Sensitivity Options of 5G 700 MHz Network Deployment in Urban Models: A Simulation for Emerging Countries

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***Abstract*—As one of Indonesia's major urban cities, Bandung is seeing rising demand for high-speed wireless connectivity; this research performs a techno-economic analysis to evaluate the feasibility of deploying a 5G network to meet this need by utilizing the 700 MHz spectrum in the city. Capacity and coverage studies are conducted to determine the required number of base stations (gNodeB) and optimal network configuration for Bandung. Economic factors are analyzed, including cost structures, feasibility, and sensitivity parameters. Network simulations demonstrate that the 700 MHz band provides good coverage across Bandung, with an average SS-RSRP of -92 dBm and SS-SINR of 9.21 dB. The economic assessment shows a positive trend, with a net present value of $11.9 million, an internal rate of return of 33.09%, and a payback period of 3 years. However, 142 gNodeBs require substantial upfront investments of $2.7 million per site. In addition, the number of gNodeB is identified as the most sensitive parameter influencing project feasibility. While deploying 5G at 700 MHz offers good propagation and indoor penetration to serve Bandung, significant infrastructure funds are needed. By adopting long-term strategies, telecom operators can realize the technological and economic potential of 5G in Indonesian cities.**

***Keywords*—5G, 700 MHz spectrum, Bandung Indonesia, feasibility study, telecommunication**

I. INTRODUCTION

The proliferation of smart devices and demand for data-intensive applications drive exponential growth in global mobile data traffic. It is estimated that monthly global mobile data traffic will reach 49 exabytes by 2021, a 3-fold increase over 2016 levels, with projections to grow by another 4-fold to reach 237 exabytes per month by 2026. This astounding demand has triggered massive investments into Fifth-Generation (5G) cellular network technology, which promises to deliver multi-gigabit peak data speeds, greater spectral efficiency, reduced latency, and support for massive machine-type communications. However, deploying 5G networks requires large amounts of capital to acquire spectrum licenses and build extensive infrastructure capable of operating at higher frequencies [1].

In Indonesia, rising incomes and rapid smartphone adoption have also led to surging mobile data usage in major urban cities such as Bandung. Though early stage 5G trials have occurred, nationwide deployment at scale is still years away. Using the 700 MHz band for 5G networks can provide excellent propagation characteristics to expand coverage cost-effectively but may limit peak data rates [2].

While early 5G deployments are underway in some advanced countries, broader adoption faces difficulties balancing substantial infrastructure costs with uncertainty in future data demand and revenue growth. Previous techno-economic analyses of 5G primarily focus on macrocell deployments in developed country contexts [3]. With Indonesia's unique geographic and demographic challenges, there remains a need to evaluate the feasibility of 5G deployments using low-band spectrum to extend coverage across urban areas cost-effectively. Though the 700 MHz spectrum provides excellent propagation, the ability to deliver high data speeds in crowded city environments has yet to be thoroughly investigated.

This research aims to conduct a detailed techno-economic analysis focused on utilizing a 700 MHz spectrum for deploying 5G Non-Standalone (NSA) networks in the high-density, high-traffic environment of Bandung City. The study investigates the technological capabilities to meet projected user demand and the commercial feasibility, given the substantial deployment costs and uncertainties in the 5G ecosystem. Network planning and simulations determine the required gNodeB, throughput performance, and infrastructure requirements. At the same time, financial modeling evaluates viability metrics, including Capital and Operational Expenditures (Capex and Opex), Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PBP). Furthermore, sensitivity analysis is undertaken to identify the most

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impactful factors during 5G network implementation [4]. The findings provide in-depth insights into the strategic roadmap and prospects for 5G network implementation in an urban Indonesian city using a 700 MHz spectrum.

This research begins with an introduction in Section I, followed by a detailed overview of the 5G network in Section II. The research methodology employed is explained in Section III. After that, Section IV presents the results and analysis of the technical, feasible, and sensitivity assessment. Finally, Section V summarizes the research and concludes the paper.

II. 5G Theoretical Concept

This section provides an overview of the fundamental concepts and characteristics of 5G technology, highlighting its capabilities, benefits, network architectures, and spectrum considerations.

A. Overview of 5G

The fifth-generation mobile telecommunications technology (5G) adopts several advanced technologies to provide higher data transfer rates, greater network capacity, and better quality of service. 5G networks are anticipated to fulfill the increasing need for consumer data traffic while facilitating the advancement of new services. 5G is precisely engineered to address the demands of rapidly increasing industrial data volume and to support the extensive utilization of mobile communication technologies across diverse industrial domains, such as factory management systems, public security applications, and advanced medical technologies.

B. Capabilities and Benefits of 5G Compared to 4G

The main objectives of designing 5G telecommunications technology are to achieve very high data transfer rates (1–10 Gbps), very low latency (below 1 ms), efficient cost and energy consumption, network capacity that is up to 1000 times greater than current capacity, broad area coverage through heterogeneous network implementation, and reliable and dependable connectivity. More detailed capabilities and benefits are shown in Fig. 1. These parameters aim to meet service quality expectations in the era of 5G technology, both from the consumer side and to support automation and machine-to-machine communication in the industrial sector.

5G networks represent a significant leap forward in wireless technology, enabling substantially faster speeds, reduced latency, and increased capacity compared to prior 4G networks. Specifically, peak data rates for 5G download speeds can reach up to 20 Gbps, whereas 4G only supports 1 Gbps, enabling users to download high-definition films in seconds rather than minutes on 4G networks. Furthermore, 5G reduces latency to approximately one millisecond between data transmission and response, representing ten times lower latency than existing 4G network infrastructure. Lower latency will support more immersive, real-time applications ranging from cloud gaming to virtual reality simulations [5].

