity for end-users. The system provides reliable communication even at high velocities, supporting mobility up to 500 km/h [15].

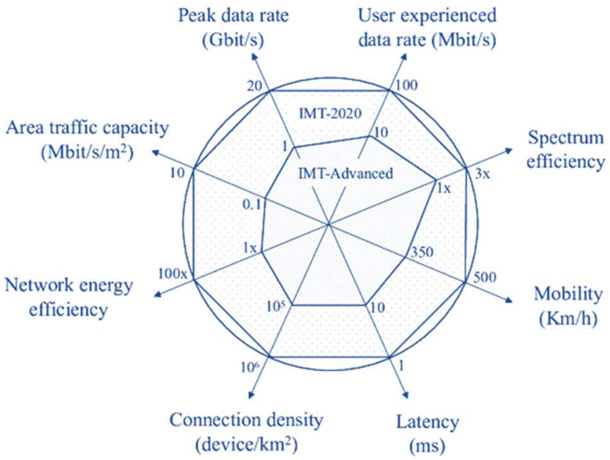


Fig. 1. Evolution of key capabilities from IMT-Advanced to IMT-2020.

A key advancement in 5G NR technology is the ultra-low latency capability, with user plane latency reduced to 1 ms and control plane latency to 10 ms. This technical achievement enables real-time applications and mission-critical communications previously impossible in mobile networks. The technology supports a connection density of up to 1 million devices per square kilometer, facilitating large-scale IoT deployments. Network energy efficiency has shown a 100-fold improvement compared to 4G systems, while spectrum efficiency has improved threefold [16, 17].

B. 5G NR Frequency Bands

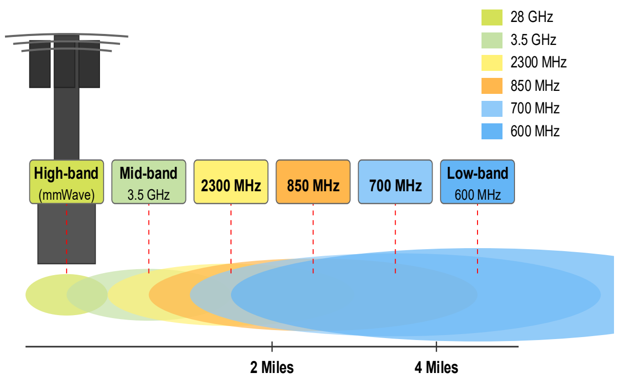


Fig. 2. Cellular frequency bands and coverage distance.

The selection of appropriate frequency bands signifies a critical factor in 5G NR deployment, particularly in urban environments where coverage and capacity requirements must be precisely balanced. Spectrum allocation for 5G NR is categorized into three distinct bands, each exhibiting specific characteristics and applications [18]. Fig. 2 illustrates the 5G NR frequency band characteristics, demonstrating the inverse relationship between frequency and coverage radius, with low-band frequencies (600 MHz) achieving propagation distances up to 4 miles, while high-band millimeter wave (mmWave) frequencies are constrained to significantly shorter distances suitable for dense urban deployments [19, 20]:

(1) Low-band frequencies: Operating below 1 GHz, these frequencies provide extensive coverage capabilities with superior building penetration characteristics. This band is optimized for rural deployment scenarios and IoT applications where coverage range takes precedence over capacity. With wavelengths exceeding 30 cm, these frequencies effectively propagate through physical obstacles and provide coverage radii exceeding 10 kilometers.

(2) Mid-band frequencies: Ranging from 1 to 6 GHz, these frequencies represent the optimal compromise for urban 5G deployments. The 2300 MHz band, situated within this range, offers an advantageous balance between coverage and capacity metrics. This frequency supports bandwidth allocations of 20−100 MHz, enabling high data throughput while maintaining practical coverage radii of 1−3 kilometers in urban environments. The propagation characteristics at these frequencies facilitate effective signal distribution in urban canyons while supporting advanced MIMO implementations.

(3) High-band frequencies: Designated as mmWave bands operating above 24 GHz, these frequencies offer substantial bandwidth capabilities, enabling ultra-high-speed data transmission. However, these frequencies experience significant path loss and limited penetration capabilities, restricting their effective range to less than 500 meters. This band is primarily targeted for dense urban deployment scenarios and fixed wireless access applications where line-of-sight conditions can be maintained.

C. Open RAN Vs RAN Traditional

The Open RAN architecture symbolizes a fundamental shift from traditional vendor-locked implementations, enabling the separation of hardware and software components through standardized, open interfaces that support multi-vendor interoperability [21, 22]. As shown in Fig. 3, conventional RAN uses a single-vendor approach with closely integrated BBU and RU components. In contrast, Open RAN separates these functions into Open-CU, Open-DU, and Open-RU components, which can be supplied by different vendors. This architectural change lowers both capital and operational costs compared to traditional RAN deployments [7].

The principal advantage of Open RAN architecture lies in the functional separation of CU and DU components, which are traditionally integrated elements within the BBU in conventional RAN implementations, as depicted in Fig. 3 [23]. This architectural separation, constrained to a maximum distance of 5 kilometers between components, facilitates efficient resource pooling wherein a single CU can service multiple RRUs, and individual DUs can support multiple CUs, thereby establishing a more flexible and resource-efficient network topology [24]. Furthermore, the disaggregated CU and DU components enable real-time performance optimization, enhancing quality of service parameters while maintaining stringent low-latency requirements through the implementation of RIC [25].

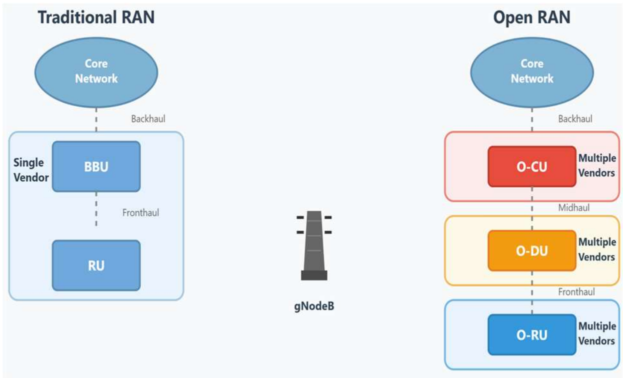


Fig. 3. Comparison of traditional RAN and Open RAN architecture.

