ANALYSIS OF THE IMPLEMENTING INTER-BAND CARRIER AGGREGATION (CA) ON THE 5G NEW RADIO (NR) NETWORKS

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Abstract--Currently, cellular technology is advancing into the 5G era, which can support data speeds up to 10 Gbps on the uplink side and 20 Gbps on the downlink side. This study aims to plan a 5G NR network by implementing the inter-band carrier aggregation (CA) method. CA is one of the techniques used to achieve high data speeds and to combine two or more radio frequency bands. The primary cell uses band n40 at 2300 MHz with a 40 MHz bandwidth, while the secondary cell uses band n78 at 3500 MHz with a 100 MHz bandwidth. The area that we used for this network design is Agung Podomoro Land (APL) Tower Central Park area in West Jakarta. The propagation model used Urban Macro. Testing process is carried out by comparing the results between using CA and not using CA on the SS-RSRP, SS-SINR, and data rate parameters. Simulation results show an average increase in each parameter after the inter-band carrier aggregation method is applied. The SS-RSRP parameter increased by 0.05% with a value of -82.02dBm, the SS-SINR parameter increased by 0.77% with a value of 15.71dB, and the data rate parameter significantly increased by 241.33% with a value of 803.66 Mbps. This proves that implementing the carrier aggregation method can improve the quality and capacity of the network, particularly the data rate, by maximizing the use of the bandwidth and resource block produced by the combination of component carriers.

Keywords: 5G-NR; carrier aggregation (CA); data rate; SS-RSRP; SS-SINR.

I. INTRODUCTION

The current pandemic and the advancing technology demand everyone to be able to communicate and to carry out activities anytime and anywhere. Therefore, internet network has become one of the most important needs today. The commonly used technology to access internet network is the 4G Long Term Evolution (LTE). However, 4G LTE technology only has data speeds up to 500 Mbps on the uplink side and 1000 Mbps on the downlink side. In contrast, 5G technology can support data speeds up to 10 Gbps on the uplink side and 20 Gbps on the downlink side [1]. Hence, this research will further discuss the 5G network technology. The 5G technology provides a larger bandwidth capacity compared to 4G, allowing for higher mobile broadband user density and supporting three main features: enhanced Mobile Broadband (eMBB), Ultra-reliable and Low Latency Communication (uRLLC), and Massive Machine Type Communication (mMTC) [2], [3].

CA is a technique that combines two more carrier frequencies, either in the same or different bands. The purpose of implementing CA is to increase the bandwidth and meet peak data rates. In LTE-Advanced technology, the support for CA enables high throughput [12][13]. The CA inter-band non-contiguous and intra-band non-contiguous methods in LTE-A networks were also conducted in the research [14].

In this research, 5G NR network planning was conducted on the 2300 MHz and 3500 MHz frequency bands with a standalone scenario. The 2300 MHz and 3500 MHz frequencies belong to the medium frequency bands coverage and capacity layer (1 – 6 GHz) or mid-band category. The mid-band frequency category is ideal for 5G NR because it can provide good network coverage and capacity [4].

The 5G network planning in this research uses the inter-band carrier aggregation method, where carrier aggregation method allows network providers to use more than one carrier simultaneously to increase network service capacity [5]. The application of the inter-band carrier aggregation method is carried out by combining the n40 2300 MHz band with a bandwidth of 40 MHz and the n78 3500 MHz band with a bandwidth of 100 MHz. The planning area used is the APL Tower Central Park area, West Jakarta City. This area was chosen because it is a potential market, surrounded by office centers, malls, densely populated residential areas, apartments, schools, and universities. In addition, this area is also categorized as Urban, so the planning will use the Urban Macro (Uma) propagation model according to the 3GPP 38.901 standard in 5G network planning [6]. This research is expected to provide an overview and reference for 5G network planning. Hence, it can serve as a reference in determining and considering the parameters needed in 5G network planning in the future.

The process of this research begins by calculating the link budget and the number of required sites based on coverage planning and the Urban Macro propagation model. Then, the 5G NR network planning simulation is carried out using Atoll 3.4 software, followed by the configuration of the inter-band carrier aggregation method in the simulation, and the analysis of the simulation results for each parameter of SS-RSRP, SS-SINR, and data rate. In the analysis process, a comparison is made between the simulation results before and after applying the inter-band carrier aggregation method in the planning.

The rest of this paper is organized as follows. Section II presents research method. Section III describes the result and discussion of implementing inter-band carrier aggregation. Finally, Section IV concludes this paper with some concluding remarks.

II. METHOD

This research includes system design, data collection, link budget calculation, and simulation process. Flowchart of this research shown in Fig.1. The flow of the research is shown in Fig.1, where the first step involves conducting a literature study related to the research. The next step is to target the planning area using the Urban Macro propagation model. Then, link budget calculations are performed to determine the required number of sites. In the first scenario, simulation is performed without using the CA method, while in the second scenario, inter-band carrier aggregation is applied. This research uses band n40 with a bandwidth of 100 MHz for Primary Cell (PCell) and band n78 with a bandwidth of 100 MHz for Secondary Cell (SCell) [7]. PCell is the primary cell that operates at a lower carrier frequency compared to SCell, aiming to achieve good coverage. The planning area is located in the Agung Podomoro Land Tower Central Park area, West Jakarta City, with a total area of 13.9 km2.

