Urban 5G NR Deployment: A Techno-Economic Case Study in Semarang

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Abstract— The deployment of 5G networks in provincial capitals such as Semarang presents challenges related to high user demand, coverage requirements, and investment costs. This research aims to evaluate the network coverage and techno-economic feasibility of 5G implementation in Semarang. Using an urban macro propagation model, two scenarios were analysed: Uplink Non-Line-of-Sight (UL-NLOS) and Downlink Non-Line-of-Sight (DL-NLOS). The UL-NLOS scenario requires 11 sites, while the DL-NLOS scenario requires 6 sites to achieve full coverage of the city. The average Synchronization Signal–Reference Signal Received Power (SS-RSRP) is −125.74 dBm, indicating sufficient signal strength. A techno-economic analysis reveals that the UL-NLOS scheme yields an NPV of IDR 292.566.473.678 with an IRR of 110.25%, while the DL-NLOS scheme yields an NPV of IDR 300.000.000.000 with an IRR of 115.38%. These results confirm that both scenarios are technically feasible and economically viable. The findings suggest that 5G deployment in Semarang can yield profitable returns, providing valuable insights for mobile operators in planning future investments.

Keywords— ***Cellular Network, Downlink-NLOS, New Radio-5G, Techno economics, Uplink-NLOS.***

I. INTRODUCTION

The emergence of 5th generation cellular technology, namely 5G New Radio (NR) mobile communications, that provide services and applications, are mapped into 3 usage scenarios, namely enhanced Mobile Broadband (eMBB), Ultra-Reliable and Low Latency Communications (URLLC), Massive Machine Type-Communication (mMTC) where this vision is widely applied to the field of Internet of Things (IoT) [1]. In Indonesia, according to the Director General of Resources for Post and Information Technology (SDPPI) of the Ministry of Communications and Information Technology, Indonesia has three frequency candidates of 3.5 GHz, 26 GHz, and 28 GHz, in the development of New Radio 5G technology will provide better network services than before on 4G LTE [2].

In Indonesia, according to Dirjen Sumber Daya Penyelenggara Pos dan Informatika (SDPPI) of the Ministry of Communication and Information Technology, Indonesia has three frequency candidates of 2.6 GHz, 2.8 GHz, and 3.5 GHz, in the development of 5G technology it will provide better network services than before on 4G LTE [3]. Millimeterwave (mmWave) frequency is the largest candidate high frequency that will be implemented in the territory of Indonesia is 2.6 GHz and 2.8 GHz, therefore this network design uses millimeterwave frequency 2.6 GHz which is the lowest mmWave frequency among other mmwave frequency range, where if the higher the frequency used, the greater the investment value [4]. The specific frequency of 2.1 GHz that will be used is the recommended frequency from the Indonesian Ministry of Communication and Information in 2023 [5].

One of the underlying things in the development of telecommunications is the need for data speed. With the development of applications and the emergence of new services, it will automatically increase the need for data speed [6]. The technology that is prepared to support high-speed data transfer is 5G technology [7]. The 5G network will support very fast data rates of up to 10 Gbps and require wider bandwidth compared to existing technologies [8]. The innovation that is ready to help the rapid movement of information is the 5G innovation. 5G organizations will support extremely fast information speeds of up to 10 Gbps and require wider transmission capacity compared to existing advances [9]. One of the cities that is being tested for 5G networks is the provincial capital, Semarang, which is a city with a high economic level and many large companies that help improve the economy in Semarang [10].

Before executing a 5G network, it is essential to conduct a techno-monetary investigation to decide whether the execution of the organization is achievable [11]. Before the implementation of the 5G network, it is necessary to analyze the techno-economics to determine whether or not the network implementation is feasible [12]. Techno analysis is about calculating pathloss to determine of coverage area, number of site and knowing the number of sites needed to cover an area, especially Surabaya [13]. While the economic analysis is to calculate the amount of CAPEX, OPEX and NPV generated from the 5G network implementation to determine the projected feasibility of implementing a network. The research will be analyzed on the use of frequencies at 2.6 GHz using the 3GPP TR 38901 Model [14].

The research [15] "Techno-Economic Analysis of 5G Mm Wave Frequency Network Implementation in South Sumatra Region" examines the techno-financial aspects of 5G organization implementation involving mm wave looping in South Sumatra region. This research, an investigation of 5G network configurations, will be carried out regarding 5G assistance inclusion and from the level of possible monetary tasks, so that this test can be utilised as a source of perspective for telecom administrators when delivering 5G services. In the inclusion arrangement, the proliferation model utilised is the SUI (Stanford University) model recreated at 28 GHz - 38 GHz

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mmWave repeats, which are the most powerful contenders to be utilised as 5G repeat standards. While the financial examination uses CAPEX, OPEX, NPV constraints to break down the awareness.