III. Materials and Methods

This section outlines the methodological framework implemented for 5G Open RAN network planning in IKN. The research methodology employs a systematic approach to analyzing network capacity and coverage tailored to the specific geographical and demographic characteristics of the target deployment area.

A. Research Framework

The methodology for 5G Open RAN network planning in IKN is illustrated in the flowchart depicted in Fig. 4. Initial parameter determination establishes the foundational network requirements, followed by acquisition of essential capacity and coverage metrics. Network planning calculations are subsequently bifurcated into two complementary analytical approaches: capacity planning and coverage planning, which are executed in parallel to ensure complete dimensioning. These planning outcomes converge into the calculation of Open RAN configuration parameters, where dimensioning of CU and DU components is performed based on network requirements and traffic projections. The consolidated network design undergoes implementation in the Atoll simulation environment for thorough performance evaluation and validation.

Key Performance Indicators (KPIs), including Synchronization Signal-Reference Signal Received Power (SS-RSRP), Synchronization Signal-Signal-To-Interference-Plus-Noise Ratio (SS-SINR), throughput, and user connectivity parameters, are systematically analyzed during performance evaluation. Detailed results and specific technical recommendations for optimal 5G Open RAN deployment in the new capital city environment are presented as the conclusion of the analytical process.

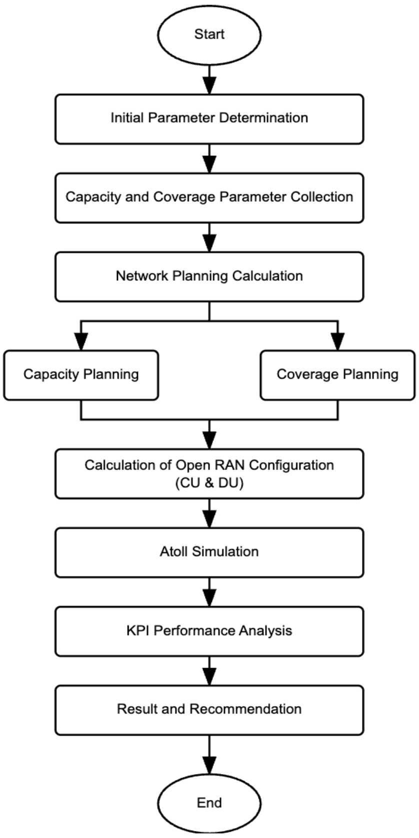


Fig. 4. Flowchart of the 5G network planning process.

B. Research Area

The analysis area in this study involves the KIPP-1A region within IKN. The geographical distribution of the 5G Open RAN deployment location is illustrated in Fig. 5. KIPP-1A occupies approximately 28.76 km² with a projected total population of 488,409 residents by 2024, resulting in a population density of 16,996 residents per km² [26, 27]. This density is consistent with a dense governmental center and reflects the concentrated nature of core administrative functions within the capital city. This region constitutes an appropriate representation for evaluating 5G Open RAN network implementation efficacy due to its integration of critical governmental infrastructure components, including the presidential palace complex, ministerial office buildings, and residential facilities for State Civil Apparatus (ASN), Indonesian National Armed Forces (TNI), and Indonesian National Police (POLRI). In the user forecasting calculations, this total population figure (U_t = 488,409) serves as the baseline input, which is then processed through operator market share and 5G technology penetration rate to derive the actual 5G user projections for network planning, yielding 76,695 users in 2024 and growing to 94,644 users by 2028.

The selection of the KIPP-1A region as the primary investigation domain is based on multiple strategic considerations, including its designation as the core governmental center within IKN and its prioritization in the initial development phase (2022−2024). Furthermore, this region was designated as the focal point for 5G Open RAN implementation based on two principal strategic factors: its role as a technical and architectural blueprint for subsequent development phases and its need for robust telecommunications infrastructure to support smart city applications and governmental operations.

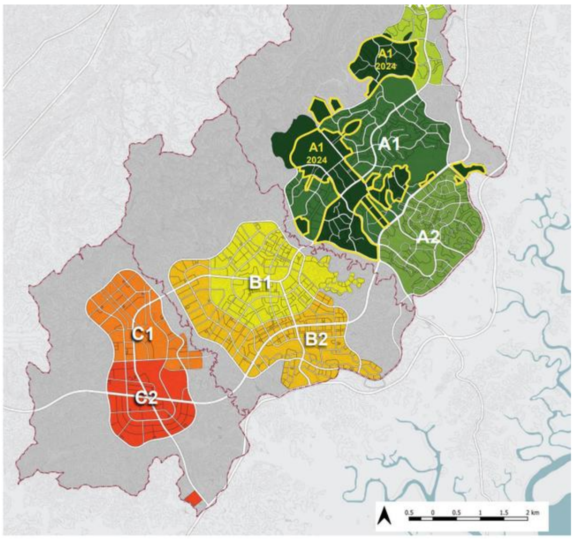


Fig. 5. KIPP-1A map region within IKN.

C. Capacity Dimensioning

Capacity planning quantitatively assesses the network's capability to meet throughput requirements. This process initiates with subscriber forecasting for the planned city development phases. Capacity dimensioning determines the requisite number of sites to accommodate projected traffic demand, encompassing user forecasting, service requirement modeling, throughput calculation, and converting these parameters into the required cell sites. The capacity analysis process encompasses several sequential calculation stages as follows:

1) User forecasting calculation

For IKN phased development, a multi-stage growth model is employed [28]. The base population projection follows Eq. (1):

$$F_u = U_t \times \frac{Ms \times NR_{pen}}{A_{zone}} \tag{1}$$

where F_u is user forecasting (users/km^2), U_t is the projected population in the target year, Ms is the operator market share, NR_{pen} is the 5G technology penetration rate, and A_{zone} is the zone's surface area (km^2).

