Implementing Carrier Aggregation on 4G Long Term Evolution-Advanced Network in a Dense Urban Area: A Techno-Economic Assessment

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Abstract **—The implementation of mobile cellular networks of the fourth generation, known as 4G Long Term Evolution-Advanced (4G LTE-A), is accelerating throughout the globe. Thus, the number of users in any given area is bound to rise with technological advancements. However, internet connectivity has become challenging in Indonesia, particularly in the dense urban area of Central Jakarta, due to network congestion caused by the region's enormous population of users and limited existing frequency. Therefore, this research aims to utilize the 2100 MHz frequency band as an additional frequency for the 4G LTE-A network in the dense urban Central Jakarta region. Furthermore, this research employs a techno-economic assessment of the deployment of 4G LTE-A with and without carrier aggregation (CA). The purpose is to see if expanding the 4G LTE-A network in the study area by adding the 2100 MHz frequency and utilizing the CA method is feasible and beneficial. According to the results, using the CA technique leads to fewer eNodeB requirements in the dense urban area of Central Jakarta than without the CA technique. Furthermore, through network simulation software, Forsk Atoll, good quality of the Key Performance Indicators (KPI) is obtained. In addition, based on the business perspective, this research acquired good Net Present Value (NPV), and the Internal Rate of Return (IRR) values are obtained, with returns on capital in the range of two to three years. Overall, these findings indicate that deploying 4G LTE-A technology in the planning region using 2100 MHz as an additional frequency with the CA technique is feasible and beneficial for cellular operators.**

Keywords **—4G, carrier aggregation, dense urban, network deployment, techno-economic model**

I. Introduction

Society's demands and expectations for telecommunications services are contingent not just on voice services but also on the viability and satisfaction of internet access. Therefore, one of the Indonesian government's challenges is to continue offering the most satisfactory telecommunications services to Indonesian internet users. This study is motivated by a news statement published by the Indonesian Ministry of Communication and Informatics Technology (MCIT) that raised the topic of network congestion conditions in ten major Indonesian cities, including Jakarta City, particularly in the Central Jakarta region that serves as the administrative and political center of Jakarta City [1].

Expanding the spectrum allocation and utilizing the carrier aggregation (CA) technique is the potential solution to the mentioned challenges. The telecom industry considers CA a game-changing method due to its ability to facilitate rapid adoption of the expanded spectrum allocation [2]. Until now, the 2100 MHz frequency band in Indonesia has been used for 3G technology. However, since 4G Long Term Evolution-Advanced (4G LTE-A) is rapidly expanding, the number of 4G users in the dense urban area of Central Jakarta is rising significantly.

Previously, a research planning of an LTE network simulation in an urban area using 700 MHz, 2100 MHz, and 2300 MHz frequencies with Quadrature Phase Shift Keying (QPSK) modulation was conducted. The results showed that in an urban area, the 2100 MHz and 2300 MHz were the most suitable frequencies to be utilized with QPSK modulation since they required fewer eNodeB than other modulations [3]. However, no research focuses on the techno-economic study of 4G LTE-A with 2100 MHz imbued with CA technique in a dense urban area.

Therefore, this research explores refarming the 2100 MHz frequency band of 3G to 4G LTE-Advanced (4G LTE-A) with the CA technique to solve the region's network congestion issue, especially in densely populated urban areas like Central Jakarta. By refarming the 2100 MHz frequency of 3G to 4G LTE-A, users will get an enhanced experience, and the rollout of 4G LTE-A with 2100 MHz frequency and CA services will be accelerated and become

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advantageous for the Indonesian government and cellular operators. Furthermore, this research employs a techno-economic assessment of 4G LTE-Advanced deployment with and without the use of CA. The goal is to find out if it is possible and helpful for the operators to improve the 4G LTE-A network in the study area by adding the 2100 MHz frequency and using the CA method.

In this paper, Section I provides the research's introduction. Section II describes the underlying theories that support the techno-economic approach of this study. In Section III, this study's methodology is presented. Section IV then discusses the results and analyses. Finally, Section V delivers the conclusion of this research.

II. Underlying Theories

A. 4G LTE-Advanced

4G LTE-A is the most widely used cellular technology in Indonesia, and it is an evolution of LTE technology known as LTE Release 10. The main focus of 4G LTE-A is to deliver higher capacity. This technology is expected to provide higher bitrates on the uplink and downlink sides at an efficient cost. The 4G LTE-A was developed by the 3rd Generation Partnership Project (3GPP) with four enhancement features: increased peak data rate (1.5 Gbps for uplink and 3 Gbps for downlink), higher spectral efficiency (from a maximum of 16 in R8 to 30 in R10), an increase in the number of active subscribers per cell, and finally improved performance at the cell's edge [4].

B. Carrier Aggregation (CA)

CA is a method of aggregating two or more component carriers with a maximum bandwidth of 100 MHz to meet the requirements of heavy service traffic and provide a high data rate [5]. CA effectively merges the fragmented carrier spectrum, resulting in a broader spectrum with increased throughput. CA is a crucial element of LTE-A Release-10 to achieve IMT-Advanced peak data throughput requirements of 3 Gbps downlink and 1.5 Gbps uplink [6]. Additionally, CA is compatible with existing technologies, allowing Release-8 and Release-9 users to share at least a portion of the total bandwidth with LTE-A. As a result, CA offers multiple advantages, such as improved data throughput with lowered network latency and increased network capacity, and maximizes an operator's spectrum assets [7].

1) Carrier aggregation spectrum scenarios

There are three different kinds of combinations of CA spectrum scenarios: intra-band contiguous, intra-band non-contiguous, and inter-band [8]. The explanations are as follows:

- Intra-band contiguous CA configurations refer to contiguous carriers combined in the same operating band. This scenario is the simplest form of LTE CA to implement
- Intra-band non-contiguous CA configuration refers to non-contiguous carriers combined in the same operating band. This scenario is more complicated than the intra-band contiguous CA, where the adjacent operator is used. A multi-carrier signal cannot be treated as a single signal; therefore, two transceivers are required.
- The inter-band CA configuration refers to the aggregation of component carriers in various operating bands, where the carriers collected in each band can be contiguous or non-contiguous.