The research [16] "Techno-monetary Analysis and Prediction for 5G Mobile Network Deployment" that portable organizations of the fourth era (4G) must overcome new difficulties that arise in the interest of versatile traffic and the Internet of Things. Therefore, OMNs (Mobile Network Operators) should want to update 4G to 5G cellular networks by 2020, which is the required year to run 5G. Techno-economic testing using a numerical demonstration approach is considered, and a new valuation model is proposed reliably using versatile broadband development. Two major cost components, specific Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) are determined and analyzed using the required revenue collected in the implementation period. The results show that 5G is highly valuable, not only because of its lower port properties than using 4G LTE but also because of the widespread use of homogeneous information presented by 5G mobile technology and the increasing number of subscribers.

The research [17] total Cost of Ownership (TCO) increases with tower height, with operational cost as the key factor. A single MNO owning a tower is economically unfeasible, as the payback period may exceed 10 years. The analysis found the 40 m tower to be the most cost-effective for 5G, while taller towers (45 m and 60 m) result in higher TCO and poor ROI. Thus, tower height must be carefully considered in 5G deployment planning.

This research analyses the deployment of 5G New Radio (NR) networks in Semarang, Central Java, by examining coverage performance through the Synchronization Signal–Reference Signal Received Power (SS-RSRP) parameter and evaluating the techno-economic feasibility of implementation. The research integrates technical aspects of 5G NR, including spectrum efficiency, coverage planning, and deployment architecture, with economic considerations such as capital and operational expenditures, as well as return on investment. By focusing on a provincial capital rather than a major metropolitan area, this study provides a novel perspective on the realistic and sustainable deployment of 5G NR in Indonesia.

II. Method

Cellular network design is the first step that needs to be done to find out and organise the area to be covered, the number of gadgets that will be connected, and how much traffic will be needed [18]. Cellular network planning in this research based on coverage planning within the 5G system architecture, which includes gNodeB deployment, core network integration, and spectrum utilization, which is seen from the area that will be covered by the design network[19]. Some parameters that affect the design of cellular networks include path loss, radio link budget calculation, sensitivity, transmit power, receive power, and cell radius. Some parameter values are not obtained directly, namely, thermal noise parameters, occupied bandwidth, and RX faded sensitivity [20]. Thermal noise occurs due to the heat effect of a device, so it is calculated using the equation [21].

$$N_{thermal} = 10 \times log\ log\ (K \times T \times B) \quad (1)$$
$$N_{thermal} = 10 \times log\ log\ (1{,}38.10^{-23} \times 293^{0} \times 100)$$

$$N_{thermal} = -183{,}93\ dBm$$

TABLE I. 5G Network Link Budget Parameter Font Size for Article [22]

Parameters	Uplink	Downlink
gNodeB transmitter power (dBm)	49	49
Resource block	273	273
Sucbarrier quantity	3276	3276
gNodeB antenna gain (dBi)	18	18
gNodeB cable loss (dBi)	0	0
Penetration loss (dB)	26.85	26.85
Foliage loss (dB)	19.59	19.59
Body block loss (dB)	3	3
Interference margin (dB)	2	6
Rain/ice margin (dB)	0	0
Slow fading margin (dB)	7	8
UT antenna gain (dB)	0	0
Bandwidth (MHz)	100	100
Boltzmann constant (J/^{0} K)	$1.38.10^{-23}$	$1.38.10^{-23}$
Temperature (Kelvin)	293^0	293^0
Thermal noise power (dBm)	-183.93	-183.93
UT noise figure (dB)	7	7
SINR (dB)	-1.1	-1.1
MAPL (dB)	**151.43**	**147.43**

Description:
K = Boltzmann Constanta ($1.38.10^{-23}$ J/^{0} K)
T = Temperature (293^0K)
B = Bandwidth (Hz)

The flowchart of this research, shown below, explains the 5G techno-economic at Semarang city in Figure 1. The flowchart illustrates the research process, starting from determining the study area, conducting link budget and site analysis, and estimating CAPEX and OPEX. These values are then used to calculate NPV and IRR, which form the basis for the economic analysis of 5G deployment feasibility.

This research uses the 5G network midband frequency of 2.6 GHz, with a bandwidth of 100 MHz and subcarrier spacing of 30 KHz.The 2.6 GHz frequency band was selected due to its favorable propagation characteristics for urban macro (UMa) environments, offering a balance between coverage and capacity. This frequency allows sufficient penetration through buildings while supporting higher data rates compared to lower bands.