2) Traffic demand and network throughput calculation

Traffic demand per user quantifies individual data consumption patterns anticipated in a modern smart city environment. This parameter integrates usage metrics across multiple service categories, including eMBB applications, IoT services, and mission-critical communications. In this research, the traffic user metric focuses primarily on 5G broadband Connectivity (eMBB) [29], representing the foundational capacity requirement for the initial deployment phase of IKN's telecommunications infrastructure. While mMTC and URLLC use cases are essential for comprehensive smart city operations and critical government services, the eMBB-focused analysis provides the baseline network capacity that can support and be enhanced for these advanced applications in subsequent deployment phases. This approach ensures adequate foundational infrastructure for governmental operations while acknowledging that future network optimization will incorporate comprehensive traffic modeling for all three 5G service categories. The base traffic user projection follows Eq. (2):

$$T_u = \sum_{i=1}^{n}(S_i \times V_i \times F_c) \quad (2)$$

where T_u is the traffic demand per user (Mbps), S_i is the average session size for service, V_i is the usage rate of service (session/day), and f_c is the carrier frequency factor of the service.

The total network throughput is the aggregate data capacity required to serve all active users during peak usage periods. This calculation considers the spatial distribution of users across the IKN area, individual traffic consumption patterns, and temporal variations in network utilization. Calculation of the total throughput required for the network during busy hours follows Eq. (3):

$$T_{net} = F_u \times A_{total} \times T_u \, x \, BH_f \times P_a \quad (3)$$

where T_{net} is the total network throughput (Mbps), F_u is total user forecasting (users/km²), A_{total} is the total planning area (km²), T_u is the traffic demand per user (Mbps), and BH_f is the busy hour factor.

3) Cell capacity calculation

Cell capacity refers to the maximum data throughput that can be achieved per cell within the Open RAN architecture. This parameter directly determines the number of users that can be simultaneously served with the required quality of service [30]. The base calculation for cell capacity follows Eq. (4):

$$C_{cell} = B \times \eta \times (1 - OH) \times N_{MIMO} \quad (4)$$

where C_{cell} is cell capacity (Mbps), B is allocated bandwidth (MHz), η is the spectral efficiency (bps/Hz), OH is the protocol overhead factor, and N_{MIMO} is the number of MIMO streams.

4) Site capacity calculation

Site capacity calculation is the capacity-driven dimensioning aspect of network planning, which must be compared against coverage-driven requirements to determine the final site quantity. The base calculation for the number of sites based on capacity follows Eq. (5):

$$N_{site} = \frac{T_{net}}{N_{sector} \times C_{cell}} \quad (5)$$

where N_{site} is the number of required sites, T_{net} is the total network throughput (Mbps), N_{sector} is the number of sectors per site, and C_{cell} is cell capacity (Mbps).

D. Coverage Dimensioning

Coverage planning constitutes the systematic process of determining the geographical area effectively serviced by radio signals from cellular network sites. This methodology ensures adequate signal strength and quality throughout the target service area, taking into account signal propagation characteristics, terrain variations, building structures, and physical obstructions. The coverage analysis process encompasses several sequential calculation stages [31, 32]:

1) Link budget calculation

The link budget calculation forms the foundational component of coverage planning, establishing the maximum allowable signal attenuation while maintaining reliable communications. This calculation accounts for all gains and losses in the radio transmission path between the base station and user equipment [33]. Link budget parameters are formulated in Eq. (6):

$$MAPL = P_{Tx} + G_{TX} - L_{System} - M_{Fade} + G_{RX} - S_{RX} \quad (6)$$

where $MAPL$ is Maximum Allowable Path Loss (dB), P_{Tx} is transmit power (dBm), G_{TX} is transmitter antenna gain (dBi), L_{System} is system losses (dB), M_{Fade} is fade margin (dB), G_{RX} is receiver antenna gain (dBi), and S_{RX} is receiver sensitivity (dBi).

2) Propagation model approach

The 3D-UMa (Urban Macrocell) propagation model, standardized by 3GPP for 5G planning, incorporates three-dimensional spatial relationships between transmitters and receivers, accounting for antenna heights and actual signal path lengths rather than merely horizontal distances [34]. The 3D-UMa propagation model was specifically selected for the KIPP-1A region, considering its planned urban development characteristics. Given the greenfield nature of IKN development, the region will feature a mix of governmental buildings, residential complexes, and planned green spaces. The Line of Sight (LOS) conditions are anticipated in open areas such as planned parks and wide governmental corridors. In contrast, Non-Line of Sight (NLOS) conditions are expected to dominate in areas with dense governmental buildings and residential blocks. The model accounts for the planned building heights, typically ranging from 3 to 15 stories for governmental facilities and 2 to 8 stories for residential areas. Street widths are designed according to modern urban planning standards, ranging from 12 to 30 meters for major corridors. To calculate path loss in the area development environment, the 3D-Uma propagation model is applied, considering both LOS and NLOS conditions.

For LOS conditions, follow Eq. (7):

$$PL_{LOS} = 40\ \log_{10}(d_{3D}) + 28 + 20\ \log f_c - 9\ ((d'_{BP})^2 + (h_{BS} - h_{UT})^2 \quad (7)$$

For NLOS conditions, follow Eq. (8):

$$PL_{NLOS} = \max(PL_{LOS}13.54 + 39.08\ \log_{10}(d_{3D}) + 20\ \log_{10}(f_c) - 0.6\ (h_{UT} - 1.5)) \quad (8)$$

where f_c is carrier frequency (GHz), d_{3D} is the three-dimensional (3D) Euclidean distance between BS and UT (m), $h_{UT}$is UT height (m), h_{BS} is BS height (m), and d'_{BP} is the breakpoint distance (m).

3) Cell radius and coverage area calculation

The cell radius calculation converts the theoretical path loss limit into concrete geographical coverage dimensions, determining the maximum distance from each base station at which reliable service can be maintained [35]. Based on the MAPL value and propagation model, the cell radius can be calculated as follows in Eq. (9):

$$d_{2D} = \sqrt{(d_{3D})^2 - (h_{BS} - h_{UT})^2} \quad (9)$$

where d_{2D} is the horizontal distance between BS and UT (m). This calculation converts the linear radius measurement into a two-dimensional coverage footprint, taking into account the sectorized deployment pattern typical of cellular networks. With the implementation of sectoral antennas, the effective coverage area per cell can be calculated as follows in Eq. (10):

$$A_{cell} = K \times d_{2D} \quad (10)$$

where A_{cell} is the cell coverage area (km^2), and K is the sectoral correction factor (for the three-sector model).