2) Carrier aggregation deployment scenarios

CA can be employed to boost individual user data rates within a single cell. Additionally, it can lessen cellular interference in heterogeneous cells. Therefore, carrier aggregation deployment scenarios (CADS) might vary depending on the specifics of the deployment and are divided into CADS1, CADS2, CADS3, CADS4, and CADS5, as shown in Fig. 1 [8]. The explanations are as follows:

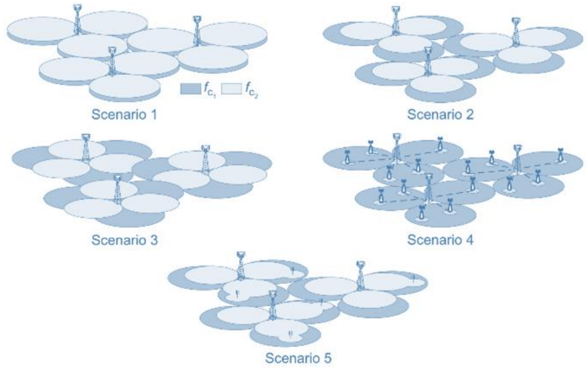

Figure 1. Five distinct types of CA deployment scenarios.

- CADS1: Cells with carrier frequencies f_{c1} and f_{c2} are stacked, and the scope is overlaid with f_{c1} and f_{c2} in the same frequency band.
- CADS2: Cells with carrier frequencies f_{c1} and f_{c2} are placed and coated with f_{c1} and f_{c2} in different frequency bands.
- CADS3: Cells with carrier frequencies f_{c1} and f_{c2} are placed with f_{c1} and f_{c2} in different frequency bands. The antenna for the cell f_{c2} is pointed to the cell boundary f_{c1} to increase cell edge data rates and user throughput.
- CADS4: Cells with carrier frequencies f_{c1} and f_{c2} are from different frequency bands. Cells associated with f_{c1} provide macro coverage, and long-range radio heads matching f_{c2} are used to increase throughput.
- CADS5: Resembling CADS2, where a frequency selective repeater is also deployed to extend the range of one of the carrier frequencies. Cells f_{c1} and f_{c2} from the same eNodeB can be merged if their scopes overlap.

C. Techno-economic Analysis (TEA)

The TEA is an approach that provides direction in investment, optimal service, and technology selection. It is a decision-making tool that evaluates available technology options based on technical, economic, environmental, social, and regulatory criteria. Techno-economic models typically combine market and service-related parameters and estimates with the cost and performance-related parameters of the technology required to provide customer services. The Techno-economic, Environmental, and Risk Analysis (TERA) models are chosen as the fundamental approach for this study because it is widely used in wireless technology and industry. The TERA model allows techno-economic evaluation and strategic analysis by combining customer density and service penetration parameters.

The TERA model's techno-economic analysis framework starts with a technical analysis of capacity and coverage [9]. Then, based on economic analysis, estimations and assumptions such as discount rates, time periods, and calculation models are made. Eventually, the criteria for decision-making based on TEA are Capital Expenditure (CAPEX), Operational Expenditure (OPEX), Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PP). Finally, a sensitivity analysis is conducted to determine which parameters have the most influence on income.

D. Key Performance Indicators (KPI) Analysis

KPIs are crucial indicators that are needed in this research in order to obtain good quality of services [10]. Therefore, the KPIs in this study are utilized to evaluate the efficacy of the 4G LTE-A system. The effectiveness of a 4G LTE-A network can be measured concerning three different types of indicators, including the Reference Signal Received Power (RSRP), Signal to Interference Noise Ratio (SINR), and throughput [11]. The classification for each of these indicators is divided into five categories, namely, excellent, good, normal, bad, and worst. The information is presented in Table I [12].

TABLE I: KPI OF RSRP, SINR, AND THROUGHPUT CLASSIFICATION

Classification	RSRP (dBm)	SINR (dB)	Throughput (Kbps)
Excellent	R > -71	15 < S ≤ 30	T > 1200
Good	-81 < R ≤ -71	-	700 < T ≤ 1200
Normal	-91 < R ≤ -81	0 < S ≤ 15	338 < T ≤ 700
Bad	-101 < R ≤ -91	-	0 < T ≤ 338
Worst	R < -101	-10 < S ≤ 0	-

III. METHODOLOGY

A. Research Planning

This research involved multiple preparation phases, including data collection, technical planning, and economic planning analysis. This research will determine the number of eNodeB necessary for adopting the 2100 MHz frequency as an additional frequency for 4G LTE-A technology using the CA technique in the densely populated urban area of Central Jakarta. The research planning framework can be seen in Fig. 2.

B. Research Area Identification

The dense urban area of the Central Jakarta region has a surface area of 52.38 km^2 and is the area used to designate the additional frequency with the CA technique on the 4G LTE-A network. Furthermore, central Jakarta was selected since it is included in the Jakarta City administrative region, the capital of Indonesia, and is the center for economic and government offices. Thus, there are many cellular network users in the Central Jakarta area. In addition, aside from Bali, many foreign visitors also have their holidays in Jakarta since it has many fascinating cultural and historical remnants to see. Therefore, it encourages the telecommunication sector to continue to provide good internet connections so that visiting tourists feel comfortable traveling and communicating while on vacation in Indonesia. Fig. 3 shows the map of the Central Jakarta area.

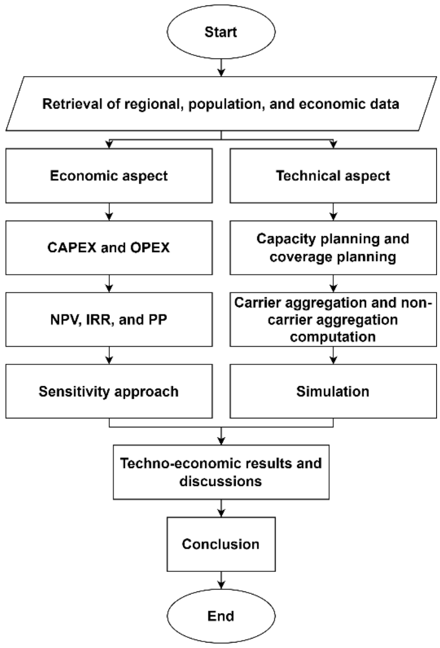

Figure 2. Research planning framework.

Figure 3. The map of central Jakarta region.

C. Simulation Scenario

The simulation in this research uses a network simulation software called Forsk Atoll to design the required eNodeB for the frequency expansion plan. In this research, the dense urban area of Central Jakarta is selected as the simulation area for planning. The simulation scenario is carried out after the computation of the capacity and coverage approaches. Finally, the results of the two approaches are compared, and the maximum number of eNodeB from the two approaches are the eNodeB requirements plotted for simulation.

The results of the simulation scenarios are to get the three KPIs values and to assess the service quality of the 2100 MHz frequency band without the CA and with the CA technique paired with 1800 MHz.

