Business Sensitivity Options of Carrier Aggregation Strategies: A Simulation Model for 4G Deployment in Emerging Countries

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Abstract **– Indonesia's growing population increasingly relies on 4G networks, presenting challenges for the Ministry managing mobile broadband adoption. There are severe data network congestion problems in metropolitan areas, particularly Jakarta, Indonesia's capital city. Urgent action is required to address infrastructure and capacity limitations and maintain reliable connectivity. Carrier aggregation (CA) may alleviate bottlenecks by giving users higher bandwidth, throughput, and data rates. This research examined the techno-economic aspects of using 2.1 GHz CA versus non-CA in an urban region of North Jakarta. CA required fewer eNodeB and performed better on key performance indicators like received signal power, signal-to-noise ratio, and throughput. Cellular operators also saw faster investment returns with CA. CA's performance and economic benefits make it a promising solution for Indonesia's 4G network congestion.**

Keywords **– 4G network, carrier aggregation, cellular technology, urban area, techno-economic.**

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1. Introduction

Over the past several decades, Indonesia has undergone immense growth in mobile communications technology. Following the launch of the pioneering 2G in the early 1990s, cellular communication services have continued to expand and become indispensable. Hence, nowadays, there is a sharp trend toward mobile broadband, which will drive the further development of cellular networks. The massive growth of data traffic in Indonesia can be traced back to the widespread use of handheld mobile devices such as smartphones and tablets and the emergence of high-speed mobile networks such as 4G Long-Term Evolution Advanced (LTE-A) networks. As a result, 4G LTE-A users are increasing so rapidly that Indonesia's Ministry of Communications and Information Technology has recently issued a news announcement initiating an investigation into the massive network congestion occurring in ten of Indonesia's most populous cities [1]. This includes the North Jakarta area, a part of the Special Capital Region of Jakarta, which turned out to be the center of growth from the Jakarta City government in the fifth century and has many historical sites and beaches for local and foreign tourists.

Many mobile network operators (MNOs) are already planning for, or are in the process of addressing, the expected increase in mobile broadband demand for their infrastructure. Several strategies have been proposed to overcome the obstacle and keep or expand the necessary coverage, capacity, and quality of service (QoS), while still getting a decent return on investment (ROI), and one of the possible solutions is to implement the carrier aggregation (CA) technique by adding the available 2.1 GHz frequency of 3G to the 4G LTE-A network [2].

Previously, a research simulation of 4G LTE-A was conducted in an urban area of the North Jakarta region by using low frequency [3]. It calculated the required number of eNodeB needed in that region based on the capacity and coverage aspects and simulated the results with network simulation software. Previous research did not conduct a study that accounts feasibility based on economic modeling to evaluate deploying a 4G LTE-A network using the 700 MHz frequency band. Furthermore, it did not consider implementing a 4G LTE-A network by adding additional frequencies through the CA technique. Therefore, this research aims to examine whether employing the CA technique by adding the 2.1 GHz frequency is beneficial and may assist operators in enhancing the network of the desired region, using a techno-economic approach.

Section I presents the introduction and the background of this research. In Section II, the underlying theoretical work that serves as the basis for the techno-economic methodology of this study is discussed. The methods utilized in this research are elaborated on in Section III. Section IV presents the findings of the study and provides discussion. Finally, Section V summarizes the conclusions derived from this research.

2. Underlying Theories

This section delves into the underlying theories that serve as the basis of this research. This section is divided into two, namely, carrier aggregation and the techno-economic approach.

2.1. Carrier Aggregation

Nowadays, in most of the country, only a handful of mobile phone service providers operate on a continuous 100 MHz spectrum. This is because of the lack of spectrum and the abundance of service providers in a nation. As a result, a new method that could help solve the problem emerged and is now known as the CA technique. CA allows combining spectrum either within the same band in a contiguous or non-contiguous manner, or across multiple separate bands. This technique allows single user equipment (UE) to utilize up to 100 MHz of radio bandwidth [4]. The radio access network working group 4 of the 3rd Generation Partnership Project (3GPP) is responsible for establishing the performance criteria for the CA method, which initially restricts aggregation to no more than two component carriers (CC), which is the aggregated channel carrier.

The number of aggregated carriers can vary between the downlink and uplink.

However, the number of uplink CCs cannot exceed the number of downlink CCs. Additionally, each CC may have a different bandwidth. As shown in Figure 1, there are three distinct CA techniques for 4G LTE-A. Those are:

- Intra-band contiguous - the sequential use of two or more channels within the same frequency range;
- Intra-band non-contiguous - a method for aggregating channels with a distance between them inside a single frequency band; and
- Inter-band non-contiguous - a technique for aggregating different bands of frequency channels [5].

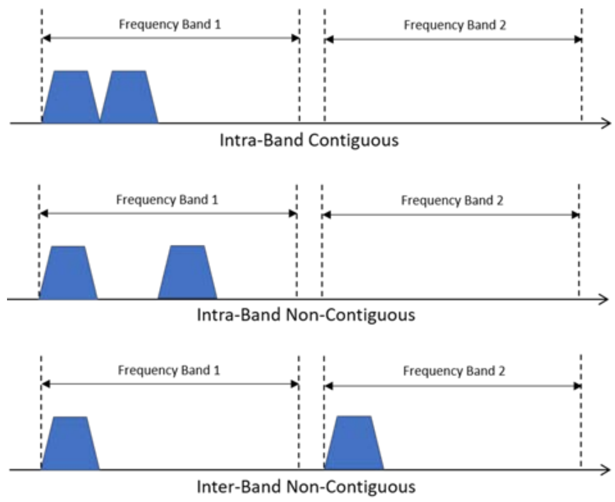

Figure 1. Three different types of CA techniques

The CA technique have two kinds of serving cells: primary serving cells (PCell) and secondary serving cells (SCell). The PCell manages the primary component carrier (PCC) for downlink, uplink, and the Radio Resource Control (RRC) connection, while the SCell handles secondary component carrier (SCC) connections. There is only one PCC, but potentially multiple SCCs. Therefore, the coverage of PCell and SCell can differ based on the frequencies utilized [6].

2.2. Techno-Economic Approach

For the purpose of determining whether or not a business project is feasible, a model that employs a techno-economic approach is utilized. This model considers both the technical and economic elements of the process. The assessment will provide a comprehensive detail that Indonesian mobile network operators (MNOs) can potentially utilize as an informative guide when deciding whether to incorporate CA or not.