4) Site coverage calculation

Site coverage area determines the minimum number of base stations required to provide continuous coverage across the entire IKN development area. The calculation of minimum site requirement follows Eq. (11):

$$N_{site} = \frac{A_{total}}{A_{cell}} \quad (11)$$

where N_{site} is the number of required sites, and A_{total} is the total surface area (km^2).

E. Calculation of Open RAN Configuration

The dimensioning methodology for CU and DU components in 5G Open RAN architecture follows a systematic analytical framework that transforms network traffic requirements into physical infrastructure specifications [8, 36, 37]. This process integrates multiple technical parameters and design constraints to derive the optimal quantity of network elements required for efficient service delivery. The calculation process determines the appropriate number of these functional components based on capacity requirements, throughput demands, and spatial distribution patterns of users.

1) CU configuration calculation

The CU configuration selection process employs network capacity requirements and user distribution analysis as primary inputs. The determination of CU quantity follows a capacity-based methodology as follows: Cell site CU or C_{CU} can be calculated following Eq. (12):

$$C_{CU-base} = 12\ Cells. 2 \times 2\ MIMO \quad (12)$$

while the centralized CU requirements can be calculated following Eq. (13):

$$N_{CU} = \frac{T_{total}}{T_{CU-max}} \quad (13)$$

where N_{CU} is the number of required CU, T_{total} is the total network throughput (Gbps), and T_{CU-max} is the maximum throughput per CU (20 Gbps for a 5x8C configuration).

2) DU configuration calculation

The DU configuration process implements analogous principles, focusing on real-time processing requirements and fronthaul constraints. The selection of appropriate DU specifications depends on cell count, bandwidth allocation, and processing capacity required for baseband functions. The determination of DU configuration can be calculated following Eq. (14):

$$N_{DU} = \frac{N_{cells-total}}{C_{DU}} \quad (14)$$

where N_{DU} is the number of required DU, $N_{cells-total}$ is the total number of cells in the network, and C_{DU} is the cell capacity per DU.

F. Simulation Tools and Key Performance Indicators

TABLE I. 5G NETWORK PERFORMANCE EVALUATION CRITERIA

Metric	Classification	Threshold Values	Measurement Unit
SS-RSRP	Optimal	> −80	dBm
	Satisfactory	−80 to −90	dBm
	Acceptable	−90 to −100	dBm
	Marginal	−100 to −110	dBm
	Inadequate	< −110	dBm
SS-SINR	Optimal	> 20	dB
	Satisfactory	10 to 20	dB
	Acceptable	0 to 10	dB
	Marginal	−5 to 0	dB
	Inadequate	< −5	dB
Data Rate/ Throughput	Maximum DL	> 100	Mbps
	Maximum UL	> 50	Mbps
User Access	Service Coverage	> 95	%
	User Concentration	1	Million/km²

The 5G network simulation for this study was conducted using Atoll software, a well-known industry tool specifically created for wireless network planning and optimization. This platform allows for precise modeling of signal propagation, scenario development, parameter setup, and a detailed evaluation of 5G network performance [38, 39]. The simulation-based method was selected because of the greenfield nature of the KIPP-1A region, where physical infrastructure and urban development are not yet present, making empirical field measurements impractical at this planning stage. The Atoll simulation uses internationally standardized 3GPP propagation models (3D-UMa), which have been thoroughly validated in similar urban settings, representing industry best practice for greenfield deployment planning. Although this method has limitations compared to field-verified measurements, it provides an essential foundation for systematic network planning in undeveloped areas. This approach enables the evaluation of multiple deployment scenarios before infrastructure construction. Performance metrics were selected in accordance with 3GPP standards and aligned with Indonesian regulations for 5G deployment [40]. The network performance analysis focuses on four key parameters: SS-RSRP, SS-SINR, data transmission rates, and user connectivity capabilities, as shown in Table I.

IV. Results and Discussion

This section presents the findings of the 5G Open RAN network planning study for IKN. Network capacity and coverage calculations were performed based on the geographic and demographic characteristics of the IKN development plan. The Open RAN configuration results include CU and DU dimensioning tailored to the specific requirements of the KIPP-1A region. Additionally, simulation results demonstrate that network performance metrics meet the established KPI standards for 5G technology deployment. Subsequently, a discussion will be presented regarding the implementation challenges and considerations to provide a practical context for the findings before proceeding to the conclusion.

A. Capacity Dimensioning Analysis

Capacity dimensioning for the 5G Open RAN network in IKN was conducted to ensure adequate network resources for projected traffic demands. The analysis incorporated population forecasts, user traffic patterns, spectrum efficiency, and network architecture parameters to determine the optimal site requirements for delivering effective service.

1) User forecasting analysis

The user forecasting calculation for IKN was performed using the multi-stage growth model described in Eq. (1). The key planning parameters used in this analysis include an operator market share of 30% and a 5G technology penetration rate of 35%, derived from proprietary telecommunications industry analysis for the Indonesian market. The 30% market share assumption reflects Indonesia's competitive telecommunications environment, characterized by three to four major operators, which represents a realistic market distribution for individual operator planning. The 35% 5G penetration rate is a conservative estimate for early-phase deployment in governmental and administrative centers, where advanced telecommunications infrastructure typically sees higher adoption rates compared to general consumer markets. These parameters were applied as static values to establish baseline network dimensioning requirements, acknowledging that sensitivity analysis of parameter variations would provide additional insights for optimization. The conservative approach ensures sufficient infrastructure capacity to accommodate reasonable fluctuations in market penetration rates during IKN's development phases. Future network planning iterations will incorporate dynamic forecasting models and sensitivity analysis as actual adoption data become available. Analysis of the projected population data for the KIPP-1A region shows a consistent growth pattern from 2024 to 2028, as seen in Table II. These parameters provide a foundational baseline for capacity dimensioning, with the understanding that actual deployment scenarios may require adjustment of these parameters based on evolving market conditions and regulatory developments.