D. Techno-economic Planning

Technical analysis is carried out to determine the technology used and various technical matters. The technical analysis will be carried out using the CA and the non-CA method. The CA scenario used in this research is an inter-band spectrum non-contiguous CA scenario by combining two different frequencies, 2100 MHz as the primary frequency and 1800 MHz as the secondary frequency. In addition, this research also uses two analyses, the capacity planning analysis and the coverage planning analysis, to figure out how many eNodeB are needed in the dense urban area of Central Jakarta.

1) Capacity planning approach

Capacity planning in 4G LTE-A network planning predicts the number of sites according to the number of users in the area and can cover all users in the planning area. The assumption used in this research is to predict cellular users in Central Jakarta for the next five years using the 2020 population. A population prediction for the next five years can be calculated using the forecasting Eq. (1),

$$P_n = P_o \times (1 + GF)^n \quad (1)$$

where P_n is the result of forecasting the number of customers in year-n. The user predictions are adjusted using P_o, the productive age population (15–65), and the growth factor, GF to determine the penetration rate. This computation is performed based on the assumption that the productive age population uses cellular services more than those outside the age group. Nevertheless, not everyone uses the same operator. In this study, Telkomsel is assumed to have a market share of 59.2%, while 4G LTE-A users are assumed to accommodate 83.5% of the population in Indonesia [12]. The predictions for 4G LTE-A customers in Central Jakarta are displayed in Table II.

TABLE II: PREDICTION OF THE NUMBER OF 4G LTE-A USERS

Parameters	Central Jakarta
Population per 2020	1,056,896
Growth factor (%)	1.53%
Population prediction in 2025	1,140,261
Productive age in (User)	726,688
Productive age in (%)	63.73%
Operator market share in (User)	430,199
Operator market share in (%)	59.2%
LTE-A penetration (%)	83.5%
Target user in 2025	359,217

This research then proceeds with calculating the network throughput. The network throughput is the multiplication value of the single user throughput with the total target user obtained from forecasting the number of users. This value can be obtained by utilizing equation (2) and Eq. (3), respectively:

$$Single\ User\ Throughput = \Sigma[(Throughput\ / Session) \times Busy\ Hour \times Penetration\ Ratio \times (1 + Peak\ to\ Average\ Ratio)]/3600 \quad (2)$$

$$Network\ Throughput\ [kbps] = Single\ User\ Throughput \times Total\ Target\ User \quad (3)$$

In the last step of the capacity planning analysis, the number of sites needed to increase the frequency of the 4G LTE-A network in the planning area is calculated. This number is based on the number of users in the planning area. Therefore, Eqs. (4)-(5) are needed to obtain the required number of sites [9],

$$Site\ Capacity = Single\ User\ Throughput \times 3 \quad (4)$$

$$Number\ of\ Site = \frac{Network\ Throughput}{Site\ Capacity} \quad (5)$$

2) Coverage planning approach

Coverage planning in 4G LTE-A network planning ensures the availability of networks and services in the targeted area. Additionally, coverage planning is conducted to identify the number of sites per region. Planning for coverage is undertaken in stages. Calculating the link budget is the initial phase of the coverage planning study. This study assumes the antenna utilized in this plan is a Huawei antenna with the ASI4518R10v06 standard. The bandwidth of 15 MHz is used for the non-CA approach, while 20 MHz is utilized for the CA method. Due to many assumptions, there will be a difference between the antenna requirements and the link budget calculation table.

TABLE III: VALUE OF LINK BUDGET FOR NON-CA METHOD

UPLINK		DOWNLINK	
UE TX Power	23 dBm	eNB TX Power	46 dBm
UE Gain	0 dBi	eNB Gain	16.8 dBi
Body loss	0 dB	Cable Loss	2 dB
EIRP	23	EIRP	60.8 dBm
eNB Noise Figure	2 dB	UE Noise Figure	7 dB
Thermal Noise	−131.75 dB	Thermal Noise	−131.75 dB
Receiver SINR	−7 dB	Receiver SINR	-9 dB
Receiver Sensitivity	−136.75 dB	Receiver Sensitivity	−133.75 dB
Interface Margin	1 dB	Interface Margin	4 dB
Masthead Gain	0 dB	Control Channel Overload	1 dB
Cable Loss	2 dB	Body Loss	0 dB
eNB Gain	16.8 dBi	UE Gain	0 dBi
MAPL	173.55 dB	MAPL	189.55 dB

The link budget calculation is performed for both the uplink and downlink sides. The link budget values for the non-CA approach are presented in Table III, with Maximum Allowable Path Loss (MAPL) calculations utilizing Eqs. (6)-(7) [11], as in,

$$MAPL_{UL} = (PT + GT - BL) - (NF + TN + SINR) - IM - CL + GR + MHA\ GAIN \quad (6)$$

$$MAPL_{DL} = (PT + GT - CL) - (NF + TN + SINR) - IM - CCO + GR - BL \quad (7)$$

where PT is the transmit power, GT is the transmit gain, GR is the receive gain, BL is the body loss, CL is the cable loss, NF is the noise figure, TN is the thermal noise, $SINR$ is the signal to interference noise ratio, IM is the interference margin, CCO is the control channel overhead, and $MHA\ Gain$ is the masthead amplifier gain.

The link budget calculation that is done by using the CA method would provide a different calculation result from the link budget that is done via the non-CA method. The following Table IV shows the link budget values for the CA method that is obtained after figuring the MAPL value through Eq. (8) [10],

$$MAPL = EIRP_{subcarrier} - MSRS - PL - SF \quad (8)$$

where $EIRP_{subcarrier}$ is the equivalent isotropic radiated power subcarrier, $MSRS$ is the minimum signal reception strength, PL is the penetration loss, and SF is the shadow fading margin.