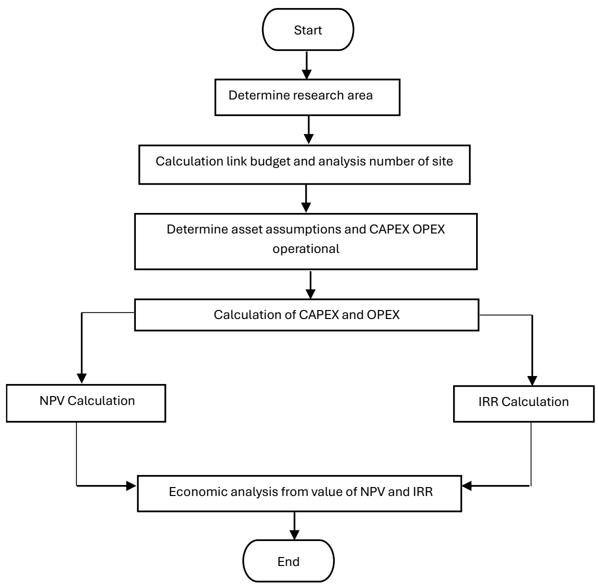


Figure 1. Flowchart 5G investment analysis

From a regulatory perspective, the 2.6 GHz band is allocated for 5G mobile broadband services in Indonesia, making it readily available for deployment without additional licensing constraints. The number of resource blocks (R_B) based on bandwidth and subcarrier spacing is 273. To determine the subcarrier quantity (S_{cq}) with the equation [23]:

$$S_{cq} = R_B \times S_{RB} \quad (2)$$
$$S_{cq} = 273 \times 12 = 3276$$

Description:
S_{cq} = Subcarrier quantity
R_B = Resource Block (273)
S_{RB} = Subcarrier per Resource Block (12)

The propagation parameters were calculated using the Urban Macro (UMa) model by applying path loss and link budget analysis, while simulations were conducted in Atoll to evaluate coverage performance and signal strength under UL-NLOS and DL-NLOS scenarios..Path loss and link budget calculations aim to determine the signal attenuation that occurs between the User Terminal (UT) and gNodeB, so that from these calculations the maximum distance between gNodeB can be determined [24]. The result of this research is the number of sites needed in a determined area, Semarang. Link budget calculation is very necessary in network design, where the link budget calculation can determine how many sites (gNode) are needed with a large area Semarang city. The calculation of the radio link budget is used to determine the Maximum Allowable Pathloss (MAPL) between the antenna and the gNodeB with the UE antenna, to determine the cell radius a propagation model is used, because the design in this study is in an urban area, it uses the Urban Macro (UMa) propagation model Non Line of Sight (NLOS) scenarios with TX height characteristics around 25 meters, RX height 1.5 meters - 2.5 meters and ISD 500 meters with the pathloss equation[16]:

$$PL1 = 22 \; log \, log \, (d3D) \; + 28 + 20 \; log \, log \, (f_c) \quad (3)$$

$$PL2 = 40 \, log \, log \, (d3D) + 28 + \; 20 \; log \, log \, (f_c) \; - 9 \; log \, log \, (d'BP)^2 (hBS - hUT)^2 \quad (4)$$

$$PL'_{NLOS} = 13.54 + 39.08 \, log \, log \, (d3D) + 20 \; log \, log \, (f_c) \; - 0.6(h_{UT} - 1.5) \quad (5)$$

Description:
PL = Pathloss (dBm)
$d3D$ = The resultant of the values ($h'BS - h'UT$)
f_c = Frequency (GHz)
$d'BP$ = Break point distance (m)
hBS = Height gNode (m)
hUT = UT height (m)

This research also analysis the techno-economics of 5G cellular networks in the Semarang city area. Calculation and design of 5G networks require data in the form of frequency, design area, link budget calculation, calculation of OPEX, NPV and IRR values [20]. The 5G cellular network frequency used is 2.6 GHz. In terms of technoeconomic calculations, CAPEX costs include the cost of development hardware details and the cost of implementing new organization components, by and large, the CAPEX effort required includes the acquisition of gNodeB, which is an innovation, 5G New Radio transmission as well as supporting frameworks for example towers, receiving cables to generators as amplifying power. 5G network OPEX cost calculations incorporate worker compensation costs where representatives are expected to work on every movement so that they can produce benefits for the organization, equipment upkeep including power costs and hardware repair costs [25]. In addition, the administration of the board and organization expenses of the executives, for example, the working expenses for the moving organization change, showing the expected expenses for presenting the item. On the part of financial investigation gotten from CAPEX and OPEX examination then it is done by ensuring income examination and the result as NPV, IRR of 5G organization execution in Semarang city will be known whether it is practical through the side effects of NPV and IRR. CAPEX can be determined with the following equation [26]:

$$CAPEX_{Total} = BS_{cost} + BSINST + BHL + SP_{License} \quad (6)$$

Where in this CAPEX estimation, the complete cost of base station construction (BS cost), base station establishment (BS inst), backhaul transmission (BHL) BHL construction cost and recurrence use privileges (BHP) cost will be determined. The equation for calculating OPEX costs is as follows [15]:

$$OPEX_{annual} = OAM_{cost} + MA \quad (7)$$

Description:
$OPEX_{annual}$ = Operational Expenditure
OAM_{cost} = Operating and Maintenance Costs
MA = Marketing and Advertising

The NPV strategy calculates how much the venture's CAPEX and OPEX support costs are, with the total all-in compensation that an organization's delivery gets. In calculating the Net Present Value (NPV), it considers the value of bank financing costs that are considered relevant to estimate the sustainable value. This NPV value is used to decide whether the speculated value of the task is worthwhile or not. If the NPV value is positive (+), the venture is profitable and the task can be completed, while if the NPV is negative (-), the venture is unprofitable or discontinued to calculate the present value, a significant levy must be settled equivalent to now [27].

$$NPV = \sum_{t=1}^{n} CFt \; (1 + K)t = \; I_o \quad (8)$$

Description:
t = Number of years
Cft = cash flow period t
Io = year 0 investment
K = interest rate.

Internal Rate of Return (IRR) is a technique for finding the cost of borrowing where the present value of future normalised income or money receipts is equivalent to the underlying business consumption and labour costs. IRR can be determined by the recipe in the condition below[8].

$$I_o = \sum_{t=1}^{n} \frac{Cft}{(1 + IRR)^t} \quad (9)$$

Description
t = Year to
n = Number of years

Io = Initial investment value
CF = Net cash flow
IRR = Interest rate sought

The selection of NPV and IRR as financial indicators allows the analysis to link technical deployment outcomes with economic feasibility. As the number of 5G users is expected to grow steadily over the next decade, these metrics provide a clear understanding of how user growth translates into revenue generation and ultimately investment returns.

III. Results and Discussion

In determining the cell radius (d_{2D}) it is necessary to know the distance between the transmitter and receiver, calculated from the UMa prop model to determine the cell radius (d_{2D}). From the cell radius, this research using three-sector coverage [28].

$$C_A = 1{,}95 \times 2{,}6 \times d^2 \quad (10)$$

For the number of sites needed in an area, the total planning area is divided by the coverage area of the gNode [4].

$$N_{gnodeB} = {}^{Planed\ area}/_{covarega\ area} \quad (11)$$

A. Analysis of link budget planning by coverage area

The result of the link budget calculation is the number of gNodes needed in the Semarang area. Semarang City has an area of 373.7 km^2. The results of uplink and downlink MAPL calculations are used in determining the Urban Macro (UMa) propagation model. The MAPL value used is large because the number of sites needed is more and the cell radius value or the distance between the gNode and the User Terminal (UT) is obtained as small as possible so that all areas can be covered by the 5G network [29] .

Coverage network planning is used to estimate the maximum attenuation that occurs between the UT and the gNodeB, so that it can be known that the device can work optimally at a certain radius to be able to serve users [30].This attenuation is commonly called Pathloss. Pathloss values are calculated both uplink and downlink. Coverage calculations consider the loss that occurs between the gNodeB device and the UT device, in performing the calculation, link budget data is needed which shows the parameters used by the UT and gNodeB.

Table II is the result link budget for scenario 1 (downlink O2O - NLOS) with coverage area 73633836.69 m^2 requires 6 sites and scenario 2 (uplink O2O - NLOS) with covergage area 39972198.72 m^2 requires 11 sites. The application of the number of gNode carried out for coverage simulation is the most sites, namely scenario 2 (uplink O2O - NLOS) so that all areas of Semarang city get 5G network signals.

B. 5G Network Coverage Simulation

Synchronization Signal - Reference Signal Received Power (SS-RSRP) parameter is a 5G parameter used to see the signal power received within the specified coverage area. In an area of 373.7 km^2 in the city of Semarang, the value of SS-RSRP shows the navy colour category, having the greatest or very good signal power or strength, and the black colour symbolisesthe condition with the weakest signal strength or even no signal.

Table III is the colour range of the SS-RSRP parameter used in the simulation of the 5G network. Simulation of 5G network implementation in Semarang city is adjusted to the results of the link budget calculation using 11 gNode, each site consists of 3 sectors and a frequency of 2.6 GHz.