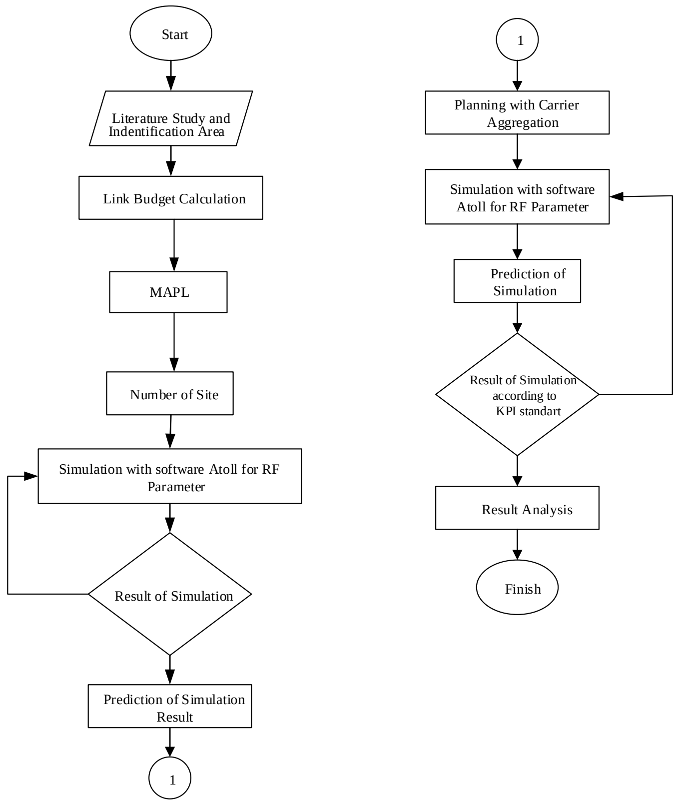

Fig. 1. Flowchart of research

A. *Link Budget Calculation*

The link budget calculation is conducted on the downlink side with frequencies of 2300 MHz and 3500 MHz. The link budget calculation is presented in Table 1, which is used to determine the total gain and loss between the transmitter and receiver [8],[9]. The pathloss value can be calculated using the equation (1).

$$Pathloss\ (dBm) = a - 10\log b + c - d - e - f - g - h - i - j + k - l - m - n \quad (1)$$

The value of resource block (RB) is determined by calculating the subcarrier quantity parameter. To calculate the thermal noise and subcarrier quantity (SCQ) in Table 1 used the equation (2) and (3):

$$Thermal\ Noise = 10\log\ (K\ T\ B) \quad (2)$$

where, K is konstanta boltzman (1,38 x 10-23 J/K), bandwidth (B) and (T) is temperature (293° K).

$$SCQ = RB\ x\ subcarrier\ per\ resource\ block \quad (3)$$

With the sum of RB is 132 and the sum of subcarrier per resource block of 12. To find the resultant value of distance (d3D), the parameter of d'_{BP}, value of h'_{BS}, h'_{UT} were needed, which can be written as:

$$h'_{BS} = h_{BS} - hE \quad (4)$$

$$h'_{UT} = h_{UT} - hE \quad (5)$$

$$d'_{BP} = 4\ x\ h'_{BS}\ x\ h'_{UT} x\ \frac{fc}{c} \quad (6)$$

where,

d'_{BP} = distance of break point (meters)
fc = frequency (GHz)
h_{BS} = height of gNodeB antenna (meters)
h_{UT} = height of user terminal antenna (meters)
c = speed of light 3 x 10^8 m/s

Model of UMa propagation for LOS condition was calculated using the equation of:

$$PL_1 = 28 + 40\ log_{10}\ (d3D) + 20\ log_{10}\ (fc) - 9\ log_{10}((d'_{BP})^2 + (h'_{BS} - h'_{UT})^2) \quad (7)$$

where PL_1 is path loss value (dBm) and d3D is resultant distance between h_{BS} and h_{UT}. After obtaining the value of based on the path loss calculation, the next step was to calculate the value of d2D which the cell radius by using the equation:

$$d2D = \sqrt{((d3D)^2 - (h_{BS} - h_{UT})^2} \quad (8)$$

Site coverage area was calculated using the equation (9):

$$Site\ Coverage\ Area = 2.6\ x\ (d_{2D})^2 \quad (9)$$

From the calculated area, the next step was to determine the number of sites needed in an area with the simulated area. The number of sites was calculated using the equation of:

$$N\ gNodeB = \frac{Total\ large\ of\ area}{Site\ coverage\ area} \quad (10)$$

The 5G network planning in this study uses the Urban Macro (UMa) propagation model according to the 3GPP 38.901 standard, which is suitable for the selected network planning area that falls under the potential market with urban conditions. Table II is parameter of propagation model urban macro and Table III is calculated result of coverage planning in this research.