2.2.1. Technical Aspect

The underlying theories related to technical parameters will be discussed in this part, including key performance indicators (KPIs), capacity planning, coverage planning, and network simulation.

- Key Performance Indicators (KPIs):
  Information on key performance indicators (KPIs) is useful for a variety of purposes, including but not limited to planning, performance analysis, and optimization of a network. This research focuses on the reference signal received power (RSRP), signal-interference-to-noise ratio (SINR), and throughput. The following Table 1 provides the categorization range for the quality of these three KPI parameters [7].

Table 1. KPIs categorization

Category	Throughput (kbps)	SINR (dB)	RSRP (dBm)
Worst	R less than -101	$-10 < S \leq 0$	-
Bad	$-101 < R \leq -91$	-	$0 < T \leq 338$
Normal	$-91 < R \leq -81$	$0 < S \leq 15$	$338 < T \leq 700$
Good	$-81 < R \leq -71$	-	$700 < T \leq 1200$
Excellent	R greater than -71	$15 < S \leq 30$	T greater than 1200

- Capacity Planning:
  When carrying out technical analysis, capacity planning is an essential aspect to consider. Capacity planning involves projecting the amount of network bandwidth and infrastructure required to meet the needs of users within a specific region. It aims to determine the optimal quantity of eNodeB base stations to deploy in a region based on factors like the total population size and density. This analysis will proceed through a number of steps, such as forecasting the number of users, calculating the network throughput, and determining the site capacity [8].
- Coverage Planning:
  It is possible to estimate how many sites will be needed to cover all of the target areas with the help of a design that is based on coverage planning. The radio link budget and the propagation model are taken into account during coverage planning.
  Through the use of a radio link budget, the maximum acceptable path loss (MAPL) between the UE and the eNodeB antenna can be estimated [8].
- Network Simulation:
  It is crucial for an operator to carefully consider the tradeoffs involved in network design and optimization in order to offer customers a high-quality network and affordable calls. This study uses the Forsk Atoll network simulator to plan new frequencies for 4G LTE-A technology. Forsk Atoll is a platform for designing and optimizing multi-technology networks that are scalable and flexible. It helps MNO from the initial design and continues through densification and optimization.

2.2.2. Economic Aspect

This section will closely look at the fundamental economic theories and models that are important for financial review and evaluating feasibility. The cost models are discussed, including capital expenditure (CAPEX) models that look at upfront investment costs and operating expenditure (OPEX) models that review ongoing operating costs. Then, the project feasibility models are explained, specifically: (i) the net present value (NPV), which calculates future cash flows; (ii) the internal rate of return (IRR), which estimates the expected return on investment; and (iii) payback period (PBP), which measures how long it takes to recover an investment. Additionally, it will cover sensitivity analysis as a way to understand how possible changes to things like costs and revenue impact outcomes. The goal is to provide an in-depth overview of business and investment evaluation. Further explanations are as follows:

- Cost
  - Capital Expenditures (CAPEX):
    When calculating the capital expenditure (CAPEX), the upfront costs associated with deploying a new wireless technology are taken into account. These expenditures are typically considered company assets. The CAPEX in this research included the cost of supporting eNodeB equipment, the cost of LTE home subscriber service (HSS), the cost of the gateway, the cost of the software licensing, and the cost of installing each eNodeB [9].
  - Operational Expenditures (OPEX):
    Operational expenditure (OPEX) is the cost of running a company on a daily basis. Expenditures on operating expenses are typically depleted within a year of acquisition.

Due to this, OPEX is fundamental for assessing the efficiency of a business. Since this is the case, it is crucial for both internal and external analysts to track the expenses for the company's operation, identify the company's major cost drivers, and evaluate management effectiveness [9].

- Feasibility
  - Net Present Value (NPV):

    When conducting a financial analysis to determine whether or not an investment in a project or business is feasible, the net present value (NPV) method is frequently employed. The profitability of a project can be calculated by using the net present value technique. It takes into account the value of money over time. As a result, future cash flows hold a lower value compared to current cash flows, particularly when spread out over a longer period [9].
  - Internal Rate of Return (IRR):

    It is common practice in the world of finance to calculate the prospective return on investment utilizing a metric named the internal rate of return (IRR). It is the metric that is commonly comprehended when the annual rate of a return causes the NPV to be equal to zero. An internal rate of return is a measure of how profitable an investment is expected to be over time. Therefore, IRR is the best way to compare possible annual return rates over time when looking at capital budgeting projects [9].
  - Payback Period (PBP):

    The time it takes for a project to earn back its initial investment is referred to as the payback period (PBP). This period is typically expressed in years and months, although any suitable time frame for the project's duration can be utilized. The PBP analyzes the investment's cash flow in detail, including the total cash flow generated by the investment up until the point at which the initial investment has been recovered [9].
- Sensitivity Model:

  A sensitivity model can help a company predict how the project will progress if certain fundamental assumptions and estimates are inaccurate. Sensitivity analysis examines how a project's bottom line would change if various assumptions or estimations were used. In this approach, the company's upper management may evaluate the project's viability better before investing in the event that could fail to produce the desired outcomes [10].

3. Research Methodology

This section will discuss the research methodology of this study. The objective is to provide a clear and structured research approach. This will include an overview of the study's area, research framework, simulated scenarios, and techno-economic design.

3.1. Area of Study

The North Jakarta region, an urban area with a surface space of 140 km^2, has been selected in this research as the location to model the 4G network with CA technique's frequency addition design. Moreover, the North Jakarta region was selected to model the 4G LTE-A network expansion because, as a commercial hub situated in the congested capital city of Jakarta, Indonesia, it is presently facing substantial network traffic bottlenecks that require urgent mitigation. In addition, North Jakarta is a popular destination for both domestic and international tourists because of its proximity to Jakarta, Indonesia's capital city. Because of this, the telecommunications industry is motivated to keep providing reliable internet access so that these travelers can feel at ease while having their holidays or businesses. The map of North Jakarta's urban area is shown in Figure 2.

Figure 2. The map view of North Jakarta region

3.2. Research Framework

Several steps were taken to complete this research, including gathering relevant data and performing technical and economic evaluations. This research intends to formulate a scheme for deploying 2.1 GHz as an additional frequency band to enhance 4G LTE-A network in the North Jakarta area, with Figure 3 outlining the overall research framework.