Figure 2 shows the results of the application of the 5G network in the city of Semarang, which is dominated by navy and green colors near the gNode, which shows that the area closest to the gNodeB gets a very good signal strength and the farthest to the gNode gets a weak or very bad signal strength. The simulation results of the application of the 5G network in the city of Semarang show that all areas of the city of Semarang are well served, which is indicated that there are no areas that are not served, meaning that all areas get the 5G network.

The results of the application of the 5G network in the city of Semarang are shown in the histogram Figure 2 showing the mean value of the SS-RSRP parameter of -125.74 dBm including the category enough all areas in the city of Semarang have received 5G network services. Histogram of SS-RSRP parameter results with the x-axis (horizontal) is the range of SS-RSRP values (dBm) and the y-axis (vertical) is the area served by the 5G network (km^2). Signal strength values in the range of -117 to -110 dBm serve an area of 49 km^2 which is a large area served by 5G networks and in the range of -81.8 to -74.9 dBm is a stronger signal strength category but only serves the smallest area of only 5 km^2 . These results show that the 5G network can be applied in the city of Semarang because all areas of the city of Semarang are already served by the 5G network even though they do not have a strong signal strength, so 5G network optimization is needed in the city of Semarang.

TABLE II. Link Budget Result for Coverage Estimation in Semarang

Comment Parameter	Scenario 1: *Downlink* O2O - NLOS	Scenario 2: *Uplink* O2O - NLOS
Thermal Noise (dBm)	-183.93	-159.16
Subcarrier Quantity	3276	936
Pathloss	151,43	147,43
h'BS(m)	24	24
h'UT(m)	0.5	0.5
d'BP (m)	416	416
d3D (m)	5330.07	3291.03
d2D/Cell *Radius* (m)	5330.02	3290.96
Coverage Area (m)^2	738633836.69	39972198.72
Number of gNode	**6 *gNode***	**11 *gNode***

TABLE III. Defined Color Ranges of SS-RSRP for Visualizing 5G Signal Coverage [4]

Signal Strength	Color	SS-RSRP Value (dBm)
Very good		RSRP >-80
Good		-90 =< RSRP < -80
Good enough		-100 =< RSRP < -90
Simply		-105 =< RSRP < -100
Bad enough		-110 =< RSRP < -105
Bad		-116 =< RSRP < -110
Very bad		-120 =< RSRP < -116
No signal		RSRP < -120

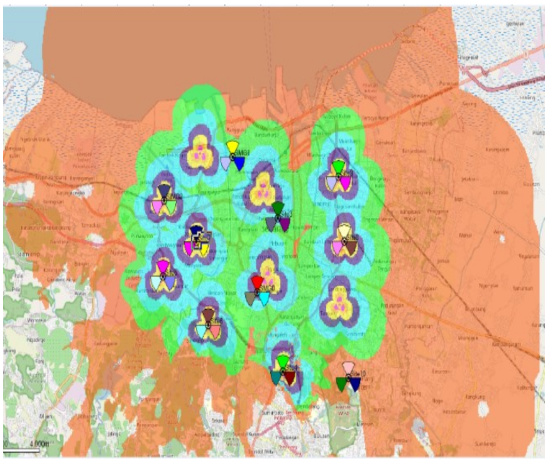


Figure 2. Simulation results of 5G network deployment in Semarang city

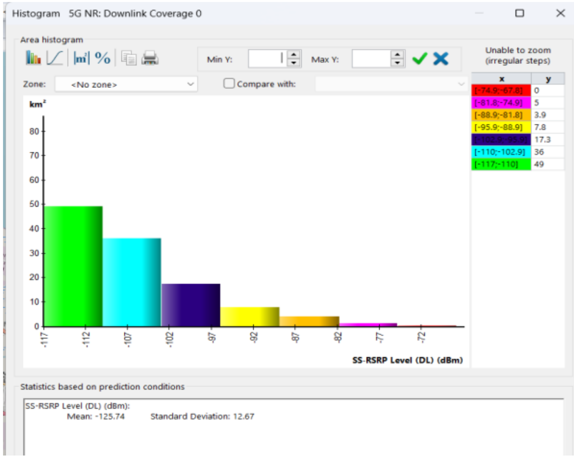


Figure 3. Histogram of SS-RSRP parameters

C. Population Density of Semarang

The traffic prediction value requires a time and a constant (rate of growth) using the following equation [13] :

$$Pt = Po(1 + r)t \tag{12}$$

Description:
Pt: *Traffic Prediction*
t : *Time*
r : *Constant* (*Rate of Growth*) (0.0029)