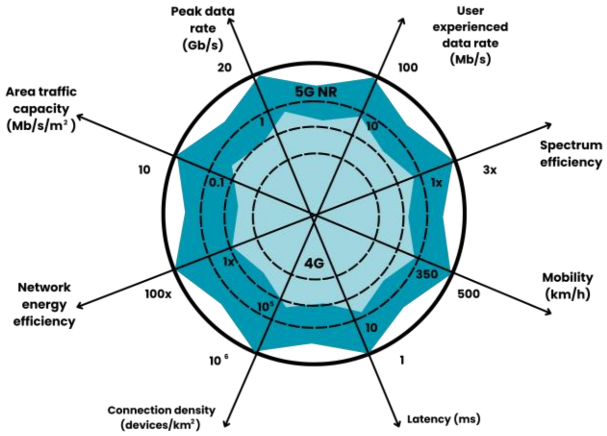

Fig. 1. Capabilities and benefits of 5G [5].

C. Network Architectures and Components of 5G

There are two main deployment options for 5G networks: non-standalone (NSA) and standalone (SA), as shown in Fig. 2. In a 5G NSA architecture, the network consists of 4G radio access technology, a 4G Evolved Packet Core (EPC), and a 5G access layer functioning together. In contrast, 5G SA implements a complete 5G core network in addition to the 5G access layer, facilitating an end-to-end next-generation infrastructure. Although the NSA requires less upfront investment from cellular network operators since it uses the existing 4G EPC, the SA cloud-native 5G core unlocks many 5G use cases, such as highly reliable low-latency communications [6].

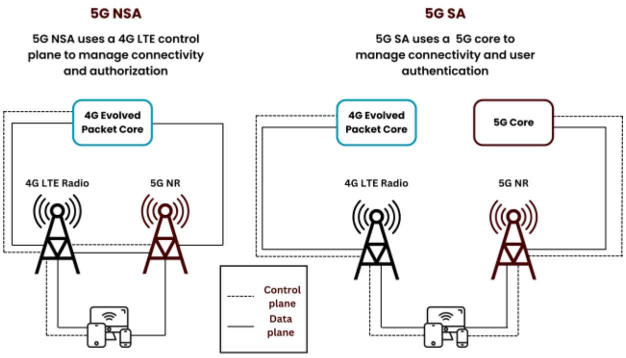

Fig. 2. Network architectures and components of 5G [6].

D. Spectrum Considerations for 5G Deployments

The propagation properties of 5G network frequency bands are divided into low, mid, and high, which exhibit variability and dependency on the operating bandwidth, as shown in Fig. 3. Sub-1 GHz low-band 5G provides extensive coverage despite having limited throughput due to the long propagation distance and in-building penetration. Mid-band 5G (1–6 GHz) provides an optimal balance between coverage and capacity, making deployment in suburban and urban areas possible. Despite its limited range, the 5G high band with 24 GHz or higher provides maximum throughput, suiting densely populated areas with greater user density than the propagation range [7].

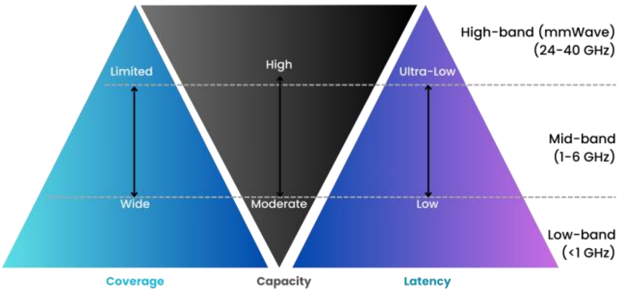

Fig. 3. Spectrum frequency of 5G [7].

E. *Benefits of Allocating 5G Low-Frequency*

Lower frequencies provide superior propagation properties, influencing the signal's range and ability to penetrate structures. Greater path loss gain results in broader cellular coverage and improved indoor penetration. Rural locations benefit from the advantage of cellular coverage since it offers operators extensive coverage over a wide area at a reasonable cost. In metropolitan regions, such as cities, towns, and villages, the sub-1 GHz spectrum is crucial for ensuring indoor coverage in locations not effectively covered by the mid-band spectrum.

High data transfer speed is a crucial factor in 4G. However, the International Telecommunication Union (ITU) envisions 5G to enhance user data speeds tenfold. The availability of a significant amount of sub-1 GHz spectrum is essential for achieving high data rates in urban and indoor areas within cities. This spectrum directly determines the actual data speeds that consumers experience. The proposition to assign supplementary low-frequency spectrum inside the 700 MHz range will enable an extra 2×35 to 2×40 MHz of low-frequency capacity. This corresponds to a speed boost of approximately 30–50% in areas relying solely on low-band spectrum connectivity. Fig. 4 depicts 5G area coverage differences across frequency bands [8].

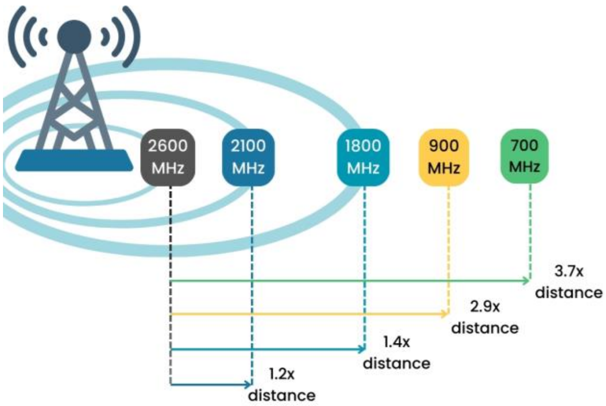

Fig. 4. 5G area coverage differences across frequency bands [8].

III. Research Methodology

This section outlines the comprehensive research framework and methodological approaches employed in this study to evaluate the techno-economic feasibility of deploying a 5G network utilizing the 700 MHz spectrum in the city of Bandung, Indonesia.