TABLE IV: VALUE LINK BUDGET FOR METHODS WITH CA

UPLINK		DOWNLINK	
Tx Power	23 dBm	Tx Power	46 dBm
Resource Block	4	Resource Block	100
Subcarrier to Distribute Power	48	Subcarrier to Distribute Power	1200
Subcarrier Power	6.2 dBm	Subcarrier Power	15.2 dBm
Tx Body Loss	0 dB	Tx Gain	16.8 dB
EIRP per Subcarrier	6.2 dBm	EIRP per Subcarrier	32.5 dBm
Thermal Noise	−130.5 dB	Thermal Noise	−130.5 dB
SINR	−7 dB	SINR	−9 dB
Rx Noise Figure	2.3 dB	Rx Noise Figure	7 dB
Receiver Sensitivity	−135.2 dBm	Receiver Sensitivity	−132.5 dBm
Rx Gain	16.8 dBi	Rx Body Loss	0 dBi
Interface Margin	1 dB	Interface Margin	4 dB
Min Signal Reception Strength	−150.5 dBm	Min Signal Reception Strength	−128.5 dBm
Penetration Loss	18 dB	Penetration Loss	18 dB
Shadow Fading Margin	9.4 dB	Shadow Fading Margin	9.4 dB
MAPL	129.3 dB	MAPL	133.6 dB

After knowing the MAPL value for the uplink and downlink sides, the next step is to determine the propagation model. The propagation model will affect the cell radius calculation used for planning the addition of frequencies for the 4G LTE-A network. Based on the frequency used in this research, 2100 MHz, the appropriate propagation model is the $COST_{231}$ propagation model. $COST_{231}$ is a commonly used empirical propagation model. This propagation model incorporates many parameters and can be adapted to measurements. Based on the research [13], it was conducted that the $COST_{231}$ propagation model can be used for a frequency of 2100 MHz because the propagation model supports up to 2200 MHz. The calculation of the path loss value using the $COST_{231}$ propagation model can be calculated using equations (9) and (10), as in,

$$COST_{231} = 49.3 + (33.9 \times log\, f_c) - (13.82 \times log\, h_b) - a(h_m) + [44.9 - (6.55 \times log\, h_b) \times log\, d] + C \quad (9)$$

$$a(h_m) = 3.2 \times [log(11.75 \times h_m)]^2 - 4.97 \quad (10)$$

where f_c is the frequency spectrum used, h_b is the height of the transmitter antenna in meters, h_m is the height of the receiver antenna in meters, d is the distance between eNodeB and the UE in kilometers, $a(h)_m$ is the correction factor for the height of the receiver antenna, C is the value parameter based on environmental differences, with the value of C = 3 dB for dense urban areas.

The following Table V shows the calculation of the $COST_{231}$ propagation model for the CA and non-CA methods.

TABLE V: CALCULATION OF COST-231 PROPAGATION MODEL

Method	$a(h_m)$	$\log d$	$d\ (km)$
Uplink CA	0.547	-0.417	0.383
Downlink CA	0.547	-0.294	0.508
Uplink Non-CA	0.547	0.840	6.916
Downlink Non-CA	0.547	1.294	19.683

The last stage of the coverage planning analysis is to calculate the number of sites needed for the planning area to increase the 4G LTE-A network frequency based on the planning area. Eqs. (11)-(12) are utilized to get the required number of sites in coverage [9], as in,

$$Cell\ Coverage = 1.95 \times 2.6 \times d^2 \quad (11)$$

$$Total\ Cell = \frac{Surface\ Area}{Cell\ Coverage} \quad (12)$$

3) *Capital expenditure and operational expenditure planning*

It is essential to assume the costs associated with adding 4G LTE-A frequencies. Cost assumptions are therefore employed for CAPEX and OPEX expenses. The device fee and the installation fee constitute the CAPEX cost. The OPEX costs include labor, maintenance, and a fee for the government's permission to use the radio frequency spectrum because the project employs an existing tower. The CAPEX cost assumptions are presented in Table VI, and the OPEX cost assumptions are shown in Table VII. The basis for the interest rate assumptions used in this research is the basic loan interest rate of Bank Mandiri, an Indonesian State-Owned Enterprise (SOE) bank, which is 10%. For Average Revenue Per User (ARPU), we utilize

Telkomsel provider's ARPU acquisition in 2020, which is Rp 44,000.

TABLE VI: CAPEX COST ASSUMPTION

Equipment	Cost per Equipment ($)	Conversion (IDR) $ 1 = Rp 14,328.60	Unit
eNodeB (support equipment)	1,570.00	22,495,902	Per extra site
LTE HSS	7,404.50	106,096,119	1
Gateway	1,959.75	28,080,474	1
License (software)	1,048.00	15,016,373	Per extra site
Installation (per eNodeB)	697.90	10,000,000	Per eNodeB

TABLE VII: OPEX COST ASSUMPTION

Equipment	Cost per Equipment (Rp)	Unit
Tower Rental	12,000,000	Per Tower
Maintenance	5,068,000	Per Sites
Electricity	5,000,000	Per Site Per Month
Marketing	10%	Gross Revenue
Salary	50,000,000	Per Month
Frequency Fee	7,012,852	Per Year
USO Fee	1.25%	Gross Revenue
Telecommunication Fee	0.50%	Gross Revenue

TABLE VIII: CRITERIA FOR NPV

If	Stand For	Then
NPV > 0	Investment provides benefits for the company.	Project executed.
NPV < 0	Investment provides losses for the company.	Project rejected.
NPV = 0	Investment does not give the company a profit or loss.	If the project is executed, it will not affect the company's finances.

4) *Feasibility study planning*

A business feasibility study is a controlled method for identifying challenges and opportunities, formulating objectives, describing conditions, defining successful outcomes, and estimating the range of costs and benefits associated with several potential solutions to a problem. The business feasibility study supports decision-making based on a cost-benefit analysis of the actual business or project viability. In this study, the Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PP) are measured.

- NPV is an economical approach carried out by discounting all future cash flows, both cash inflows and cash outflows, generated from the project at a given discount rate and then added together. NPV can be calculated using equation (13), as in,

$$NPV = \sum_{t=1}^{n} \frac{CF_t}{(1+K)^t} - I_0 \qquad (13)$$

where CF_t is the net cash flow generated by the project in year *t*, K is the discount rate, and I_0 is year zero of investment. NPV assessment criteria are shown in Table VIII [13].

- IRR is the discount rate that equates the present value of net cash flow with the current value of the investment. IRR is the discount rate that makes the NPV equal to zero. The IRR value can be calculated using Eq. (14), as in,

$$IRR = NCF_0 + \frac{NCF_1}{(1+IRR)_1} + \cdots + \frac{NCF_n}{(1+IRR)_n} = 0 \qquad (14)$$

where NCF is the net cash flow value in year-n. In this calculation, the investment decisions that are feasible or not feasible can be taken based on the IRR value obtained. The investment can be accepted if the IRR value exceeds the specified interest rate. On the other hand, if the IRR value obtained is less than the fixed interest rate, the investment cannot be accepted [14].

- PP is an assessment technique for the period needed to cover the initial investment using the cash inflow generated by the project. The PP value can be calculated using the equation (15), as in,

$$PP = n + \frac{a-b}{c-b} \times 1\ year \qquad (15)$$

where n is the last year the amount of cash flow has not been able to cover the initial investment capital, a is the amount of the initial investment, b is the cumulative amount of cash flows in the nth year, and c is the cumulative amount of cash flows in the n+1 year. If the rate of return based on the PP is faster than the company's estimation, then the investment proposal is acceptable, and if the rate of return based on the PP is slower than the company's estimation, the investment proposal may be rejected [15].