Table IV shows the traffic prediction of Semarang city for the next ten years from 2023 to 2033. To determine the assumptions of cellular users in the city of Semarang for the next ten years using the components of cellular penetration, 5G PT penetration, 5G usage penetration and population [24].

$$User\ 5G\ (2023) = cellular\ penetration \times 5G\ PT \times penetration \times 5G\ usage\ penetration \times population = 0{,}67 \times 0{,}5 \times 0{,}72 \times 1.694.743 = 408.772$$

Table V shows the assumed number of cellular network users in Semarang city for the next ten years from 2023 to 2033. The assumed value of 5G users is used to determine the prediction of the number of subscribers based on the optimistic scenario cost benefit analysis.

TABLE IV. TRAFFIC PREDICTION SEMARANG (2023-2033)

Year	T	R	*Traffic Prediction*
2023	0	0.0029	1.694.743
2024	1	0.0029	1.699.657
2025	2	0.0029	1.704.586
2026	3	0.0029	1.709.529
2027	4	0.0029	1.714.486
2028	5	0.0029	1.719.458
2029	6	0.0029	1.724.444
2030	7	0.0029	1.774.452
2031	8	0.0029	1.825.911
2032	9	0.0029	1.878.862
2033	10	0.0029	1.933.348

TABLE V. PREDICTED NUMBER OF5G SUBSCRIBER OVER 10 YEAR

Year	Mobile Penetration	5GPT X *Penetration*	5G *Usage Penetration*	Total Population	5G *Users*
2023	0.67	0.5	0.72	1.694.743	408.772
2024	0.67	0.5	0.72	1.699.657	409.957
2025	0.67	0.5	0.72	1.704.586	411.146
2026	0.67	0.5	0.72	1.709.529	412.338
2027	0.67	0.5	0.72	1.714.486	413.534
2028	0.67	0.5	0.72	1.719.458	414.733
2029	0.67	0.5	0.72	1.724.444	415.935
2030	0.67	0.5	0.72	1.774.452	427.997
2031	0.67	0.5	0.72	1.825.911	440.409
2032	0.67	0.5	0.72	1.878.862	453.181
2033	0.67	0.5	0.72	1.933.348	466.323

D. Analysis of Cost Benefit

Cost benefit presents techno-economic modeling scenarios by utilizing several scenarios using technical calculations to find the number of sites required with outdoor-to-outdoor scenarios based on NLOS uplink and downlink. To predict the 5G network before its launch, the Bass model parameters have been reparameterized. S-shape parameters to find out the positive/favorable NPV and IRR output findings, the value of v was chosen for 95% penetration (v=95%) at typical duration (time to reach market penetration level measured from ts).

The research will cover both technical and cost benefit elements, with an emphasis on how they relate to each other. The cost benefit aspects include OPEX, and NPV. OPEX refers to the costs incurred while the network is in use. NPV can be calculated after obtaining OPEX data to determine whether it is feasible to build a 5G network in the Semarang city area.

This research analyzes the cost benefit of the optimistic scenario. In the optimistic scenario cost benefit calculates the value of OPEX and NPV to determine the next 10 years. Annual revenue at an operator is calculated by multiplying Average Revenue per User (ARPU) by the number of subscribers of year revenue output from OPEX input value which calculates the amount to get revenue income from the projected number of subscribers.

Figure 4 shows the revenue projection of Semarang city from 2023 to 2033 which continues to increase, with an average growth of 40%. As 5G technology is introduced and marketed, there is an increase every year.