A. *Research Framework*

Fig. 5 outlines this paper's 5G network planning research framework. The process begins by gathering relevant data on factors that characterize the geographic area, such as population size, total area, and population density. These metrics inform the conditions of the region. The next step involves developing plans for both capacity and coverage. This entails projecting subscriber growth, estimating traffic demand across the intended coverage zone, determining the capabilities of the technology to be deployed, and defining the business model for 5G network deployment. From there, determinations are made regarding 5G implementation to achieve coverage and capacity. This includes selecting the frequency, modulation, transmitting power, and other technical specifications and calculating cell radius. Following this structured framework, the key inputs, and decisions necessary for effective 5G network design can be systematically analyzed.

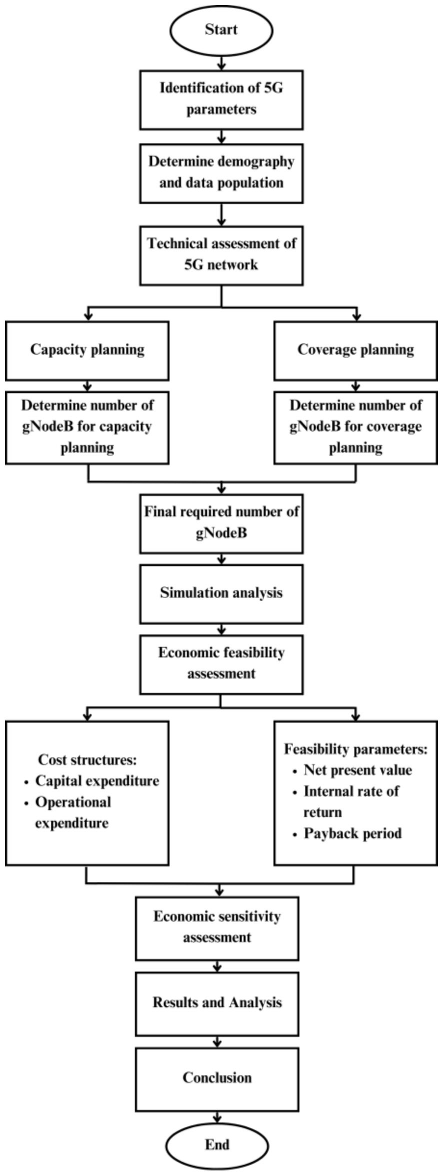

Fig. 5. 5G deployment research framework.

B. 5G Deployment Research Framework

The demographic study of Bandung, Indonesia, aims to map the distribution and traits of the urban populace that the 5G network will serve. A comprehensive examination of the demographics related to 5G includes mapping population density, age distribution, technological literacy, preferences for high-speed data services, and activity patterns relevant to 5G network development.

Fig. 6. Map of Bandung city.

Fig. 6 displays a map of Bandung, a city in Indonesia. Bandung covers an area of approximately 167.31 square kilometers and has a population of 2,503,710 residents, ranking it among the country's most densely populated urban centers. Given its high network density, the Indonesian Ministry of Communication and Information Technology selected Bandung to pilot the introduction of 5G technology. The potential for 5G adoption in Indonesia is significant due to Bandung's large market and existing telecommunication infrastructure. Thus, the city was chosen as the research case study [9].

C. Demand Forecasting Assessment

Forecasting user demand is a crucial parameter that can influence capacity requirements in network design. User demand modeling must be conducted properly so network deployment can be effective. Therefore, this study uses the Bass model to project users/markets for network design. This model was introduced by Bass in 1969 and assumes technology adoption depends not only on internal system influences but also on external influences [10].

The Bass model is a differential equation showing how many firms have adopted an innovation by time t. To calculate user projection and market capacity, we can use the following Eq. (1) [10]:

$$N\,(t) = M\left(\frac{1-e^{-t(p+q)}}{1+\frac{p}{q}e^{-t(p+q)}}\right) \tag{1}$$

where $N\,(t)$ is the number of users who have adopted up to time t. Then, M is the market capacity. Followed by p, which is the innovation coefficient that shows the probability of initial purchase when a new network is deployed. Lastly, $q \geq 0$ is the imitation coefficient, which refers to the group size of future users.

D. Technical Assessment

Coverage and capacity planning in this study involve three key factors: link budget parameters, propagation model selection, antenna usage for the coverage area, and the system's capacity. Trisector antenna deployment is utilized here to improve 5G network reach and quality.

1) Link budget

Link budget calculations can be used to predict the maximum allowable path loss for uplink and downlink communications. The standard path loss propagation equation per 3GPP 38.901 UMa standards is presented in Eq. (2) as follows [7]:

$$\begin{aligned} Link\ Budget = {} & Transmit\ Power \\ & - 10 \times 10log_{10}(Subscriber\ Quantity) \\ & + Antenna\ Gain - Cable\ Loss \\ & - Path\ Loss - Penetration\ Loss \\ & - Foliage\ Loss - Body\ Loss \\ & - Interference\ Margin - \frac{Rain}{Ice} Margin \\ & - Slow\ Fading\ Margin \end{aligned} \tag{2}$$

2) Propagation model

The 5G path loss propagation model differs from previous technologies. 5G utilizes the 3GPP 38,901 standard models covering Urban Macro/dense Urban/suburban (UMA), Rural Macro (RMA), and Urban Micro/Dense Urban (UMI). This study bases propagation modeling on the 3GPP 38,901 standards. The standard UMA LOS propagation model equation per 3GPP 38,901 is shown in Eq. (3) as follows [7]:

$$\begin{aligned} PL_{(UMa-LOS)} = {} & 28 + 30log_{10}(d_{3D}) + 20log_{10}(f_c) - \\ & 9log_{10}[(d'_{BP})^2 + (h_{BS} - h_{UT})^2] \end{aligned} \tag{3}$$

where $PL_{(UMa-LOS)}$ is the path loss. Then, d_{3D} is the distance between the Base Station (BS) and the User Terminal (UT) in meters. d'_{BP} is the breakpoint distance in meters. h_{BS} is the BS antenna height in meters. h_{UT} is the user antenna height in meters. f is the center frequency in Hertz. Then, the values of d'_{BP} and radius coverage of the base station (d_{2D}) can be found using Eqs. (4)–(5) as follows [11]:

$$d'_{BP} = 4\ x\ h'_{BS}\ x\ h'_{UT}\ x\ \frac{f_c}{c} \tag{4}$$

$$d_{2D} = \sqrt{(d_{3D})^2 - (h_{BS} - h_{UT})^2} \tag{5}$$

where c is the speed of light in meters per second, then d_{2D} is the BS-UT distance or cell radius in meters, followed by h'_{BS} which is the BS antenna height minus equipment height in meters, h'_{UT} is the user antenna height minus equipment height in meters, and lastly, f_c is the center frequency in Hertz.