TABLE II. User Forecasting for IKN KIPP-1A Region

Year	User Forecast
2024	76,695
2025	79,684
2026	84,388
2027	86,016
2028	94,644

2) Traffic demand and total network throughput analysis

The traffic demand per user was calculated using Eq. (2), where (F_u) was derived from the projected population, operator market share (30%), and 5G penetration rate (35%). With a traffic demand per user (T_u) of 36.39 Mbps, busy hour factor (BH_f) of 1.35, and active user percentage (P_a) of 60%, the analysis for the IKN KIPP-1A region yielded a traffic demand of 36.39 Mbps per user. The per-square-kilometer traffic density follows a similar pattern, rising from 2.36 Gbps/km² in 2024 to 2.91 Gbps/km² by 2028.

After determining the traffic demand per user, the total network throughput was calculated using Eq. (3). The results indicate that the network throughput requirements are 26,115.69 Mbps for the uplink and 83,667.97 Mbps for the downlink, representing the aggregate capacity required during peak hours.

3) Cell capacity result

The cell capacity analysis indicates that each 5G cell can support approximately 2,558.4 Mbps of throughput using the specified configuration. For the 5G deployment in IKN using a 30 MHz channel bandwidth at 2300 MHz, the cell capacity values were determined through SS-SINR probability distribution analysis, as shown in Table III.

TABLE III. The Cell Capacity Calculation Result

Parameter	Value	Unit
Allocated Bandwidth (B)	30	MHz
Spectral Efficiency (η)	7.8	bps/Hz
Protocol Overhead Factor (OH)	0.18	ratio
Number of MIMO Streams (NMIMO)	4	streams
Cell Capacity (Cell)	2,558.4	Mbps

4) Site requirement capacity result

Based on the total network throughput and cell capacity calculations, the number of required sites was determined using Eq. (5), assuming a standard tri-sector configuration for each site. The total site requirement calculation incorporates network throughput demands and cell capacity analysis, as presented in Table IV.

TABLE IV. TOTAL SITE CALCULATION RESULT

Parameter	Uplink	Downlink	Unit
Network Throughput (MAC)	26,115.69	83,667.97	Mbps
Cell Throughput	2,093.88	1,744.90	Mbps
Site Capacity (3 sectors)	6,281.63	5,234.69	Mbps
Required Sites	5	17	sites
5G NR Users per Site	18,929	5,916	users/site
Coverage per Site	5.75	1.80	km²/site
Coverage per Cell	1.92	0.60	km²/cell
Cell Radius	1.60	0.89	km

B. Coverage Dimensioning Analysis

Coverage dimensioning is a necessary aspect of 5G Open RAN network design, ensuring adequate signal availability throughout the target service area. This analysis determines the geographical reach of each cell site and the collective network footprint across IKN.

1) Link budget analysis

The link budget calculation focuses on determining the MAPL using the components detailed in Table V. Based on the analysis for 5G network planning in the 2300 MHz frequency band, distinct parameters emerge for both uplink and downlink transmission scenarios.

TABLE V. LINK BUDGET CALCULATION RESULTS

Parameter	Uplink Value	Downlink Value
TX Power	23 dBm	53 dBm
Body Loss	2 dB	5 dB
EIRP	−6.833 dBm	34.167 dBm
Thermal Noise	−99.059 dBm	−99.059 dBm
SINR	5 dB	5.53 dB
Penetration Loss	10.84 dB	22 dB
MAPL	81.886 dB	80.696 dB

2) Propagation model result

The path loss analysis for 5G network deployment employs the 3D-UMa model, as specified in Eqs. (8−9), for both LOS and NLOS scenarios in the urban environment. The resulting path loss calculations are presented in Table VI. The propagation analysis confirms that 81.89 dB represents the maximum path loss value for cell radius calculations, considering the more restrictive condition between uplink and downlink paths.

TABLE VI. PROPAGATION MODEL CALCULATION RESULT

Condition	Uplink Path Loss	Downlink Path Loss	Maximum Path Loss
LOS	81.89 dB	80.70 dB	81.89 dB
NLOS	81.89 dB	80.70 dB	81.89 dB

3) Cell radius and coverage area calculation

Based on the MAPL value and the propagation model, the cell radius was calculated for both LOS and NLOS conditions. The results are presented in Table VII. For the LOS scenario, calculations yield a cell radius of 2.311 km for downlink and 2.475 km for uplink. In contrast, the NLOS scenario exhibits significantly reduced coverage capabilities, with a cell radius of 1.004 km for the downlink and 1.077 km for the uplink.

The selection of NLOS conditions for determining the final cell radius and subsequent site count calculations is justified by the anticipated urban morphology and functional requirements of the KIPP-1A region. As the core governmental administrative center, the area will feature building configurations with governmental office complexes ranging from 3 to 15 stories, residential blocks for government personnel of 2 to 8 stories, and ceremonial buildings, creating predominantly NLOS propagation environments. The planned street widths, ranging from 12 to 30 meters, are designed by modern urban planning standards and will be flanked by continuous building structures that create urban canyon effects and obstruct direct line-of-sight paths. The integration of planned green spaces and landscaped areas introduces vegetation-induced signal attenuation, which supports the prevalence of NLOS conditions. The building density coefficient for the KIPP-1A region is anticipated to reach a 60−70% coverage ratio, with building-to-street width ratios ranging from 0.4 to 1.25, which may create signal obstruction scenarios. NLOS-based planning ensures adequate indoor coverage penetration for governmental facilities where consistent connectivity is required for administrative operations. This approach provides sufficient service quality margins to accommodate signal variability in dense governmental environments while ensuring reliable network performance across operational scenarios within the administrative complex.