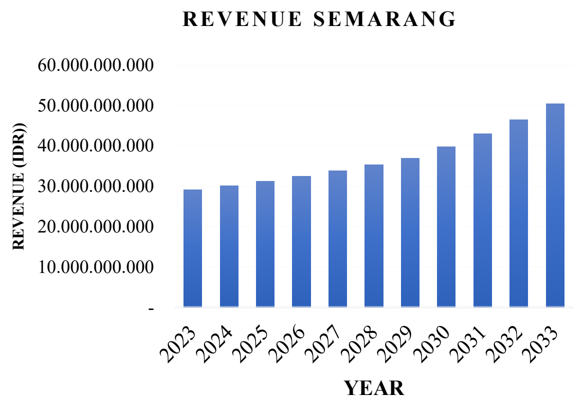


Figure 4. Semarang City Revenue

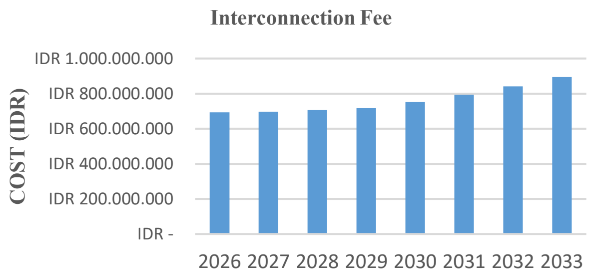
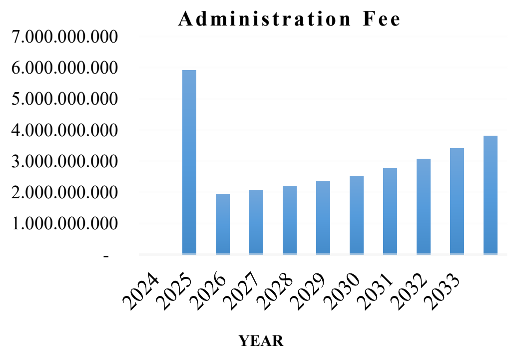


Figure 5. Semarang City Interconnection Cost



. Figure 6. Semarang City Administrative Cost

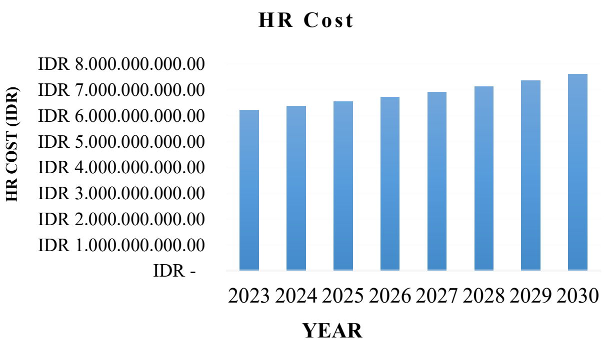


Figure 7. Semarang City Human Resource Cost

Figure 5 shows the estimated operational cost of interconnection starting from 2026 of IDR 700.000 it should be noted that the growth in the value of interconnection each year does not experience significant changes.

Figure 6 shows the projected administrative costs of Semarang city in 2025 reaching IDR 6.000.000.000.000 because the beginning of the 5G network implementation requires a lot of administrative costs compared to the following years, but after marketing the following years the operational expenses for administration do not jump high.

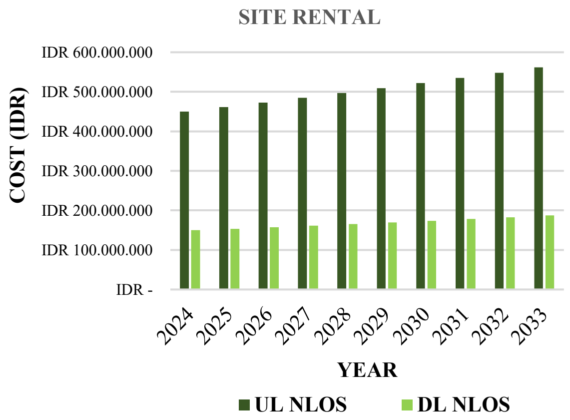


Figure 8. Site Rental Fee

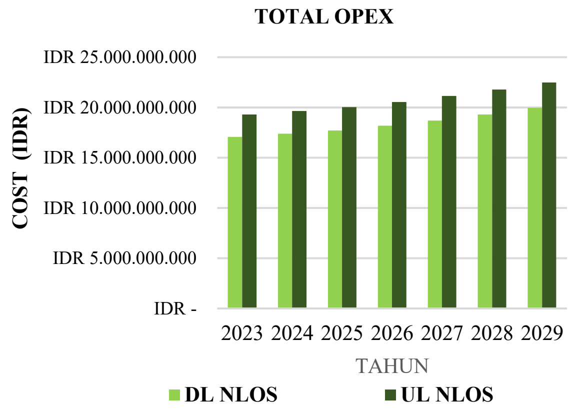


Figure 9. Grand Total OPEX

Figure 7 shows the calculation of HR costs in Semarang city, which consists of calculating the salary of the number of employees obtained from the assumption of the area of Semarang city to determine the number of employees needed in Semarang city. The cost of employee salaries is assumed to follow the Semarang minimum wage of IDR. 3.243.969.000. The projection results show that each year until 2033 continues to grow with an average of 2.71%.

Site rental costs are assumed to be 70% owned and 30% rented to the tower provider. Figure 8 shows the operational costs for site rental from 2024 to 2033 for the NLOS uplink scenario (11 sites) if calculated from the total rental of 30% so that 4 sites are rented with a rental cost of Rp. 150,000,000 per day then $4 \times IDR\ 150.000.0000 = IDR\ 600.000.000$. The site rental cost is more constant because the increase in the number of gNodes is not too significant, so the cost increases not too high for the next 10 years.