3) Coverage area

Each base station in a cellular system has a different coverage range. To calculate coverage area per site in 5G deployment, a tri-sector approach is used based on Eq. (6) as follows [8]:

$$Coverage\ area = 1.95 \times (d_{2D})^2 \quad (6)$$

By obtaining the coverage area, we can then calculate the number of gNodeB for 5G coverage with Eq. (7) as follows [8]:

$$Number\ of\ gNodeB = \frac{Large\ of\ Area}{Coverage\ Area} \quad (7)$$

where the large area is the total area of the designated area in km^2, and the coverage area is the value of the coverage area in km^2.

4) System capacity

By forecasting user demand and network traffic requirements, network density per km can be determined for deployment across the study area. Traffic demand can be calculated using Eq. (8) as follows [8]:

$$G(t) = \rho \times \frac{8}{N_{dh}\ x\ N_{md}} \times \frac{1}{3600}\ \varphi\ (t) \times D_k \quad (8)$$

where $G(t)$ is the traffic demand projection up to time t. Then, ρ is the user density, which shows the average number of users per area. N_{dh} is the number of busy hours per day when demand is highest. N_{md} is the number of days per month during which demand occurs. $\varphi(t)$ is the percentage of active users in time t , with 100% representing peak traffic demand. D_k is the average demand per month. Then, to calculate the user density ρ, the following Eq. (9) can be utilized [8]:

$$\rho = \frac{P \times T \times M_S}{A} \quad (9)$$

where P represents the total number of potential users. The technology take-up or penetration among the total potential users is shown as T. This refers to what portion or percentage of the total potential users have access to the technology. Lastly, M_s represents the market share of the primary provider in the area.

Cellular system deployments have varying capacities influenced by the number of sites, sectorization, and frequency efficiency. Spectrum efficiency can be calculated using Eq. (10) as follows [12]:

$$C = Bw \times Number\ of\ Site \times Number\ of\ Cell \times Spectrum\ Eff \quad (10)$$

E. Network Planning Simulation

Forsk Atoll is an advanced radio tool that can accurately simulate coverage prediction. When planning coverage, it is crucial to consider the transmitter's power, the receiver's sensitivity, the antenna gain, and other relevant factors. The scope of this study relies on different regional conditions and propagation models on 5G network performance indicators. Specifically, the research will analyze two key signal metrics - Synchronization Signal Reference Signal Received Power (SS-RSRP) and Synchronization Signal Signal-to-Interference Noise Ratio (SS-SINR). The quality categorization of these two parameters is presented in Table I [13].

TABLE I. CATEGORIZATION OF SS-RSRP AND SS-SINRSS

Category	Range for SS-RSRP	Range for SS-SINR
Excellent	Greater than –90 dBm	Greater than 15 dB
Good	–104 to –90 dBm	11 to 15 dB
Fair	–114 to –105 dBm	6 to 10 dB
Poor	Less than equal to –115 dBm	Less than equal to 5 dB

F. Feasibility Assessment

Upon concluding the capacity and coverage planning phases, this research proceeds to economic planning for 5G network deployment. The economic planning methodology undertakes financial modeling to ascertain the cost structures, including Capital Expenditures (Capex) and Operational Expenditures (Opex), associated with implementing the planned 5G architecture. This will be followed by assessing the feasibility metrics such as the net Present Value (NPV), Internal Rate of Return (IRR), and the Payback Period (PBP).

1) Cost structures

The cost structures that are assessed in this paper are the Capex and Opex parameters as follows:

a) Capex

Capex utilizes the multi-year budget allocation. These long-view allotments equip the infrastructure with vital hardware. Examples are the backbone components like routers, switches, and servers. Moreover, system installation and construction require Capex planning. Unlike Opex, these Capex allocations are not completely expended in one fiscal period. Instead, their usefulness stretches across many future cycles. The goal is to avoid obsolete hardware while enabling stable long-term growth [10].

b) Opex

Opex primarily consists of the costs associated with operating, maintaining, and repairing networking infrastructure. A significant portion of an organization's budget is typically allocated to Opex. Opex is an expense deducted from revenue to determine net income or loss for a period. Unlike Capex, which depreciated over time, Opex is fully expensed in the accounting period it was incurred. Opex is considered a recurring cost necessary for the ongoing functioning of the business. Opex's key components include network operations and management expenses, technical support, and administrative overhead [14, 15].