This research begins with data collection, which includes gathering information on the selected area, such as the population and economic data. Following that, a detailed technical study was carried out. Two approaches were used to conduct the technical analysis: a capacity planning analysis and a coverage planning analysis using the CA and the non-CA methods.

In addition, three different approaches were used to do the economic study: one that focused on cost metrics, another on the feasibility of the business, and the third on the sensitivity study that analyzed the impact of potential variables on the outcome. Finally, the research continued with results and discussion before reaching a conclusion.

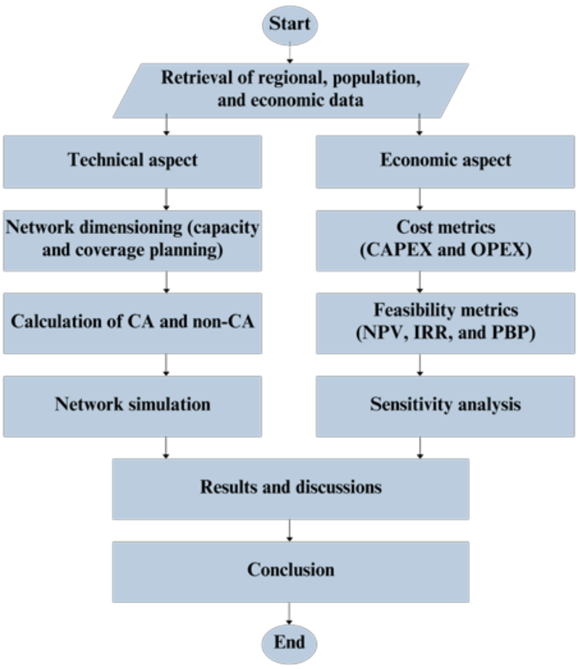

Figure 3. Framework for conducting this research

3.3. Simulation Scenarios

After the completion of capacity and coverage planning, which is also known as network dimensioning, the simulation scenario is executed. Subsequently, the two network plans are evaluated comparatively and the simulation employs the design that requires the larger quantity of eNodeB base stations. The results of this research's simulation scenario are the three KPI values (RSRP, SINR, and throughput) and a service quality evaluation based on the primary frequency of the 2.1 GHz band with the CA technique implemented, that is paired with 1.8 GHz as the second frequency and when the 2.1 GHz frequency is implemented without the CA technique.

3.4. Techno-Economic Design

This research's techno-economic design incorporates essential planning factors including capacity, coverage, CAPEX, OPEX, NPV, IRR, and PBP, as well as an analysis of sensitivity to assess feasibility and performance in determining the viability of implementing CA technique.

3.4.1. Capacity Planning

Predicting the expected number of users is the first step in the capacity planning computation. This research makes use of a demographic projection for North Jakarta in 2021 to project future cellular usage over the next five years. In this study, population forecasting results are adjusted based on penetration on the number of people in productive age, which is assumed to be between 15 and 65 years old for cellular users in North Jakarta. This is also due to most people who use 4G LTE-A users falls within the working age group. Furthermore, not all working-age adults utilize the same operator. For our analysis, we have chosen Telkomsel, an Indonesian telecommunication company, as a case study because of its large market share (59.2%) and projected high adoption rate (83.5%) of 4G LTE-Advanced technology. Equation 1 is utilized to estimate the number of populations in the research area for the upcoming five years,

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

where P_n is the predicted quantity of users in a specific year n. Then we have P_o as the population in the working age range (15-64), and the growth factor, GF, is used to find the users' projections of the rate in penetration [10]. Table 2 shows the anticipated growth of 4G LTE-A subscribers in the North Jakarta urban area.

Table 2. Estimating the 4G LTE-A network subscribers

Key Parameters	Region of North Jakarta
2021 population	1,778,981
Growth rate (%)	0.76 %
2026 population projection	1,140,261

The next step is to figure out the network's throughput. In order to calculate the network throughput, we only need to multiply the throughput for a single user by the predicted total number of users. Both equation (2) and equation (3) can be used to calculate this value [11].

$$Throughput_{Single\ user} = \Sigma[(Throughput\ / \ Session) \times Peak\ Hour \times Penetration\ Rate \times (1 + Peak\ to\ Average\ Ratio)] / 3600 \qquad (2)$$

$$Throughput_{network} = Throughput_{Single\ user} \times Total\ Target\ User \qquad (3)$$

Once all other necessary capacity elements are accounted for, the capacity planning analysis proceeds to ascertain the quantity of eNodeB needed to augment the network frequency. This estimation is derived from data collected from the planning area, which in this case is North Jakarta. For this reason, the number of eNodeB needed for capacity planning can be found by calculating equation (4) and equation (5) [11].

$$Capacity_{site} = Throughput_{Single\ user} \times 3 \quad (4)$$

$$Capacity\ Number_{eNodeB} = \frac{Throughput_{network}}{Capacity_{site}} \quad (5)$$

3.4.2. Coverage Planning

Another crucial factor of technical analysis is anticipating the required eNodeB to cover the whole research area through coverage planning. The objective of coverage planning is to ensure users within a specific area can access the network's services. In addition, the overall number of sites that will be monitoring the region is determined through coverage planning. Coverage planning requires defining the link budget, path loss, and propagation models for predicting uplink and downlink signal.

There would be some differences between the outcomes of link budget calculations performed using the CA technique and those performed using the non-CA technique. Therefore, both uplink and downlink, link budgets are calculated in this research. Table 3 summarizes the link budget values for the CA technique and for non-CA technique [12].