TABLE VII. CELL RADIUS AND COVERAGE AREA RESULT

Parameter	LOS Value	NLOS Value
Uplink Cell Radius	2.475 km	1.077 km
Downlink Cell Radius	2.311 km	1.004 km
Selected Cell Radius (minimum)	2.311 km	1.004 km
Coverage Area per Site (3-sector)	2.25 km²	1.97 km²
Reuse Distance (Cluster 3)	3.23 km	3.01 km

4) Site requirement coverage result

Based on the coverage planning approach that incorporates site calculation results and network coverage requirements as defined in Eq. (11), Table VIII presents the key parameters for implementing a 5G network in the KIPP-1A region. The site requirement calculations based on the coverage area per site and the total area to be covered are summarized in Table IX. This coverage differential necessitates additional sites for downlink requirements, resulting in the final determination of 12 sites to ensure network performance throughout the target area.

C. Open RAN Configuration Analysis

Based on network capacity requirements and site calculations, Open RAN architecture components were dimensioned as shown in Table X. The dimensioning indicates that the entire network can be managed with a single CU, given the total throughput requirement. However, the DU calculation yields a fractional result of 5.33, which necessitates rounding up to 6 DUs to support the 51 cells (17 sites with three sectors each).

TABLE VIII. COVERAGE PLANNING KEY PARAMETERS

Parameter	Results
Total Coverage Area	28.76 km²
Uplink Coverage per Site	2.25 km²
Downlink Coverage per Site	1.97 km²
Uplink Reuse Distance	3.23 km
Downlink Reuse Distance	3.01 km

TABLE IX. SITE REQUIREMENT CALCULATION RESULT

Parameter	LOS Value	NLOS Value
Total Area to Cover	28.76 km²	21.97 km²
Coverage Area per Site (3-sector)	2.25 km²	1.97 km²
Number of Sites Required	13 sites	12 sites

The 1:6 ratio of CU and DU configuration presents a highly efficient resource allocation for the KIPP-1A region. This architecture leverages the fundamental advantage of Open RAN's disaggregated approach, allowing optimized distribution of network functions across the infrastructure. With a theoretical maximum throughput capacity of 2,406.29 Gbps and server capacity of 2,048.06 Gbps, the single CU implementation provides sufficient headroom (approximately 15%) for traffic fluctuations while avoiding excessive overprovisioning.

TABLE X. OPEN RAN COMPONENT DIMENSIONING RESULT

Component	Final Value
Number of Users	94,644
Throughput Requirements (Mbps)	83,667.97
Required Sites	17
Total Cells (3 sectors/site)	51
Estimated Total Throughput (Gbps)	2,406.29
Server Capacity (Gbps)	2,048.06
Required CU	1
Required DU	6

D. *Simulation Planning Result Analysis*

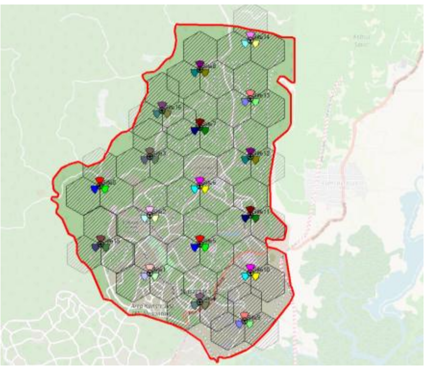


Fig. 6. 5G Site deployment map for IKN KIPP-1A region.

The simulation planning for 5G Open RAN deployment in IKN was conducted using both coverage and capacity dimensioning approaches. The analysis results indicate a disparity between coverage-based and capacity-based site requirements. In this research, coverage planning evaluation was performed by analyzing SS-RSRP and SS-SINR parameters. Meanwhile, the capacity planning focused on throughput distribution parameters and traffic parameters (number of connected users, especially for 5G broadband services). Fig. 6 illustrates the network coverage simulation results using the optimized 17-site configuration across the IKN development area. The simulation was performed using specialized radio planning software incorporating the 3GPP 38.901 propagation model.

1) Signal strength (SS-RSRP) performance analysis

The signal strength performance was analyzed through simulation to evaluate the coverage effectiveness of the planned 5G deployment in the KIPP-1A region. Fig. 7 presents the 5G site deployment map with signal strength coverage, while Fig. 8 illustrates the detailed SS-RSRP distribution performance. The histogram results show a mean SS-RSRP value of −73.13 dBm with a standard deviation of 5.92 dBm, which falls within the "Optimal" classification (above −80 dBm) according to the evaluation criteria in Table I. Approximately 96% of the coverage area experiences signal strength above −75 dBm. This surpasses the target service coverage quality of 95%, indicating excellent signal strength throughout the coverage area.

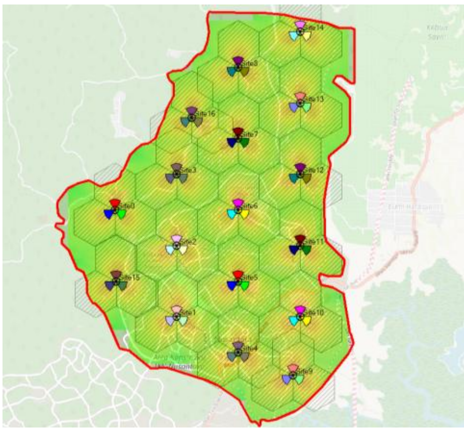


Fig. 7. 5G signal strength coverage map for the area.

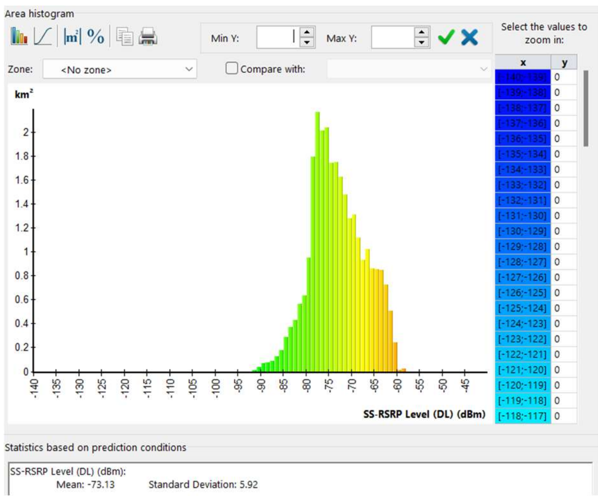


Fig. 8. 5G signal strength distribution performance result.