2) Feasibility Metrics

The feasibility metrics that are assessed in this paper are the NPV, IRR, and PBP parameters such as follows:

a) NPV

NPV is the capital budgeting technique used to estimate the profitability of a project by comparing the present value of projected cash inflows to the present value of anticipated cash outflows. Executives utilize NPV analysis to make capital budgeting decisions on funding projects, as it replaces simply looking at cash inflows and outflows to consider the time value of money. A positive NPV indicates the investment is economically worthwhile, while a negative NPV suggests the project may incur losses and thus lack financial justification. The NPV formula used in this research is shown in Eq. (11) [16]:

$$NPV = \frac{\sum_{t=1}^{n} R_t}{(1+r)^n} \tag{11}$$

where R_t is the projected periodic net cash flow, r is the required rate of return, and t is the project's duration.

b) IRR

IRR is the discount rate resulting in a net present value of zero for a project's expected cash flows. This calculated rate represents the projected rate of return for the project. Companies often have a target IRR threshold, approving projects that meet or exceed it and rejecting those that fall below it. IRR can be estimated mathematically using a project's cash inflows and outflows over time. The IRR calculation is presented in Eq. (12) as follows [16]:

$$IRR = r_a + \frac{NPV_a}{NPV_a - NPV_b} \times (r_b - r_a) \tag{12}$$

where r_a is the lower discount rate, r_b is the higher discount rate, NPV_a is the NPV at r_a, and NPV_b is the NPV at r_b.

c) PBP

The PBP technique evaluates the time required for a project to generate sufficient cash flows to recover its initial investment. It is based on the principle that a project needs to pay back the capital invested in it over an acceptable time frame. Companies can use predetermined PBP thresholds to decide whether to accept or reject proposed projects; those that meet the target payback period may be approved, while ones that take too long to recoup costs may be rejected [16].

Table II presents the summary categorization of feasibility parameters. The table summarizes the feasibility parameters into different categories. These categorized feasibility parameters allow for an overview of the feasibility analysis [15, 16].

TABLE II. CATEGORIZATION OF FEASIBILITY PARAMETERS

NPV		IRR		PBP		Category
≥ 0	F	≥ 15%	F	≥ 5 Years	F	Feasible (F)
< 0	N	> 15%	N	> 5 Years	N	Not Feasible (N)

G. Sensitivity Assessment

After obtaining the feasibility study analysis, the next step is to understand the sensitivity of factors or parameters that influence it through sensitivity analysis. This analysis aims to show the influence of variables and the assumed values of several business feasibility factors and parameters. Subsequently, how these factors affect the acceptability of an investment alternative will be observed. This research will examine the effects of increasing the number of 5G users, the number of gNodeBs, and investment costs. Table III presents this paper's sensitivity assessment [17].

TABLE III. CATEGORIZATION OF SENSITIVITY PARAMETERS

Scenario	Changes Made to Parameters
Pessimistic	−10% from baseline
Baseline	No changes
Optimistic	+10% from baseline

IV. RESULT AND DISCUSSION

This section presents the findings and analysis derived from the demand forecasting, technical assessments, network simulations, feasibility evaluations, and sensitivity analyses conducted in this study.

A. Demand Forecasting Analysis

Demand forecasting is a crucial initial parameter in determining the calculations and results in the assessment and economic assessment techniques related to the 5G network deployment plan. Demand calculations are carried out by considering population data in the year before deployment to facilitate prediction of the number of users in the future. A comprehensive analysis of 5G network deployment needs to be done within a sufficient period; in this paper, we utilized a data range of six years, from 2021 to 2026, to see the demand growth trend. This demand forecast calculation uses the bass model formula in Eq. (1). Thus, the calculation of demand forecasting for the next five years is shown in Table IV.

TABLE IV. DEMAND FORECASTING FOR 5G 700 MHZ

City	Bandung
Initial demand projections	2,582,148
N (1)-2021	80,469
N (2)-2022	187,668
N (3)-2023	326,520
N (4)-2024	499,972
N (5)-2025	707,098
N (6)-2026	941,523

In developing countries with high population growth rates and demand for data services, projections of future 5G users are expected to increase significantly from year to year. This can be seen in the illustrative diagram of 5G user projections in particular developing countries. Fig. 7 illustrates 5G network user projections in developing countries with high population growth rates. Based on the illustration, the increase in demand each year is very significant.

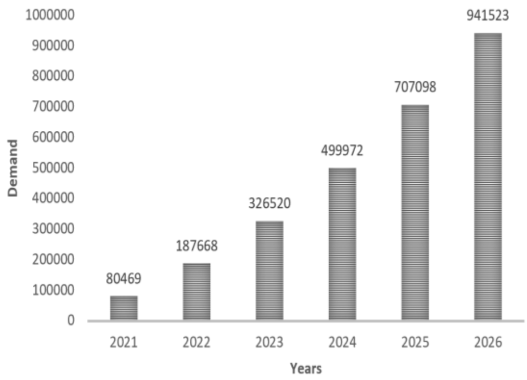

Fig. 7. 5G users' demand forecasting.

B. Technical Assessment Analysis

The main objective of this technical analysis of 5G network design is to estimate the number of gNodeBs required. The technical design uses commonly used network planning methods, namely design analysis based on capacity planning and coverage planning. Capacity planning ensures that network capacity can accommodate projected future traffic demand. Coverage planning aims to ensure that 5G signals can cover the planned service area according to minimum service quality standards.

C. Coverage Analysis

The coverage calculation is based on the link budget calculation and utilizes the maximum coverage of each gNodeB. The number of gNodeBs required is determined based on the coverage distance of each gNodeB. The key parameters supporting the coverage design analysis are shown in Table V. The key parameters include base station transmit power, antenna gain, propagation losses, signal reception threshold, and fade margin.

TABLE V. KEY PARAMETERS FOR COVERAGE ANALYSIS

Link Budget		
Parameters	UL	DL
Subcarrier Space (kHz)	30	30
Channel Bandwidth (MHz)	100	100
gNodeB Transmitter		
Max Power gNodeB (dBm)	23	53.8
gNodeB Body Block Loss (dB)	3	0
gNodeB Antenna Gain (dBi)	2	10
User Equipment Receiver (Rx)		
High User Equipment (m)	1.5	1.5
Rx Cable Loss (dB)	0	0
Interference Margin (dB)	2	6
Slow Fading Margin (dB)	7	7
Path Loss Propagation Model		
Path Loss (dB)	105.1	114.41
Break Point (m)	560	560
Height of User Equipment (m)	1	1
Height of gNodeB (m)	25	25

The path loss and coverage area calculations and analyses can be carried out after the link budget parameters have been obtained. We utilized the 3GPP Release 15 (38.901) propagation model to ascertain the quantity of gNodeBs needed for this investigation. A coverage area radius of 1.18 km^2 for the uplink and 3.45 km^2 for the downlink was determined by calculating the link budget and propagation path attenuation. In addition, the needed number of gNodeBs and the results of the calculations for coverage area planning are displayed in Table VI.