Table 3. Uplink and downlink link budget values for both CA and non-CA techniques

Uplink CA		Downlink CA		Uplink Non-CA		Downlink Non-CA	
Transmitter Power (dBm)	23	Transmitter Power (dBm)	46	Transmitter Power for UE (dBm)	23	Transmitter Power for eNB (dBm)	46
Block	4	Block	100	Gain for UE (dBi)	0	Gain for eNB (dBi)	17
Subcarrier to Distribute Power	48	Subcarrier to Distribute Power	1200	Loss of Body (dB)	0	Loss of Cable (dB)	2
Power for Subcarrier (dBm)	6	Power for Subcarrier (dBm)	15	EIRP (dBm)	23	EIRP (dBm)	61
Transmitter's Loss of Body (dB)	0	Gain for Transmitter (dB)	17	Noise Figure for eNB (dB)	2	Noise Figure for UE (dB)	7
Subcarrier's EIRP (dBm)	6	Subcarrier's EIRP (dBm)	32	Noise for Thermal (dB)	-132	Noise for Thermal (dB)	-132
Noise for Thermal (dB)	-131	Noise for Thermal (dB)	-131	Signal-noise Ratio for Receiver (dB)	-7	Signal-noise ratio for Receiver (dB)	-9
Signal-noise Ratio (dB)	-7	Signal-noise Ratio (dB)	-9	Receiver Sensitivity (dB)	-137	Receiver Sensitivity (dB)	-134
Noise Figure for Receiver (dB)	2	Noise Figure for Receiver (dB)	7	Margin for Interference (dB)	1	Margin for Interference (dB)	4
Receiver Sensitivity (dBm)	-135	Receiver Sensitivity (dBm)	-132	Gain for Masthead (dB)	0	Control Channel Overload (dB)	1
Gain for Receiver (dBi)	17	Loss of Body for Receiver (dBi)	0	Loss of Cable (dB)	2	Loss of Body (dB)	0
Margin for Interference (dB)	1	Margin for Interference (dB)	4	Gain for eNB (dBi)	17	Gain for UE (dBi)	0
PL (dB)	129	PL (dB)	134	PL (dB)	174	PL (dB)	190

Once the uplink and downlink MAPL values have been obtained, the propagation model can be selected. In this research, the COST231 propagation model is most applicable for this research because the selected 2.1 GHz frequency fits in the maximum range of COST231 frequency, which is 2.2 GHz. The equation (6) and equation (7) are used to obtain the path loss value when utilizing the COST231 propagation model.

$$COST231 = 49.3 + (33.9 \times \log f_c) - (13.82 \times \log h_b) - a(h_m) + [44.9 - (6.55 \times \log h_b) \times \log d] + C \quad (6)$$

$$a(h_m) = 3.2\,[\log(11.75 \times h_m)]^2 - 4.97 \quad (7)$$

where f_c represents frequency, h_b and h_m signifies transmitter and receiver antenna's height respectively, d equals distance in kilometers between transmitter and user, $a(h)_m$ denotes factor of correction, and C takes on a value of 3 dB for urban environments. In the COST231 propagation model, the value of $a(h)_m$ stays the same for both uplink and downlink for both techniques (CA and non-CA). Meanwhile, $\log d$ and d value differs. In the $\log d$, uplink CA is -0.417, downlink CA is -0.294, uplink non-CA is 0.840, and downlink non-CA is 1.294. Lastly, in the value of d, uplink CA is 0.383, downlink CA is 0.508, uplink non-CA is 6.916, and downlink non-CA is 19.683.

Lastly, to conclude the coverage planning design, we will determine how many eNodeB will be required in the research planning area in order to provide the desired 4G LTE-A network frequency for the 4G LTE-A population users [12]. Therefore, the coverage planning for eNodeB requirements can be calculated by employing equation (8) and equation (9).

$$Coverage_{cell} = 1.95 \times 2.6 \times d^2 \quad (8)$$

$$Coverage\ Number_{eNodeB} = \frac{Surface\ Area}{Coverage_{cell}} \quad (9)$$

3.4.3. CAPEX and OPEX Planning

To add 4G LTE-A frequencies, it is necessary to consider the CAPEX and OPEX. The CAPEX expense is the sum of the device fee and the labor cost to install the device. Since this project uses an already existing tower, operating expenses consist of personnel, maintenance, and a fee to the government for the radio frequency spectrum. Table 4 and Table 5 provide the CAPEX and OPEX cost assumptions, respectively. This research's interest rate assumptions are based on an Indonesian Government Bank, Bank Mandiri's 10% basic loan interest rate.

Furthermore, the average revenue per user (ARPU) used is Rp 44,000, which is from Telkomsel [13].

Table 4. Required equipment for CAPEX

Equipment	Cost per Equipment (Rupiah)	Unit
eNodeB (support equipment)	22,495,902	Per extra eNodeB
LTE home subscriber server (HSS)	106,096,119	1
Gateway	28,080,474	1
Software license	15,016,373	Per extra eNodeB
Installation	10,000,000	Per eNodeB

Table 5. Required equipment for OPEX

Equipment	Cost per Equipment (Rupiah)	Unit
Base transmitter tower (BTS) Rental	12,000,000	Per BTS
Maintenance fee	5,068,000	Per eNodeB
Electricity fee	5,000,000	Per eNodeB monthly
Marketing fee	10%	Gross revenue
Salary for personnel	50,000,000	Monthly
Spectrum frequency fee	7,012,852	Annually
Universal service obligation (USO) fee	1.25%	Gross revenue
Telecommunication fee	0.50%	Gross revenue

3.4.4. NPV Planning

The net present value for a project is computed by applying a specified discount rate to reduce future cash inflows and outflows to present value then combining the resulting discounted cash flow amounts. The NPV can be determined by computing equation (10), as in,

$$NPV = \sum_{n=1} \frac{CF_n}{(1+K)^n} - I_0 \quad (10)$$

where the net present value calculation sums the present value of each year's net cash flow CF_n discounted at rate K over the project lifetime n after initial investment I_0 occurs in year zero. Table 6 presents the NPV evaluation criteria [14].

Table 6. Evaluation criteria for NPV parameter

Condition	Meaning	Action
NPV > 0	The business will gain profit from the investment.	Execute project.
NPV < 0	The investment will result in a loss for the business.	Reject project.
NPV = 0	The investment results in neither profit nor loss for the company.	Does not affect the company.

3.4.5. IRR Planning

The internal rate of return is the discount rate that produces a net present value of zero, calculated using equation (11).

$$IRR = NCF_0 + \frac{NCF_1}{(1+IRR)_1} + \cdots + \frac{NCF_n}{(1+IRR)_n} = 0 \quad (11)$$

where NCF in year n is the value of net cash flow within that specified time. The IRR values generated from this computation can be used to determine whether an investment opportunity is viable. If an investment's internal rate of return surpasses the mandated minimum rate it is considered acceptable, whereas if the computed IRR is lower to the fixed interest rate, the investment is rejected [15].