TABLE IX: SENSITIVITY CRITERIA AND INDICATORS

Scenarios	Indicators	Criteria
Optimistic	ARPU increase	Income +3.12%
	Dollar exchange rate change	Rp 13,662
	Increase in number of users	Users +3.12%
Moderate	Fixed ARPU	Normal
	Fixed dollar rate	Normal
	Fixed number of users	Normal
Pessimistic	ARPU decrease	Income-3.12%
	Dollar exchange rate change	Rp 16,367
	Decrease in number of users	Users –3.12%

5) *Sensitivity study planning*

A business sensitivity study is conducted to examine the effect of production parameter modifications on the profitability of the production system [16]. The study utilizes three distinct scenarios: optimistic, moderate, and pessimistic. Changing some variables under optimistic and pessimistic situations reveals the anticipated state. The baseline change rate estimation was 3.12% for 2016-2020. In addition, the optimistic and pessimistic dollar exchange rate assumptions for 2016–2020 are used. The highest rate was Rp 16,367 in March 2020 and Rp 13,662 in January 2020. Table IX shows the sensitivity scenario's criteria and indications.

IV. Results and Analysis

A. Technical Analysis

1) Capacity planning analysis for carrier Aggregation and non-carrier aggregation

The final stage in this capacity planning analysis is to calculate the number of sites needed for the planning area, namely the Central Jakarta areas. The number of sites required for each plan differs based on the parameters used for the non-carrier aggregation and carrier aggregation methods. Table X shows the results of the calculation of capacity planning with the CA method, and Table XI shows the results of the capacity planning with the non-CA method.

TABLE X: Capacity Planning Results for CA

Parameters	Uplink	Downlink
Number of Cell	55	271
Number of Site	19	91
Number User per Site	18,907	3,948
Cell Coverage (km^2)	2.757	0.576
Cell Radius (km)	0.737	0.337
Cell Radius Atoll (km)	0.595	0.272

TABLE XI: Capacity Planning Results for Non-CA

Parameters	Uplink	Downlink
Site Capacity (Mbps)	153.135	127.613
Number of Site	26	129
Number User per Site	13,817	2,785
Cell Coverage (km^2)	2.015	0.406
Cell Radius (km)	0.630	0.283
Cell Radius Atoll (km)	0.508	0.228

Based on the calculation results, for the CA method, the Central Jakarta area requires 19 sites for the uplink and 91 sites for the downlink. On the other hand, for the calculation results using the non-CA method, 26 sites are needed for the uplink and 129 sites for the downlink. Therefore, the number of sites obtained can cover 359,217 LTE-A users in the Central Jakarta area in 2025 with excellent network quality.

2) Coverage planning analysis for carrier aggregation and non-carrier aggregation

After knowing the radius value from the calculation of the propagation model, the next step is to calculate the number of sites needed for the planning area based on the calculation of the coverage area. For the CA and the non-CA method, it is possible to have differences in the results of the number of sites due to differences in the parameters used in the link budget calculation. Table XII shows the coverage planning calculation results for the CA method, and Table XIII displays the coverage planning calculation results for the non-CA method. Based on the calculation results, the non-carrier aggregation and carrier aggregation methods obtained the same number of sites; 23 sites are required for both the uplink and downlink sides.

TABLE XII: Coverage Planning Results for CA

Parameters	Uplink	Downlink
Cell Coverage (km^2)	0.744	1.309
Cell Coverage (Atoll) (km^2)	2.337	2.337
Total Cell (site)	71	41
Total Cell (Atoll) (site)	23	23

TABLE XIII: Coverage Planning Results for Non-CA

Parameters	Uplink	Downlink
Cell Coverage (km^2)	242.516	1964.220
Cell Coverage (Atoll) (km^2)	2.337	2.337
Total Cell (site)	1	1
Total Cell (Atoll) (site)	23	23

3) Comparison of capacity and coverage planning analysis

A comparison of capacity planning and coverage planning is conducted to determine the number of sites used for simulation on the Atoll. Simulations are carried out to plan the addition of frequencies and to know the quality-of-service predictions through the KPIs. The value used for simulation on Atoll is the highest number of sites from the two analysis results and is assumed to cover the entire area, and all users in the planning area receive a network with good quality. The comparison results for the simulation CA method are shown in Table XIV, and the results for the non-CA method are shown in Table XV.

TABLE XIV: Number of Sites Based on CA

Region	Capacity Planning		Coverage Planning	
	Uplink	Downlink	Uplink	Downlink
Central Jakarta	19	91	23	23

TABLE XV: Results of NPV, IRR, and PP

Methods	Parameters		
	NPV (Rp)	IRR	PP
CA	16,189,799,587	115.73%	0.869 ≈ 9 months
Non-CA	1,267,594,571	15.40%	3.9 ≈ 3 years 10 months

Based on the comparison between capacity planning and coverage planning results for the simulation with the CA method, the highest number of sites for the Central Jakarta area is 91 sites. On the other hand, for the simulation using the non-CA method, the highest number of sites for the Central Jakarta area is 129. With the number of sites obtained, a simulation will be carried out using Atoll software to determine the research results from a technical point of view.

B. 4G LTE-Advanced Planning Simulation

After comparing the capacity planning and coverage planning analysis results, a simulation of the deployment of the 4G LTE-A network is carried out using Atoll. The Atoll software can help simulate network deployments before actual deployment. In addition, from the simulation, we can see the results of the performance predictions generated from the design. The KPI in this research is used to measure the performance of the 4G LTE-A network and to get the desired results. Several parameters are used to determine the performance of the 4G LTE-A network, namely:

- Reference Signal Received Power (RSRP): This analysis is carried out to determine the signal quality that users in an area receive.
- Signal to Interference Noise Ratio (SINR): This analysis compares the strength of the signal transmitted to the user with interference and noise or noise mixed with the primary signal emitted.
- Throughput: This analysis is conducted to determine the rate of data access obtained by customers in an area. Throughput is the actual bandwidth at a particular time and condition.

1) 4G Planning with carrier aggregation and non-carrier aggregation

Based on the capacity and coverage planning results for adding frequencies on the 4G LTE-A network. The CA method, which utilizes a frequency of 2100 MHz as the primary frequency and 1800 MHz as the secondary frequency, requires 91 sites with a radius of 0.272 km are needed for the Central Jakarta area. Fig.4 shows the CA method's results of planning simulations in the Central Jakarta area. Meanwhile, in the non-CA method, Central Jakarta needed 129 sites with a radius of 0.228 km. Fig. 5 shows the results of planning simulations in the Central Jakarta area using non-CA.