TABLE VI. NUMBER GNODEB FOR COVERAGE ANALYSIS

Number of gNodeB		
Parameters	UL	DL
Area (km2)	167.31	167.31
Cell Radius (m)	779.68	1333.89
Coverage Area (km2)	1.18	3.45
Number of gNodeB	142	43

D. Capacity Analysis

User and traffic demand data is required to obtain the number of gNodeBs in the capacity design. Hence, this analysis begins with calculating the demand in the design area, which has been previously calculated in demand forecasting. Several key parameters are used to perform calculations and analysis. These parameters are shown in Table VII.

TABLE VII. KEY PARAMETERS FOR CAPACITY ANALYSIS

Parameters	**Uplink**	**Downlink**
Subject Area	Outdoor	Outdoor
Sectors Area	3	3
Center Frequency (MHz)	700	700
BW (MHz)	100	100
Monthly Demand (GB)	100	100
Market Penetration (%)	45	45
Surface area	167.31 km^2	167.31 km^2
Population Density	2,652,960	2,652,960

In the traffic demand calculation, population density, market penetration, and service demand significantly impact the final result of the estimated gNodeB requirements for capacity analysis. Based on the traffic demand calculation results in the planning area, a high monthly traffic demand of 2.8 Gbps/km^2 is obtained. Hence, the number of base stations (gNodeB) required to meet future traffic demand can be estimated. The analysis results show that 30 gNodeBs are necessary for this 5G network planning area of 167.31 km^2, as shown in Table VIII.

TABLE VIII. NUMBER GNODEB FOR CAPACITY ANALYSIS

Parameters	**Uplink**	**Downlink**
Avg- capacity system	2.81 Gbps	10, 35 Gbps
Traffic demand	2.18 Gbps/km^2	2.18 Gbps/km^2
Surface area	167.31 km^2	167.31 km^2
Number of gNodeB	130	54

E. Final Required gNodeB

Thus, the results of a comprehensive technical analysis of 5G design in capacity and coverage can be used as a reference for optimal 5G network design, especially in determining the number of base stations and locations since we have obtained the estimated number of gNodeB to determine this study's final total gNodeB requirement. Consequently, the maximum number of gNodeB from each planning approach will be used.

From the calculation results, 130 gNodeBs are required based on capacity planning and 142 gNodeBs based on coverage area planning. After both are compared, the highest number of gNodeBs, namely 142 sites, will be selected as the estimated total gNodeB requirement in this study. The selection of the highest number of gNodeBs from these two planning approaches aims to ensure that the optimal traffic capacity and coverage area can be met according to the design parameters set previously. Thus, the results of this technical simulation can be used as a reference for a comprehensive 5G network design in terms of capacity and coverage.

F. Network Simulation Analysis

This study will validate the 5G NR network design by simulating the network using the Atoll software after comparing the findings of the capacity and coverage area analysis's calculations of gNodeB requirements. This simulation examines how the quantity and placement of gNodeBs impact the 5G design area's signal strength (SS-SINR) and quality (SS-RSRP). The ability to precisely model 5G network performance and signal propagation in Atoll software led to its selection for deployment in field trials. After 142 gNodeBs were simulated in the design area using Atoll, the results can be seen in Fig. 8.

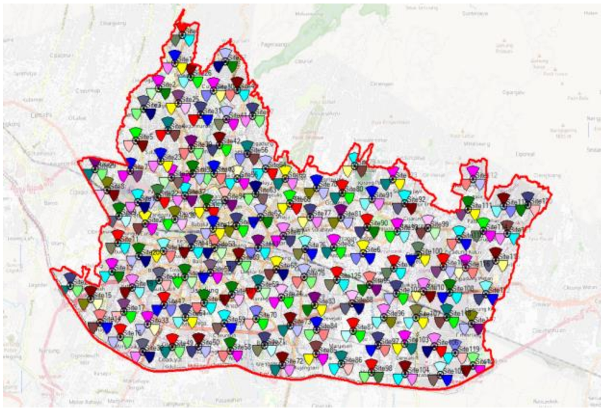

Fig. 8. Design planning result.

1) SS-RSRP results analysis

The SS-RSRP parameter histogram results from the Forsk Atoll simulation are shown in Fig. 9. The SS-RSRP values range from –140 dBm to –60 dBm, with an average of –92 dBm based on the simulation and are considered good SS-RSRP characteristics. The region farthest from the gNodeB transmitting antenna has the lowest SS-RSRP value, indicating poor signal reception due to the distance. The SS-RSRP results, however, meet the design requirements for the given simulation parameters.

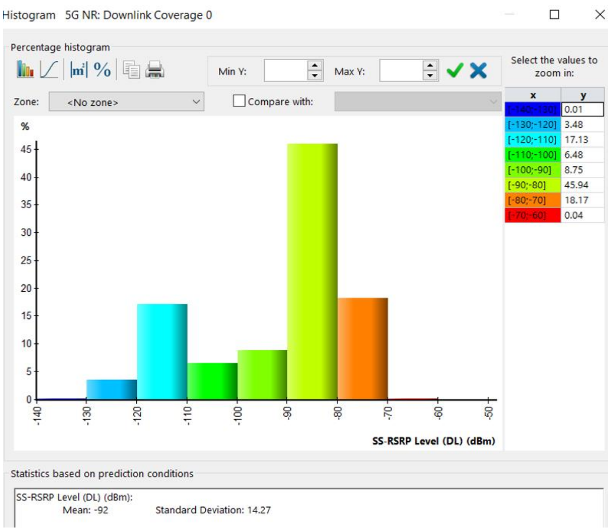

Fig. 9. Histogram of SS-RSRP.