3.4.6. PBP Planning

The PBP is a method for estimating how long it will take for a project to recoup its funding through income. Equation (12) is utilized to get the value of the PBP.

$$PBP = n + \frac{x-y}{z-y} \times annual\ year \quad (12)$$

where the payback period formula calculates the time n in years for cumulative cash flows y to exceed the initial investment x by also considering cash flows z in the following year $n+1$, and an investment is typically accepted if the payback period return surpasses estimations but rejected if less than estimates [16].

3.4.7. Sensitivity Analysis

Business sensitivity analysis explore how the performance parameters change and affect the profitability of the business. The analysis includes optimistic, moderate, and pessimistic scenarios. The baseline estimate for the currency change rate is obtained from averaging data between 2016 to 2020, which is 3.12%, where the highest change rate occurs in March 2020, with Rp 16,367. The prerequisites for sensitivity scenarios are outlined in Table 7.

Table 7. Prerequisites for sensitivity scenarios

Scenarios	Indicators	Criteria
Optimistic	Increase in ARPU	+3.12%
	Dollar currency change rate	Rp 13,662
	Increase in 4G subscribers	+3.12%
Moderate	Fixed ARPU	Normal
	Fixed Dollar Currency Rate	Normal
	Fixed subscribers	Normal
Pessimistic	Decrease in ARPU	-3.12%
	Dollar currency change rate	Rp 16,367
	Decrease in 4G subscribers	–3.12%

4. Results and Discussion

In this section, the results and analysis of the research study are presented. In addition, tables, figures, and charts are included to assist in explanation and highlighting the achieved findings.

4.1. CA and Non-CA Capacity Planning Analysis

The quantity of eNodeB needed in North Jakarta is finalized through capacity planning, with the CA and non-CA approaches demanding distinct eNodeB totals. Table 8 presents the parameters derived from the computation of capacity planning using CA and non-CA techniques for uplink and downlink views.

Table 8. Capacity results for both CA and non-CA

Parameters	Uplink CA	Downlink CA	Uplink Non-CA	Downlink Non-CA
Number of eNodeB	27	123	39	176
Users per eNodeB	22,316	4,899	15,450	3,424
Cell Coverage (km^2)	5.185	1.138	3.589	0.795
Cell Radius (km)	1.011	0.474	0.841	0.396

According to the CA technique, North Jakarta needs 27 uplink and 123 downlink eNodeB. On the other hand, the non-CA approach requires 39 uplink and 176 downlink eNodeB for analysis results. Hence, in capacity planning, 123 eNodeB is chosen to represent the CA technique and 176 eNodeB for the non-CA technique.

4.2. CA and Non-CA Coverage Planning Analysis

When the cell coverage area has been determined, the next step is to figure out how many eNodeB will be required. The link budget computations determine that CA and non-CA approaches require different eNodeB amounts, with Table 9 presenting the results for both techniques. The CA technique requires 23 eNodeB for uplink and downlink while the non-CA technique requires 60 eNodeB. Based on these data, in coverage planning, 23 eNodeB is chosen to represent the CA technique, while 60 eNodeB for the non-CA technique.

Table 9. Coverage results for both CA and non-CA

Parameters	Uplink CA	Downlink CA	Uplink Non-CA	Downlink Non-CA
Cell Coverage (km^2)	2.337	2.337	242.516	1964.220
Number of eNodeB	23	23	60	60

4.3. Determine the Final Required Number of eNodeB

The final required eNodeB number is determined by comparing capacity and coverage planning outcomes, with the Atoll simulation utilizing the maximum eNodeB value from them. Based on the results of these two different planning approaches, the CA technique in North Jakarta comprises 123 eNodeB. Meanwhile, 176 eNodeB is used to represent the non-CA technique. Atoll software will be utilized to simulate the network by using these data to evaluate the technical aspect of the research.

4.4. Simulation Results

The simulation results are comprised of the results from planning the simulation with CA and non-CA techniques, as well as the results from the three KPIs. Additionally, the results from conducting feasibility and sensitivity analyses are also included.

4.4.1. Planning Simulation

Based on 4G LTE-A frequency planning results, North Jakarta needs 123 eNodeB with a radius of 0.474 km for the CA technique, which uses 2.1 GHz and 1.8 GHz frequencies. Figure 4 displays the CA technique planning simulations in North Jakarta. Then, the North Jakarta requires 176 eNodeB with a 0.396 km radius in the non-CA technique.

Figure 5 illustrates the non-CA technique planning simulations in North Jakarta.

Figure 4. CA predicted coverage results

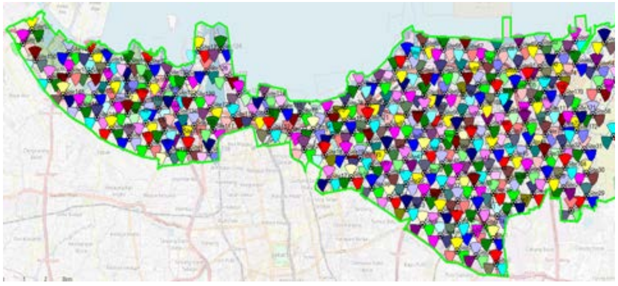

Figure 5. Non-CA predicted coverage results

4.4.2. RSRP Simulation

Based on Table 1's RSRP assessment parameters, the CA technique yields an average RSRP value of -69.42 dBm, with 38.99% of North Jakarta having a "normal" value between -80 and -85 dBm, and these data are delivered in Figure 6. On the other hand, the non-CA technique yields an average RSRP value of -68.68 dBm, with 61.40% of North Jakarta having a "normal" value between -80 and -85 dBm, and these data are provided in Figure 7.