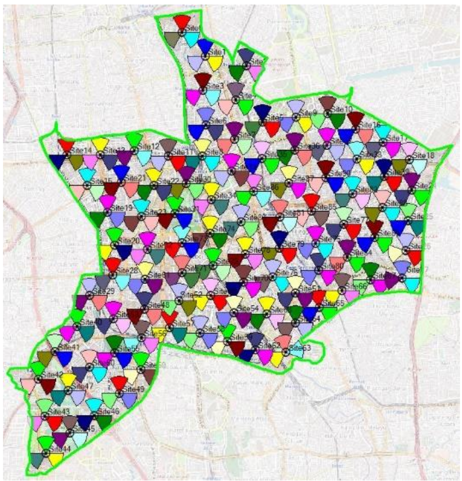

Figure 4. Predicted planning results of coverage using CA.

2) Reference signal receiver power (RSRP)

The RSRP assessment parameters used are referred from Table I. For the CA method, the average RSRP value obtained is -66.43 dBm, with 54.03% of the entire Central Jakarta area having a value in the "good" range with an RSRP value between -75 dBm to -80 dBm. The prediction results of signal coverage in the Central Jakarta area using CA are shown in Fig. 6. Meanwhile, for the non-CA method, the average RSRP value obtained is -61.69 dBm, with 68.82% of the entire Central Jakarta area having a value in the "normal" range with an RSRP value between -80 dBm to -85 dBm. The prediction results of signal coverage in the Central Jakarta area using non-CA are shown in Fig. 7.

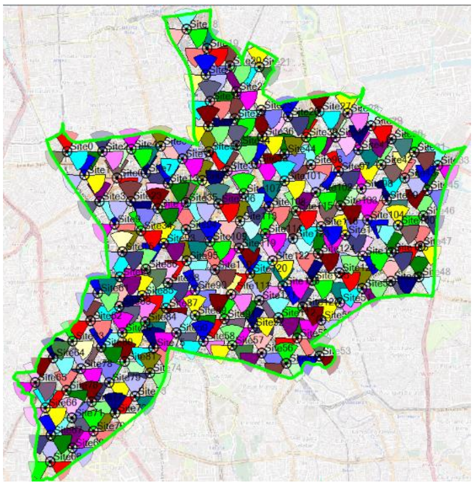

Figure 5. Predicted planning results of coverage using non-CA.

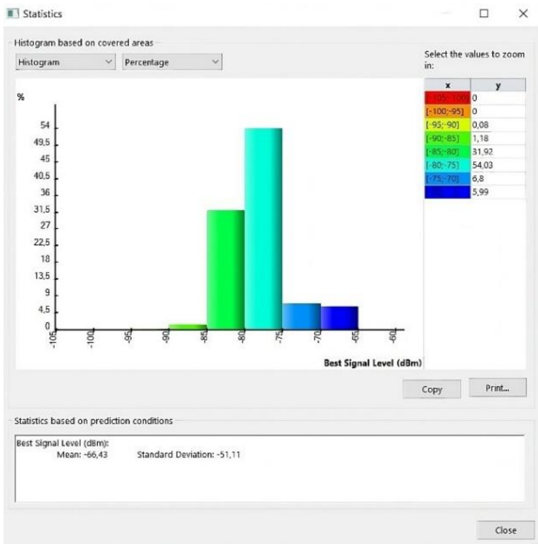

Figure 6. RSRP results for Central Jakarta using CA.

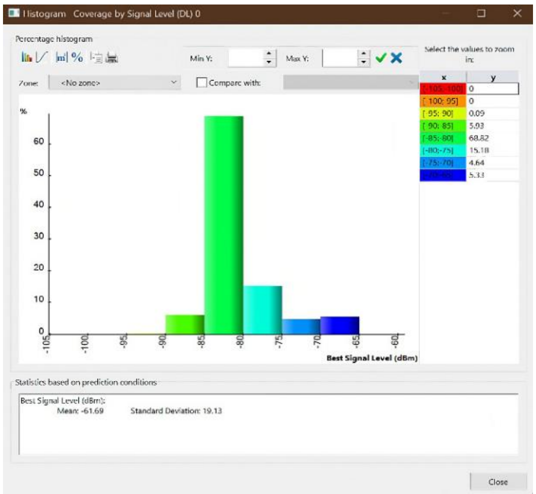

Figure 7. RSRP results for Central Jakarta using non-CA.

3) Signal to interference noise ratio (SINR)

The SINR assessment parameters used are referred from Table I. The average SINR value is 3.57 dB for using the CA method and is shown in Fig.8. Meanwhile, the non-CA method provided an average SINR of 3.52 dB, which is shown in Fig. 9. These results indicated that the interference and noise on the signal frequency are normal and not too disturbing when implemented on the dense urban area of Central Jakarta.

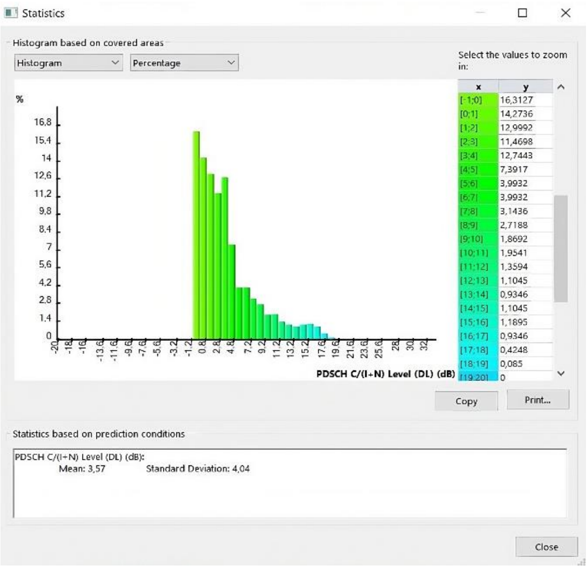

Figure 8. SINR results for Central Jakarta using CA.