2) SS-SINR results analysis

The simulation yields an average value of 9.21 dB for this parameter, with a possible range of –5 dB to 35 dB. Fig. 10 shows that regions with SS-SINR values between –5 dB and 0 dB are deemed to have fair SS-SINR characteristics. This is because topographical factors and building density hinder signal propagation to users. The average SS-SINR value is within the satisfactory range. To ensure that service quality standards are consistently satisfied, optimizing the placement of gNodeB in locations with low SS-SINR values is necessary.

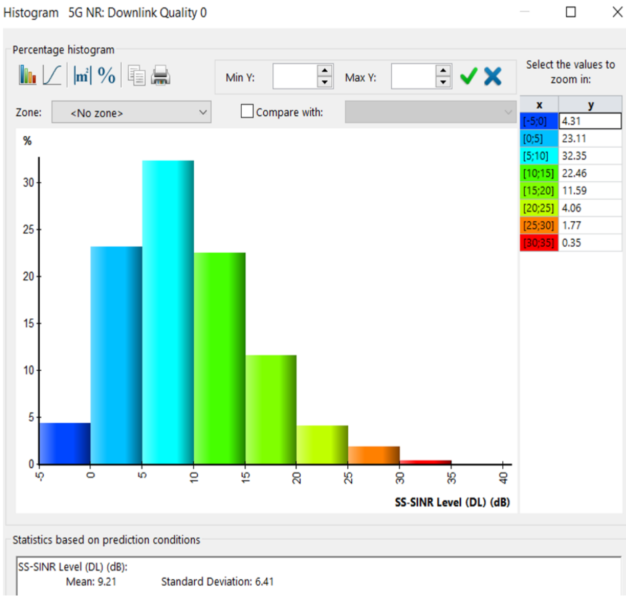

Fig. 10. Histogram of SS-SINR.

G. Feasibility Assessment Analysis

The main objective of this economic analysis on 5G network design is to evaluate the feasibility based on the economic scenario in developing countries. The economic feasibility of 5G technology is assessed through several quantitative indicators, such as capital and operating cost structures and investment feasibility parameters. In this study, the economic calculation parameters refer to field and reference data from one of the operators in Indonesia by considering location-specific conditions. The key parameters are shown in Table IX and X.

TABLE IX. CAPEX KEY PARAMETERS

Capex Parameters	Value
Base Band Unit (UMPT, UBBP)	$ 1,578,834.53
RRU Module, 3 Sector	$ 253,806.81
Antenna Sectoral (macro)	$ 460,657.49
Combiner (3 pcs)	$ 192,387.10
Additional Rectifier	$ 30,232.26
Supporting Material Installation	$ 13,741.94
Installation Fee	$ 37,561.29
Installation Equipment (inc. non-technical components)	$ 109,289.32
Software and License	$ 65,961.29

TABLE X. OPEX KEY PARAMETERS

Opex Parameters	Value
Power Consumption	$ 415,197.04
Transport Fee of gNodeB Optic	$ 7,942,995.67
Consumable Part	$ 11,611.83
Operational & Maintenance (10% CAPEX)	$ 87,948.39
Additional O&M per Year (5% CAPEX)	$ 18,322.58
Marketing and Advertising (10.7% Revenue)	$ 7,493,757.29
Spectrum License	$ 329,462.29

3) Cost structure results

Capex and Opex form the cost structure of technology investment. This research comprehensively maps the Capex and Opex parameters for 5G network deployment in Bandung as the urban area case study for 5G network support areas. The Capex parameters were initiated at the beginning of the year based on the results from the gNodeB in coverage planning. Unlike Capex, Opex parameters were initiated yearly since they include the company's yearly subscriptions and payments. Capex and Opex results for 5G networks are shown in Table XI

TABLE XI. CAPEX KEY PARAMETERS

Year	Year-N	Opex	Capex
2022	0	$ 7,942,995.67	$ 1,578,834.53
2023	1	$ 8,537,185.68	–
2024	2	$ 9,043,287.79	–
2025	3	$ 9,675,503.54	–
2026	4	$ 10,430,457.77	–
2027	5	$ 11,936,025.09	–

4) Economic feasibility results

The design of 5G networks is considered feasible to implement. The economic feasibility analysis of 5G implementation in urban areas shows that the Indonesian government can realize the investment in the future. The feasibility analysis examined the financial parameters of NPV, IRR, and PBP. The full results of the economic feasibility analysis are shown in Table XII.

TABLE XII. FEASIBILITY PARAMETERS' RESULTS

Feasibility indicator	Value	Result
NPV	$11,874,190.03	Feasible
IRR	33,09%	Feasible
PBP	3 years	Feasible

a) Net Present Value (NPV) analysis

NPV is the difference between cash inflows' present value and cash outflows' present value over the investment period. An investment project is declared financially feasible if it has a positive NPV and not feasible if it has a negative NPV. Therefore, the NPV value is one of the critical parameters used to evaluate the feasibility of a project or business from a financial perspective. Based on the results, the NPV of $11,874,190.03 indicates a positive net financial benefit, making the 5G investment economically viable. The NPV calculation with a discount rate of 15% resulted in an NPV value of $11,874,190.03 for 5G network investment in the urban area of Bandung City. This positive NPV indicates that the present value of future cash inflows exceeds the present value of investment expenditures.

b) The IRR analysis

The IRR analysis shown in Fig. 11 shows that the calculated IRR value of 33.09% exceeds the discount rate set as the minimum acceptable rate of return for this investment. Since the IRR is higher than the discount rate, it indicates that the 5G investment is projected to generate financially adequate and viable returns based on the analysis's assumptions.