2) Signal quality (ss-sinr) performance analysis

Beyond signal strength, signal quality is equally critical for ensuring 5G performance. The signal quality performance was analyzed through simulation to evaluate the effectiveness of interference management in the planned 5G deployment in the KIPP-1A region. Fig. 9

presents the 5G SS-SINR coverage map, which shows the distribution of signal quality across the planning area. Fig. 10 illustrates the detailed SS-SINR distribution histogram.

The SS-SINR histogram in Fig. 10 quantifies the signal quality distribution, showing a mean SS-SINR value of 15.55 dB with a standard deviation of 7.89 dB. According to the evaluation criteria in Table I, this falls primarily within the "Satisfactory" classification (10 to 20 dB), with significant portions of the coverage area experiencing "Optimal" conditions (greater than 20 dB). The color-coded distribution indicates that approximately 85% of the service area experiences SS-SINR values above 10 dB, sufficient for high-order modulation schemes that enable peak throughput performance.

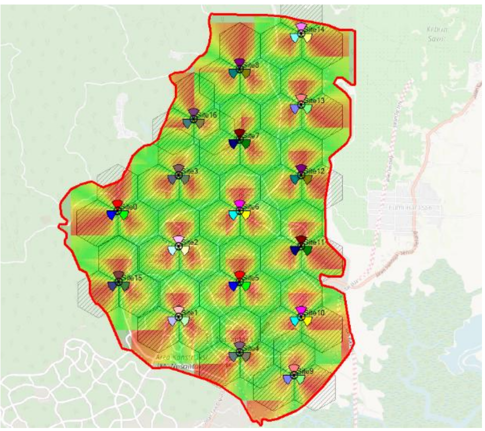


Fig. 9. 5G signal quality distribution map for the area.

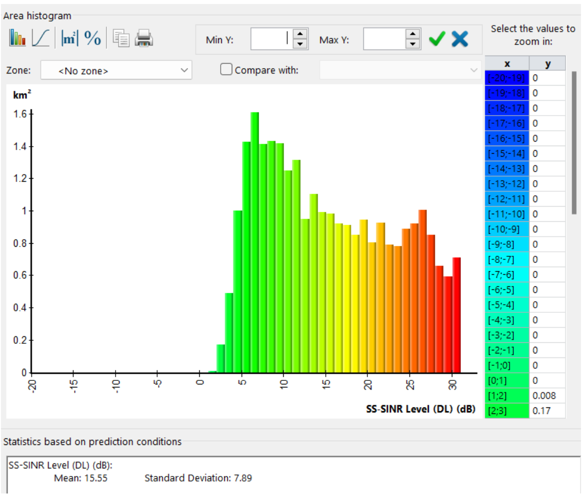


Fig. 10. 5G signal quality distribution performance result.

3) Throughput performance analysis

The throughput performance was analyzed through simulation to evaluate the data capacity of the planned 5G deployment in the KIPP-1A region. Fig. 11 illustrates the throughput coverage map across the planning area, while Fig. 12 presents the histogram of peak RLC channel throughput.

The throughput histogram in Fig. 12 reveals solid performance characteristics, with the majority of the coverage area achieving peak downlink throughput rates above 50 Mbps. The mean peak RLC channel throughput, also referred to as the mean throughput, is calculated to be 138.58 Mbps with a standard deviation of 70.80 Mbps. These simulated values exceed the IMT-2020 user-experienced data rate target of 100 Mbps, as specified in Table I, with individual users achieving 38.6% above the minimum requirement. This confirms that the network design complies with the requirements of fifth-generation mobile networks.

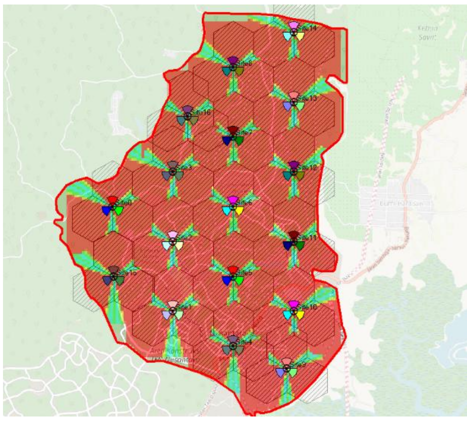


Fig. 11. 5G throughput distribution map for the area.

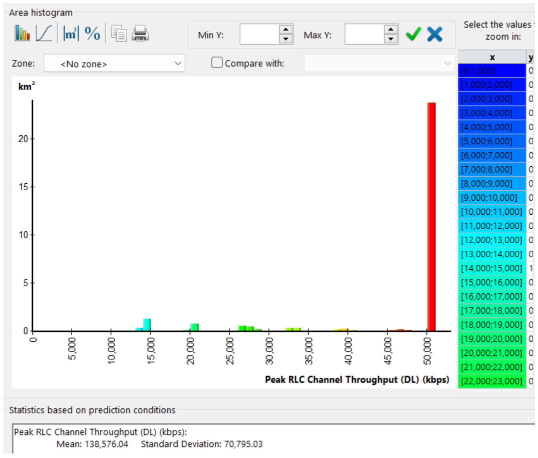


Fig. 12. 5G throughput distribution performance result.

4) Traffic performance analysis

The traffic performance was evaluated through simulation to assess the network's capacity to handle anticipated user loads and data transmission requirements in the KIPP-1A region. The analysis presents two key performance indicators. Fig. 13 displays the user connectivity map, illustrating the spatial distribution of coverage, while Fig. 14 provides quantitative measurements of traffic parameters.

The user connectivity analysis in Fig. 13 demonstrates sufficient coverage across the KIPP-1A region, with successful connection establishment shown throughout the target deployment area. The simulation results confirm that the proposed network design provides broadband 5G connectivity to 95.9% of users, meeting the minimum service coverage requirements for the planning area.

The traffic performance evaluation indicates satisfactory network capacity. The downlink performance shows peak RLC cumulative throughput of 3,999.51 Mbps and cumulative application throughput of 3,788.89 Mbps under operational conditions. The uplink performance achieves peak RLC cumulative throughput of 4,984.09 Mbps and cumulative application throughput of 4,734.84 Mbps.