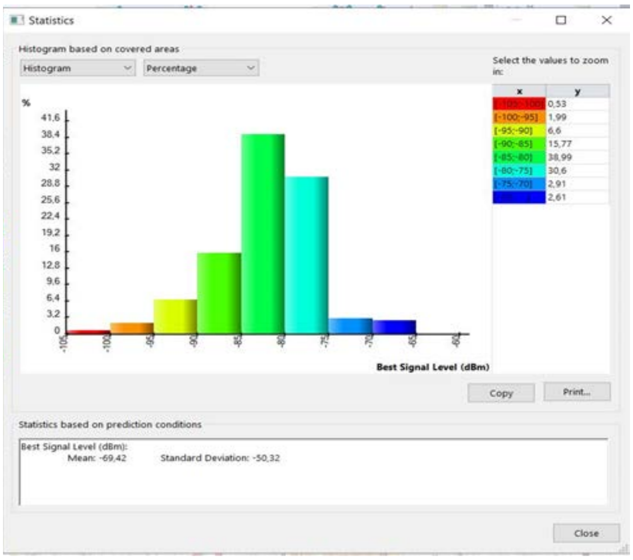

Figure 6. CA technique RSRP results

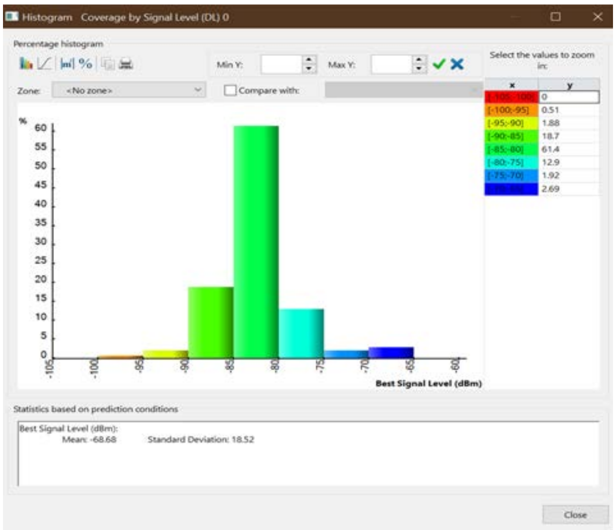

Figure 7. Non-CA technique RSRP results

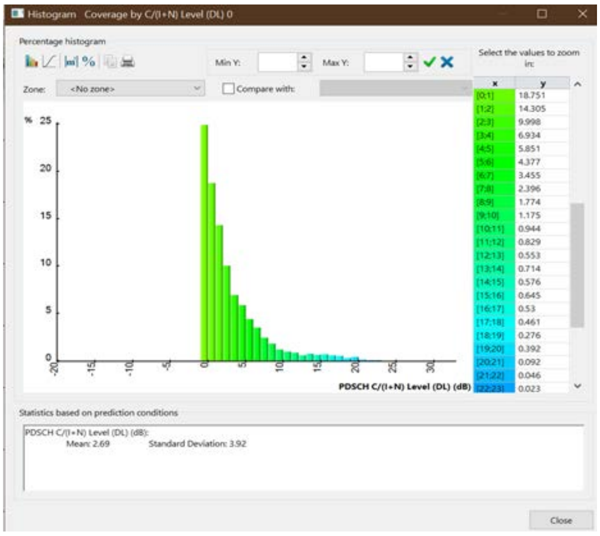

Figure 9. Non-CA technique SINR results

4.4.3. *SINR Simulation*

With SINR assessment parameters from Table 1, Figure 8 shows an average SINR of 2.61 dB for the CA technique in North Jakarta's urban area. On the other hand, an average SINR of 2.69 dB resulted from utilizing the non-CA approach, as exhibited in Figure 9. This demonstrates the SINR ranges are normal and non-disruptive in this region.

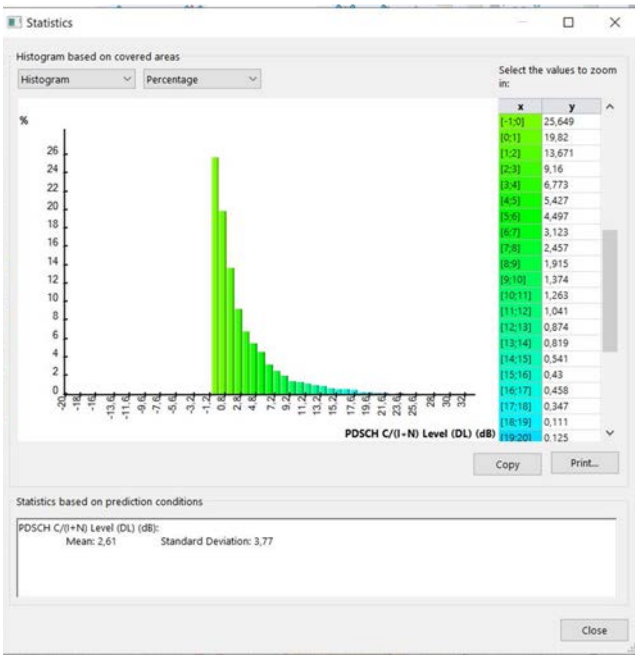

Figure 8. CA technique SINR results

4.4.4. *Throughput Simulation*

Based on Table 1's throughput assessment parameters, the CA technique has an average throughput of 26,442.18 kbps for North Jakarta, whereas the non-CA technique has 20,735.53 kbps. Indicating that in 2026, 4G LTE-A clients in North Jakarta will have good throughput. Figure 10 shows the throughput for North Jakarta using the CA technique, while Figure 11 shows the non-CA technique results.