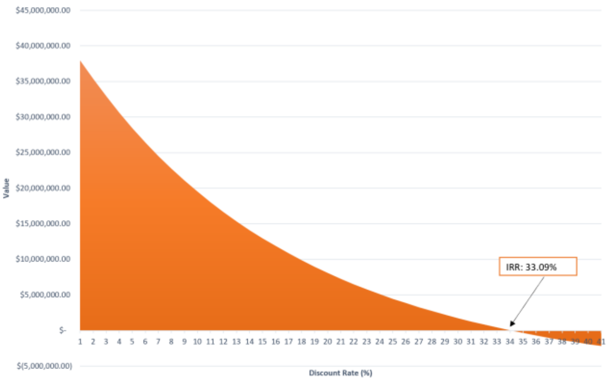

Fig. 11. Diagram of IRR results.

c) The Payback Period (PBP) analysis

The PBP analysis shown in Fig. 12 reveals a break-even point of three years, indicating a short and favorable investment payback period compared to the project's overall economic life. To determine these values, the analysis considers initial investment costs, projected revenue, and operating expenses over time. By the fifth-year, the cumulative net cash flow of the project is estimated to reach approximately $44 million. This significant positive cash flow suggests that the project generates substantial returns after recovering the initial investments.

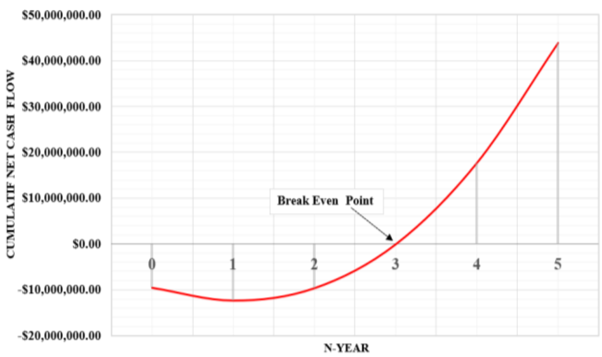

Fig. 12. Diagram of PBP results.

H. Sensitivity Assessment Analysis

This research employs sensitivity analysis to determine which factors influence project viability within anticipated parameter ranges. The study provides validation of each parameter through analysis against a defined deployment scenario for rolling out 5G technology utilizing the 700 MHz frequency band with 100 MHz of bandwidth in the city of Bandung. This study investigates: (i) Capex, (ii) the number of subscribers, (iii) the number of gNodeB, (iv) costs for marketing, (v) average revenue per user, and (vi) costs for operation and maintenance. These parameters are modeled under three scenarios, namely: (i) baseline values with no change, (ii) optimistic above baseline (+10%), and (iii) pessimistic below baseline (–10%). Through this approach, the sensitivity analysis identifies the key factors impacting the feasibility of the 5G deployment. Fig. 13 shows the sensitivity parameters assessment analysis.

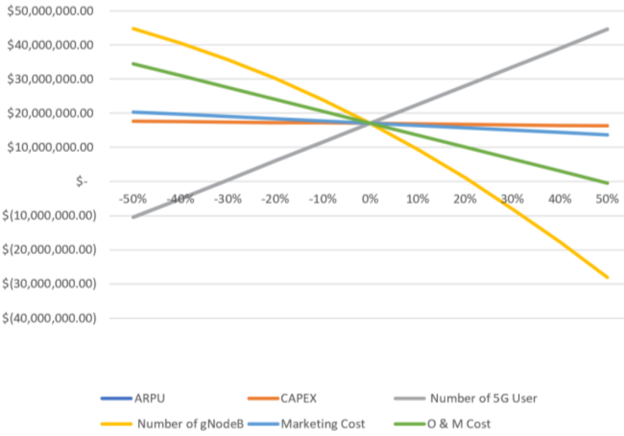

Fig. 13. Sensitivity parameters assessment analysis.

Based on the sensitivity analysis results, it was shown that the number of gNodeB base stations has the highest impact on the feasibility of implementing 5G at 700 MHz with 100 MHz of bandwidth in Bandung. The number of projected 5G users ranks as the second most impactful parameter. Operational and maintenance costs have the third highest influence on the viability of this modeled deployment scenario. Capex follows as the fourth most impactful factor. Finally, the ARPU and marketing costs have the lowest impact on the sensitivity assessment analysis.

V. Conclusions

The results of this study provide valuable insights into the feasibility and optimal planning considerations for deploying 5G networks in the 700 MHz band across urban areas of emerging countries. The technical analysis for Bandung City shows 142 gNodeB base stations are required to achieve adequate coverage and capacity based on projected demand growth to 941,523 users by 2026. Network simulations demonstrate that the 700 MHz spectrum can deliver good 5G signal quality across Bandung's dense urban terrain with an average SS-RSRP of -92 dBm and SS-SINR of 9.21 dB. The economic assessment indicates positive returns for telecom operators with an NPV of $11.9 million, IRR of 33.09%, and payback period of 3 years. However, substantial upfront investments of $2.7 million per gNodeB site are needed to fund this extensive infrastructure build-out. The sensitivity analysis indicates that the most impactful parameters are the number of gNodeB base stations, the number of 5G subscribers, and operational and maintenance costs. These findings suggest that with careful planning, the 700 MHz band can accelerate 5G adoption in emerging countries, helping bridge the digital divide. Future work could explore standalone architectures, utilizing higher frequency bands, partnerships to share infrastructure costs, and examining how the proposed 5G NSA deployment would react to interference and support low-latency communications.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Muhammad Imam Nashiruddin is responsible for the overall research project's conceptualization, planning, and execution, including research supervision, writing original draft reviews, editing, and funding acquisition. Muhammad Adam Nugraha calculated the 5G network capacity and coverage area. Using Atoll software, Putri Rahmawati simulated capacity and coverage design results and economic feasibility analysis. Lastly, Deni Suherman helps to provide resources and review the manuscript; all authors had approved the final version.

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