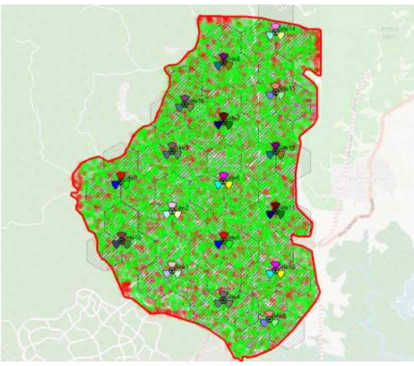
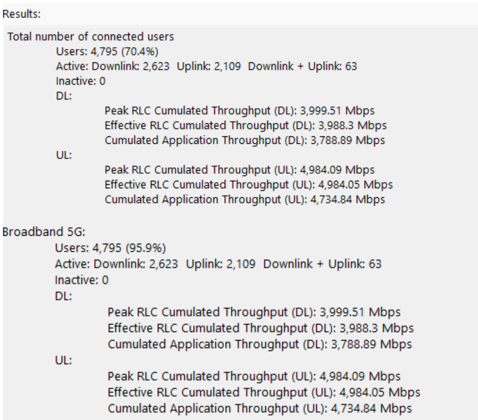


Fig. 13. 5G user connectivity map for the area.



Results:
Total number of connected users
Users: 4,795 (70.4%)
Active: Downlink: 2,623 Uplink: 2,109 Downlink + Uplink: 63
Inactive: 0
DL:
Peak RLC Cumulated Throughput (DL): 3,999.51 Mbps
Effective RLC Cumulated Throughput (DL): 3,988.3 Mbps
Cumulated Application Throughput (DL): 3,788.89 Mbps
UL:
Peak RLC Cumulated Throughput (UL): 4,984.09 Mbps
Effective RLC Cumulated Throughput (UL): 4,984.05 Mbps
Cumulated Application Throughput (UL): 4,734.84 Mbps

Broadband 5G:
Users: 4,795 (95.9%)
Active: Downlink: 2,623 Uplink: 2,109 Downlink + Uplink: 63
Inactive: 0
DL:
Peak RLC Cumulated Throughput (DL): 3,999.51 Mbps
Effective RLC Cumulated Throughput (DL): 3,988.3 Mbps
Cumulated Application Throughput (DL): 3,788.89 Mbps
UL:
Peak RLC Cumulated Throughput (UL): 4,984.09 Mbps
Effective RLC Cumulated Throughput (UL): 4,984.05 Mbps
Cumulated Application Throughput (UL): 4,734.84 Mbps

Fig. 14. Traffic parameters result in the total number of connected users and the 5G broadband users' simulation result.

E. Implementation Challenges and Considerations

While the capacity and coverage analysis demonstrate the technical feasibility of 5G Open RAN deployment in IKN, several implementation challenges must be acknowledged for practical deployment considerations. These are:

(1) Vendor interoperability is a key challenge, as Open RAN requires smooth integration between CU, DU, and RU components from different vendors. The standardized interfaces must be carefully tested to ensure compatibility and consistent performance across diverse equipment.

(2) Security challenges emerge from multi-vendor architecture, requiring comprehensive security frameworks to manage potential vulnerabilities across vendor boundaries and standardized interface points.

(3) Logistical considerations specific to greenfield deployment include coordinated vendor management, synchronized equipment delivery, and the availability of a skilled workforce for Open RAN technology implementation at the remote IKN location.

Mitigation strategies include establishing vendor certification programs, implementing comprehensive security auditing protocols, and developing local technical expertise through training initiatives. These challenges, while significant, do not affect the core capacity and coverage requirements outlined in this analysis; however, they are important considerations for the deployment phase.

V. Conclusion

This research demonstrates that the 5G Open RAN deployment in the KIPP-1A region of IKN achieves exceptional performance metrics that exceed standard technical specifications. The capacity planning analysis indicates that 17 sites constitute the minimum infrastructure requirement to support the projected traffic demand of 83,667.97 Mbps for an anticipated 94,644 users by 2028. This capacity-driven threshold surpasses the coverage-based requirement of 12 sites, confirming that the network deployment is primarily capacity-limited rather than coverage-constrained.

Performance evaluation indicates strong signal coverage throughout the planning area, with mean SS-RSRP values of −73.13 dBm with a standard deviation of 5.92 dBm and 96% of the coverage area experiencing signal strength above −75 dBm. The SS-SINR distribution presents a mean value of 15.55 dB with a standard deviation of 7.89 dB, enabling high-order modulation schemes across the service area. The mean throughput is 138.58 Mbps, significantly exceeding the minimum 5G requirement of 100 Mbps. Meanwhile, cumulative throughputs of 3,999.51 Mbps downlink and 4,984.09 Mbps uplink effectively accommodate the asymmetric traffic patterns characteristic of governmental and administrative functions.

The implemented architecture, comprising 1 CU and 6 DUs, supporting 17 radio sites, validates the technical and economic advantages of disaggregated network infrastructure for greenfield deployments with an urban morphology characteristic. This study presents a technical framework for the efficient implementation of 5G telecommunications in emerging smart city environments, balancing coverage requirements, capacity demands, and architectural complexity while providing extensibility for future network evolution.

For future research, exploring techno-economics and conducting a sensitivity analysis could further enhance the feasibility of 5G Open RAN deployment. Additionally, exploring the integration of emerging 6G technologies with the established Open RAN infrastructure would provide valuable insights for long-term telecommunications planning in developing smart cities.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Putri Rahmawati conceptualized the research framework, conducted the investigation, performed formal analysis, developed the methodology, created the software implementation, performed validation, and wrote the original draft; Muhammad Adam Nugraha provided manuscript review and editing, including enhancing sentence structure, ensuring proper figure and table numbering, validating logical flow, and verifying technical accuracy throughout the paper; Aisyah Novfitri and Lia Hafiza acquired funding resources, performed data curation, administered the project, and provided necessary resources for the research execution; Syifa Maliah Rachmawati assisted with data visualization and contributed to the literature review section; all authors reviewed and approved the last version of the manuscript before submission.

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