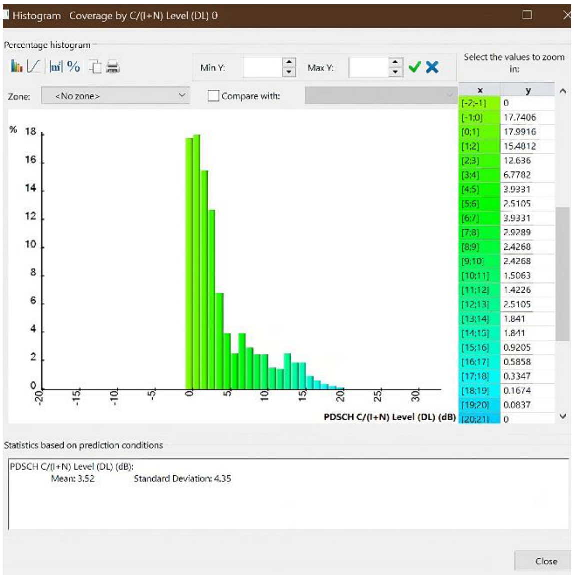

Figure 9. SINR results for Central Jakarta using non-CA.

4) Throughput

The throughput assessment parameters used are referred from Table I. Based on the throughput analysis, the average throughput value for the Central Jakarta area is 30,926.13 kbps with the CA method, and the average throughput value for the non-CA method is 23,227.93 kbps. Therefore, the throughput results indicate that the data access obtained by 4G LTE-A customers in the Central Jakarta areas in 2025 is excellent. The results of the SINR analysis for Central Jakarta using CA are shown in Fig. 10, and non-CA are demonstrated in Fig. 11.

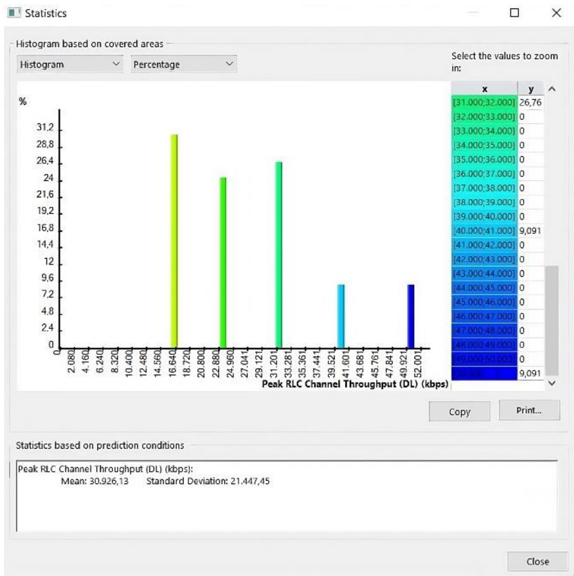

Figure 10. Throughput results for Central Jakarta using CA.

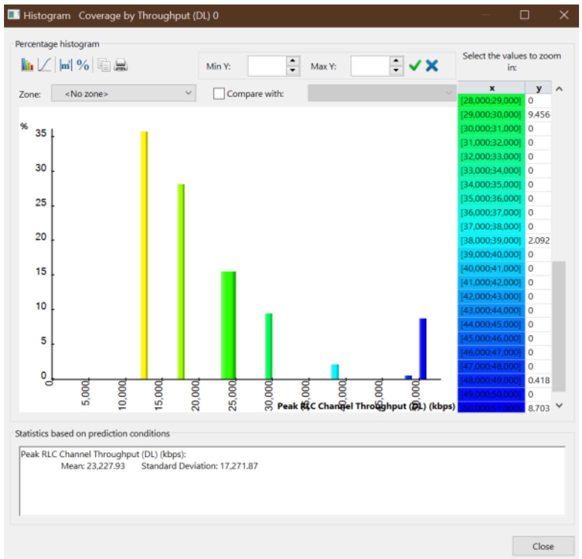

Figure 11. Throughput results for Central Jakarta using non-CA.

C. Economic Analysis

1) Capital expenditure and operational expenditure analysis

The calculation of CAPEX and OPEX costs in this research is influenced by the number of sites needed, the number of active users, and the condition of network availability. In this research, these assumed conditions are the same for the CA and non-CA methods. The calculation of CAPEX and OPEX in this research is based on the cost assumptions shown in Table VI for CAPEX assumptions and Table VII for OPEX assumptions. The estimation of CAPEX is shown in Fig. 12, and OPEX is shown in Fig. 13. The graph for each scenario is in a million rupiahs. In the graph, the labeled CA CJ stands for Carrier Aggregation Central Jakarta, and the NCA CJ stands for Non-Carrier Aggregation Central Jakarta).

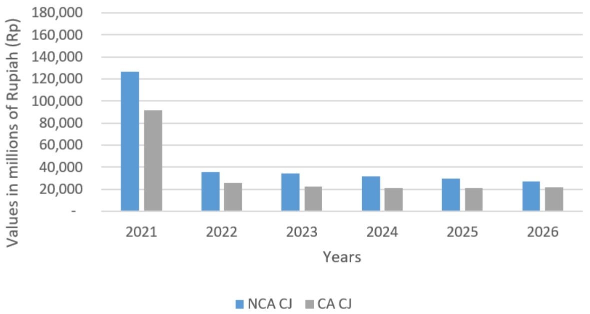

Figure 12. CAPEX for central Jakarta.

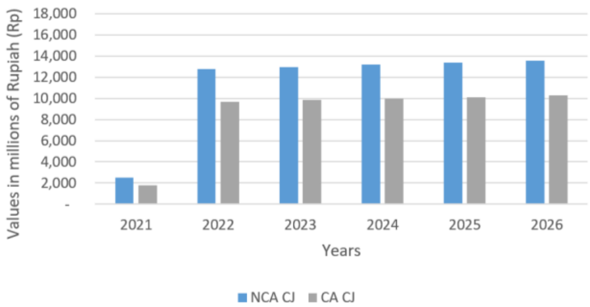

Figure 13. OPEX for central Jakarta.

Based on Fig. 12 and Fig. 13, we can see that for every year, there is a decrease in CAPEX while there is an increase in OPEX. Therefore, for comparison based on the method used, the CA method implementation requires a lower cost than the implementation of the non-CA method. This difference occurs because the number of sites needed for the CA method is less than for the non-CA method.

2) Business feasibility analysis

In conducting a business feasibility analysis, the parameters of concern are NPV, IRR, and PP values. A business is possible if the NPV value is greater than zero, the IRR value is higher than the specified interest rate, and the PP value is smaller than the maximum fixed rate of return. CAPEX and OPEX values are used for the references in the business feasibility analysis in this research. Table XVI shows feasible results from NPV, IRR, and PP values for both CA and non-CA methods since the NPV is larger than zero and the IRR is larger than 10%. For the PP value, the application of additional frequency is carried out using the CA method, providing a return in the first year.