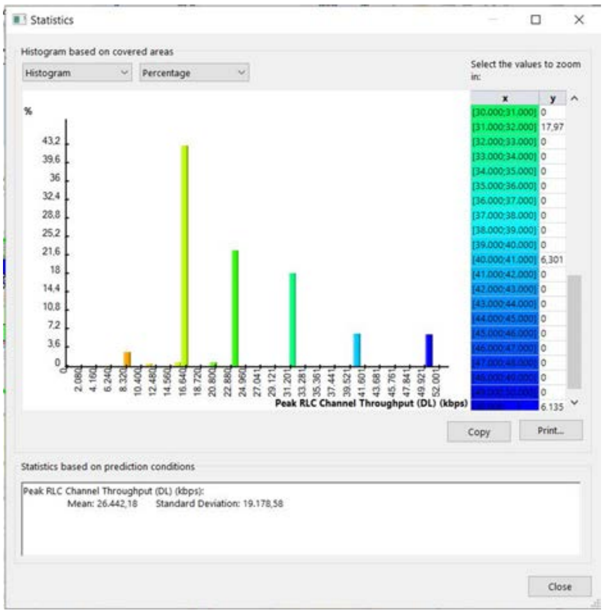

Figure 10. CA technique throughput results

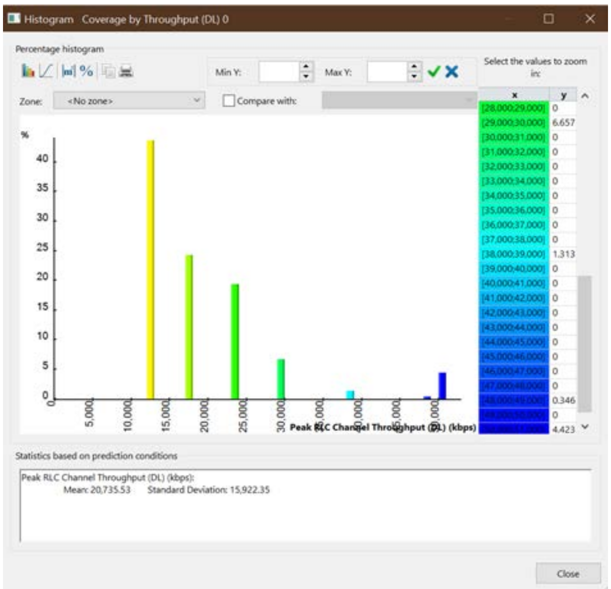

Figure 11. Non-CA technique throughput results

4.5. CAPEX and OPEX Analysis

This research calculates CAPEX and OPEX costs based on identical assumptions between CA and non-CA for eNodeB amounts, active users, and network availability. This research calculated the CAPEX and OPEX using the cost assumptions from Tables 4 and 5, where we obtained the CAPEX estimations in Figure 12 below, while the Figure 13 estimates the OPEX. The graph labeled Carrier Aggregation North Jakarta as CA NJ and Non-Carrier Aggregation North Jakarta as NCA NJ. Figures 12 and 13 show that CAPEX decreases while OPEX increases every year. The CA technique is cheaper to implement than the non-CA technique since CA requires fewer eNodeB than non-CA techniques.

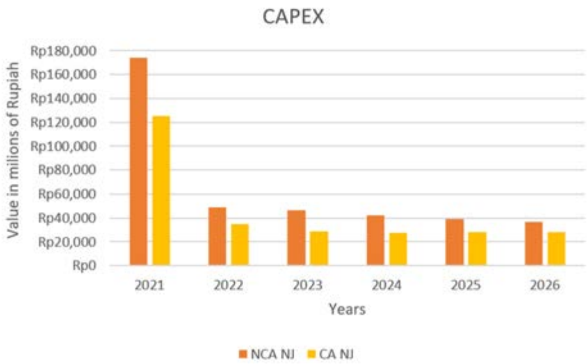

Figure 12. CAPEX in the urban North Jakarta region

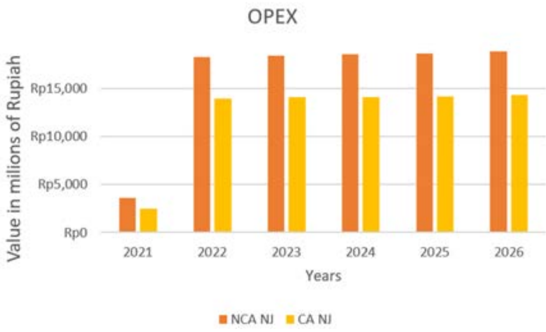

Figure 13. OPEX in the urban North Jakarta region

4.6. NPV, IRR, and PBP Analysis

A business feasibility study considers NPV, IRR, and PBP values, with viability requiring positive figures. Thus, this research is conducted based on CAPEX and OPEX, with Table 10 showing the analysis results. The CA technique returns investment in the first year while non-CA requires almost three years, so CA is most reasonable to implement given its faster payback period.

Table 10. NPV, IRR, and PBP results

Technique	NPV (Rupiah)	IRR	PBP
CA	33,239,970,428	104.91%	0.958 ≈ 12 months
Non-CA	9,022,229,924	29.64%	2.92 ≈ 2 years 11 months

4.7. Sensitivity Analysis

Sensitivity analysis results demonstrate that the specified elements factors strongly affect revenue. Figures 14–16 illustrate each scenario's CAPEX-OPEX chart (optimistic, moderate, and pessimistic). Due to fewer eNodeB needs, the CA technique is cheaper.

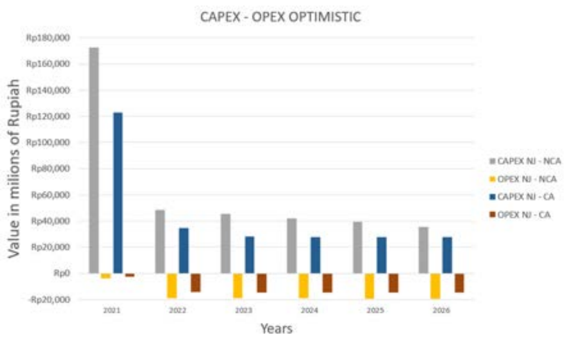

Figure 14. Optimistic scenario for CAPEX-OPEX

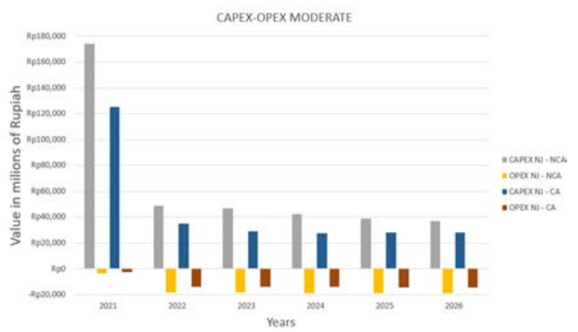

Figure 15. Moderate scenario for CAPEX-OPEX

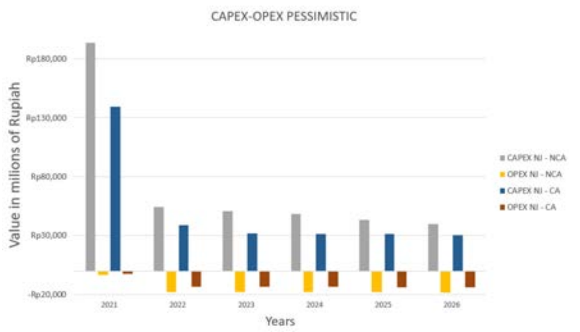

Figure 16. Pessimistic scenario for CAPEX-OPEX

The analysis of the optimistic, moderate, and pessimistic scenarios in Table 11 is essential to assess adding 4G LTE-A frequency in North Jakarta. The CA technique produces positive NPV, IRR, and PBP values faster than the maximum timeframe in all cases. In contrast, non-CA takes longer with lower returns, but remains viable. Therefore, CA is the preferable approach for deploying the additional 2.1 GHz band, providing operators with better financial outcomes compared to non-CA.