Figure 9 shows the overall total OPEX (operating cost) of the optimistic scenario with stable DL-NLOS and UL-NLOS scenario values. The total OPEX value increases every year, so the cost benefit of this optimistic scenario is suitable and feasible to be applied to 5G networks in Semarang city.

Table VI, Figure 10 and Figure 11 show the cost benefit analysis of NPV and IRR. The results of this study on the UL-NLOS scheme resulted in an NPV of IDR. 292.566.473.678 and an IRR of 110.25% and for the DL-NLOS scheme resulted in an NPV of IDR. 300.000.000.000 and an IRR of 115.38%. These results show that the 5G NR network with assumptions and projection calculations for the next 10 years is feasible, said to be feasible because the NPV value> 0. When viewed from the results of the IRR above < 100%, it shows that the deployment of 5G NR networks in the city of Semarang is still efficient in financial income as well.

TABLE VI. COST BENEFIT ANALYSIS OPTIMIC SCENARIO

Scenario	*Cost Benefit*	*Value*
Uplink Non-Line of Sight	NPV	IDR 292.566.473.678
	IRR	110.25%
Downlink Non-Line *of Sight*	NPV	IDR 300.000.000.000
	IRR	115.38%

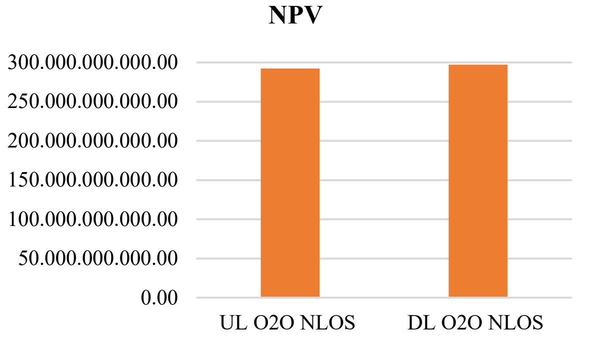


Figure 10. NPV Cost Benefit Graph

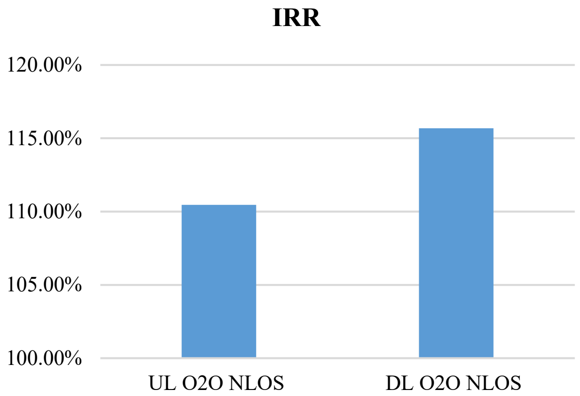


Figure 11. IRR Cost Benefit Graph

These results demonstrate that positive NPV and high IRR values reflect strong profitability and investment attractiveness, which are particularly important for long-term telecommunications infrastructure projects. Compared with similar studies in Surabaya and the Pulogadung region [18], [21], the findings in Semarang show consistent patterns of economic feasibility, reinforcing the broader potential of 5G deployment in Indonesian metropolitan and provincial capital cities. This research is limited by assumptions on user growth projections, potential fluctuations in electricity prices, and regulatory risks, which may influence both technical and economic outcomes in practice. The implications of these findings suggest that mobile operators should prioritize efficient site planning and phased investment strategies, while regulators should provide supportive policies to ensure sustainable 5G rollout in major cities.

IV. CONCLUSION

This research analysed the techno-economic feasibility of 5G deployment in Semarang through coverage planning, propagation analysis, and financial evaluation. The findings show that 11 sites are required under the UL-NLOS scenario and 6 sites under the DL-NLOS scenario, with simulations confirming full coverage of the 373.7 km² area despite a mean SS-RSRP of −125.74 dBm. From the economic perspective, both scenarios are feasible, with the UL-NLOS scheme yielding an NPV of IDR 292.566.473.678 and an IRR of 110.25%, while the DL-NLOS scheme achieved an NPV of IDR 300.000.000.000 and an IRR of 115.38%. The positive NPV and high IRR values demonstrate strong investment potential for 5G in Semarang. Future studies could optimize network coverage, assess QoS performance under varying traffic conditions, and explore additional frequency bands such as 3.5 GHz to enhance deployment strategies in Indonesian cities.

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