If the additional frequency is applied using the non-CA method, the return on capital is in the third year. Therefore, based on the obtained PP values, the most suitable method that can be applied is the implementation done using the CA method because the return on capital is faster than the application of the non-CA method.

3) Sensitivity analysis

TABLE XVI: NPV, IRR, AND PP IN SENSITIVITY ANALYSIS

Methods	Optimistic	Moderate	Pessimistic
NPV CA	Rp 18,863,292,669	Rp 16,189,799,587	Rp 13,044,305,091
NPV Non-CA	Rp 3,531,487,949	Rp 1,267,594,571	-Rp 1,866,909,798
IRR CA	131.94%	115.73%	89.88%
IRR Non-CA	27.73%	15.40%	-2.98%
PP CA	0.769 ≈ 8 months	0.869 ≈ 9 months	1.927 ≈ 1 years 10 months
PP Non-CA	2.922 ≈ 2 years 10 months	3.9 ≈ 3 years 10 months	5.889 ≈ 5 years 9 months

Sensitivity analysis is carried out to determine the impact of changes in production parameters on production system performance in generating profits. The results show that the parameters that have been selected are very influential on the income to be obtained. Fig. 14, Fig. 15, and Fig. 16 show the CAPEX-OPEX graph for each scenario in a million rupiahs. The CA requires lesser cost than the non-CA method due to smaller requirements for the number of eNodeB.

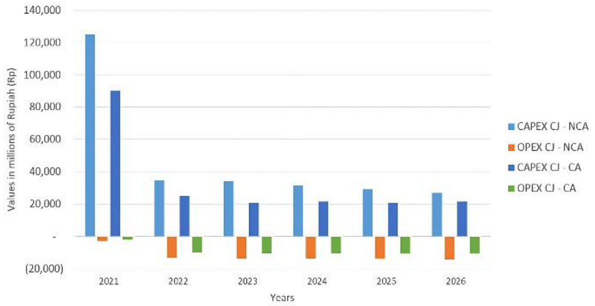

Figure 14. CAPEX-OPEX chart for the optimistic scenario.

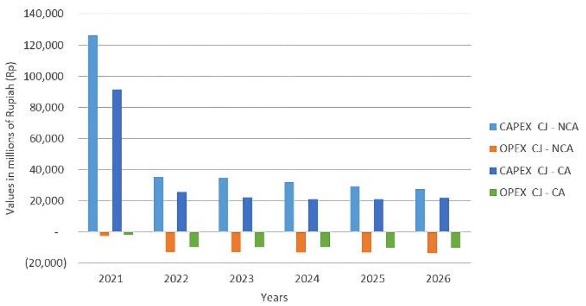

Figure 15. CAPEX-OPEX chart for the moderate scenario.

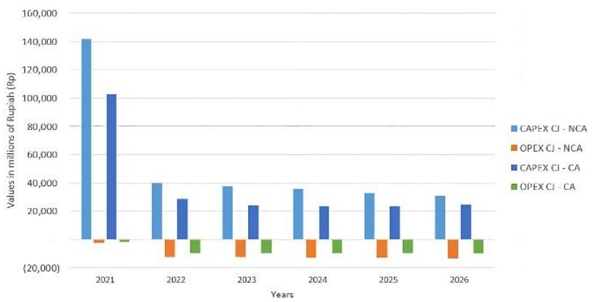

Figure 16. CAPEX-OPEX chart for the pessimistic scenario.

The following Table XVII presents the results of the feasibility study for implementing the additional frequency for 4G LTE-A in the dense urban area of Central Jakarta, specifically in the sensitivity analysis. The results are based on optimistic, moderate, and pessimistic scenarios and are of significant importance when conducting the feasibility study. It is essential to consider these results carefully to ensure a successful implementation. In the CA method, the NPV and IRR values obtained in every scenario is positive, as well as the resulting PP value, which is faster than the maximum period. However, in the non-CA method, the NPV, IRR, and PP are feasible only if the scenario is in optimistic conditions since, in the pessimistic scenario, the NPV returns negatively with an IRR of -2.98%, and the period of investment return exceeded the maximum required period. Nevertheless, throughout these values, it is not exaggerating to say that implementing 4G LTE-A with the additional 2100 MHz frequency is feasible and provides favorable conditions and results to operators via the CA method only.

TABLE XVII: NPV, IRR, AND PP IN SENSITIVITY ANALYSIS

Methods	Optimistic	Moderate	Pessimistic
NPV CA	Rp 18,863,292,669	Rp 16,189,799,587	Rp 13,044,305,091
NPV Non-CA	Rp 3,531,487,949	Rp 1,267,594,571	-Rp 1,866,909,798
IRR CA	131.94%	115.73%	89.88%
IRR Non-CA	27.73%	15.40%	-2.98%
PP CA	0.769 ≈ 8 months	0.869 ≈ 9 months	1.927 ≈ 1 years 10 months
PP Non-CA	2.922 ≈ 2 years 10 months	3.9 ≈ 3 years 10 months	5.889 ≈ 5 years 9 months

V. Conclusions

In this research, we obtained that implementing the CA method required 91 eNodeB to cover the dense urban area of Central Jakarta and to provide an average RSRP of -66.43 dBm, an average SINR of 3.57 dB, and an average throughput of 30,926.13 kbps. In addition, the CA method provided an NPV of Rp 16,189,799.587 with an IRR of 115.73% and a PP of investment in only nine months. Meanwhile, in the non-CA implementation, we obtained that 129 eNodeB is needed to cover the whole dense urban area of Central Jakarta. The RSRP average value was -61.69 dB, an average SINR of 3.52 dB, and an average throughput of 23,227.93 kbps. As a result, the non-CA method gave an NPV of Rp. 1,267,594,571, with an IRR of 15.40% and an annual rate of return of three years and ten months in PP. Based on the sensitivity analysis results, changes in the dollar exchange rate will affect the required CAPEX and OPEX expenses. At the same time, changes in the number of users and variations in ARPU will affect the amount of generated profit. In conclusion, these results suggest that establishing 4G LTE-A technology in the planning region utilizing 2100 MHz as an additional frequency with the CA method is more feasible and advantageous for cellular operators. For future research, we recommend exploring new possible techno-economic approaches that include Indonesian regulations that are related to different frequency usage in 4G LTE-A or 5G networks.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Muhammad Imam Nashiruddin is responsible for the overall research, both in technical and economic aspects. Pinasthika Aulia Fadhila was responsible for the planning and execution of the research. This research was also supported by Nachwan Mufti Adriansyah, who contributed to the technical aspects. Muhammad Adam Nugraha and Putri Rahmawati supported the research and analysis; all authors have approved the final version.

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