Table 11. Sensitivity results of three scenarios

Methods	**Optimistic**	**Moderate**	**Pessimistic**
NPV CA (Rp)	38,233,684,331	33,239,970,428	27,025,341,307
NPV Non-CA	13,480,652,442	9,022,229,924	2,614,770,914
IRR CA	120.08%	104.91%	82.66%
IRR Non-CA	39.49%	29.64%	14.08%
PBP CA	0.838 ≈ 10 months	0.958 ≈ 12 months	1.938 ≈ 1 year 11 months
PBP Non-CA	2.92 ≈ Almost 3 years	2.92 ≈ Almost 3 years	3.904 ≈ Almost 4 years

5. Conclusion

This research found that 123 eNodeB were needed to cover North Jakarta's area with an average RSRP of -69.42 dBm, SINR of 2.61 dB, and throughput of 26,442.18 kbps using the CA technique. Furthermore, CA produced an NPV of Rp 33,239,970,428, an IRR of 104.91%, and a one-year PBP, while the non-CA approach required 176 eNodeB in North Jakarta. The average RSRP value was -68.68 dB, the average SINR was 2.69 dB, and the average throughput was 20,735.53 kbps. Therefore, the non-CA technique yielded an NPV of Rp 9,022,229,924, an IRR of 29.64%, and an investment return of PBP in two years and eleven months. Each scenario from the sensitivity results gave acceptable and feasible outcomes for both CA and non-CA techniques, noting that the CA technique had better sensitivity results than the non-CA. In conclusion, CA adoption for deploying 4G LTE-A in the intended region by appending 2.1 GHz as an added band is more appropriate and operator-beneficial than non-CA. For future research, we recommend assessing different techno-economic techniques that consider the CA technique's utilization on the forthcoming 5G cellular network's low, mid, and high band frequencies.

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References:

[1]. Ministry of Communication and Information Technology. (2017). Physical Condition of Cellular Mobile Telecommunication Network Congestion in Non-Rural Areas. 1–5.

[2]. Nashiruddin, M. I., Aulia Fadhila, P., Adriansyah, N. M., Nugraha, M. A., & Rahmawati, P. (2023). Implementing Carrier Aggregation on 4G Long Term Evolution-Advanced Network in a Dense Urban Area: A Techno-Economic Assessment. *Journal of Communications*, 357–368. Engineering and Technology Publishing. Doi: 10.12720/jcm.18.6.357-368

[3]. Nashiruddin, M. I., Aulia Fadhila, P., & Nugraha, M. A. (2021). 4G LTE-Advanced Network Planning and Simulation Study in an Urban Region Utilizing the 700 MHz Frequency. *2021 IEEE 12th Annual Ubiquitous Computing, Electronics & Mobile Communication Conference.*

[4]. Akselrod, M. (2020). Application-Level Performance of Carrier Aggregation in a Live LTE Network. *2020 IEEE 92nd Vehicular Technology Conference (VTC2020-Fall)*, 1–6.

[5]. Ameen, A. S. (2021). A proposed efficiency metric for LTE-advanced carrier aggregation. *IET Communications*, *15*(6), 840–849.

[6]. Anritsu. (2015). *Understanding Carrier Aggregation*[White paper]. Anritsu Company. Retrieved from: http://vertassets.blob.core.windows.net/download/a8782958/a8782958-3c88-44d2-9204-f6e37a862025/understanding_carrier_aggregation_white_paper_june_2015.pdf [accessed: 10 March 2023].

[7]. Wahyudin, A., & Sakinah, S. (2017). Perancangan Dan Analisa Penggelaran LTE Pada Frekuensi 700 MHz Dengan Metode Adaptif Modulation Coding Untuk Implementasi Digital Dividend di Wilayah Sub-urban Dan Rural Kabupaten Banyumas. *Jurnal Elektro Dan Telekomunikasi Terapan*, *3*(2).

[8]. Ruben Jose, N. S. (2019). Forecasting the capacity of LTE mobile networks [Master's thesis, Iscte - Instituto Universitário de Lisboa].

[9]. De Souza, M. A., Kuribayashi, H. P., Saraiva, P. A., Farias, F. D. S., Vijaykumar, N. L., Francês, C. R. L., & Costa, J. C. W. A. (2021). A techno-economic framework for installing broadband networks in rural and remote areas. *IEEE Access*, *9*, 58421-58447.

[10]. Fitri, F., Munadi, R., & Adriansyah, N. M. (2021). Feasibility Study of LTE Network Implementation on Working Frequency 700 MHz, 2100 MHz, and 2300 MHz in Indonesia. *International Conference on Quality in Research (QIR): International Symposium on Electrical and Computer Engineering*, 147–152.

[11]. Telecom, knowledge. (2014). *UMTS Capacity Estimation.* Telecom, knowledge. Retrieved from: https://telecom-knowledge.blogspot.com/2014/11/umts-capacity-estimation.html [accessed: 15 May 2023].

[12]. Jha, A., & Saha, D. (2019). Coverage and Capacity Dynamics in 4G-LTE Deployment in India. *2019 International Conference on Electronics, Information, and Communication*, 1–8.

[13]. Telkomsel. (2021). *Telkomsel About us*. Telkomsel. Retrieved from: https://www.telkomsel.com/about-us/ [accessed: 03 May 2023].

[14]. Cui, X., Li, Y., Wang, X., & Wang, Z. (2022, March). Analysis of the net present value and equivalent annual cost in optimal machine life. In *2022 7th International Conference on Financial Innovation and Economic Development (ICFIED 2022)*, 2929-2933. Atlantis Press.

[15]. Dobrowolski, Z., & Drozdowski, G. (2022). Does the Net Present Value as a Financial Metric Fit Investment in Green Energy Security? *Energies, 15*(1), 353.

[16]. Sangwa, S. (2021). Capital Investment Appraisal Report for AYR Co.: Comparative Analysis of Project Aspire vs Wolf. *International Journal of Management Research and Economics*, *1*(4), 15.