TABLE I
Link Budget Parameter [8],[9]

Parameter	Notation	2300 MHz	3500 MHz
gNodeB Transmitter Power (dBm)	a	49	49
Resource Block	RB	106	273
Subcarrier quantity	b = 12*RB	1272	3276
gNodeB antenna gain (dBi)	c	18.6	15.7
gNodeB cable loss (dBi)	d	0	0
Penetration loss (dB)	e	23.41	26.85
Folliage loss (dB)	f	19.59	19.59
Body block loss (dB)	g	3	3
Interference Margin (dB)	h	6	6
Rain/Ice margin (dB)	i	0	0
Slow fading margin (dB)	j	7	7
UT antenna gain (dB)	k	0	0
Bandwidth (MHz)	BW	40	100
Konstanta boltzman (mWs/K)	K	1.38 x 10^{-20}	1.38 x 10^{-20}
Temperature (Kelvin)	T	293	293
Thermal noise power (dBm)	l = 10*log(K*T*BW)	-157.91	-153.93
UT noise figure (dB)	m	9	9
Demodulation treshold SINR (dB)	n	22.9	22.9
MAPL (dB)	**PL**	**103.565**	**89.137**

TABLE II
Parameter of Propagation Model Urban Macro [10]

Parameter	Variable	2300 MHz	3500MHz
Carrier Frequency	fc	2.3GHz	3.5GHz
Propagation Velocity in Free Space	c	3 x 10^8 m/s	3 x 10^8 m/s
Antenna Heights User Terminal	h_{UT}	1.5 m	1.5 m
Antenna Heights Base Station	h_{BS}	25 m	25 m
The Effective Environment Height	h_E	1 m	1 m
The Effective Antenna Heights User Terminal	h'_{UT}	0.5 m	0.5 m
The Effective Antenna Heights Base Station	h'_{BS}	24 m	24 m
Breakpoint Distance	d'_{BP}	368 m	560 m

TABLE III
Calculate Number of Site with Coverage Planning

Parameter	2300MHz	3500MHz
Model Propagasi	Urban Macro	Urban Macro
Luas Wilayah Perencanaan	13.9km^2	13.9km^2
MAPL downlink	103.565dB	89.137dB
Cell Radius	729.57m	310.46m
Site Coverage Area	1383908.201 m^2	250602.07 m^2
Number of Sites	10	56

Based on the calculations for each frequency, it was found that the required number of sites for planning with a frequency of 2300MHz is 10 sites with a coverage area of 1.38 km^2, and for a frequency of 3500MHz, it is 56 sites with a coverage area of 0.25 km2.

Table IV shows that the network planning uses a bandwidth of 40 MHz for 2300 MHz frequency and 100 MHz for 3500 MHz frequency. The subcarrier spacing used is 30 KHz in accordance with numerology μ = 1, with 1 component carrier (CC) for each 2300 MHz and 3500 MHz frequency, and 2 CC for carrier aggregation. The modulation order used is 4, which corresponds to the modulation scheme used in this design, i.e., using 16 QAM modulation. The MIMO type used is 4T4R, enabling a maximum supported layer of 4, scaling factor of 1, resource block count according to bandwidth and numerology, and an overhead of 0.14, which corresponds to 32 frequencies and the downlink FR1 category of network planning scenario.

B. Coverage Planning with Inter-band Carrier Aggregation

In 5G New Radio, carrier aggregation technology supports up to 16 component carriers (CC) both contiguous and non-contiguous with different numerologies in frequency range 1 and frequency range 2 [11].

In coverage planning, links are estimated according to elements such as planning area, network capacity, and device performance to obtain maximum path loss. The maximum cell radius is obtained according to the radio propagation model and the maximum allowed path loss (MAPL). Thus, the coverage area of the site is calculated and the required number of sites is determined. In scenario 1, 5G network planning was carried out at a frequency of 2300 MHz with a bandwidth of 40 MHz. In the second scenario, a configuration was added to increase network capacity by applying the inter-band carrier aggregation method. The frequency band in scenario 1, 2300 MHz with a bandwidth of 40 MHz, will be combined with the 3500 MHz band with a bandwidth of 100 MHz. The specifications and configuration of inter-band carrier aggregation in this study are shown in Table V.

TABLE IV
Calculated of Data Rate

Parameter	2300 MHz	3500 MHz	CA 230 MHz & 3500 MHz
Bandwidth	40 MHz	100 MHz	140 MHz
Subcarrier Spacing	30 KHz	30 KHz	30 KHz
Component Carrier	1	1	2
Modulation Order	4	4	4
Number of Layer	4	4	4
Scalling Factor	1	1	1
Numerology	1	1	1
Number of Resource Block	106	273	379
Overhead	0.14	0.14	0.14
Data Rate (Mbps)	453.7	1168.5	1622.2

TABLE V
Spesification of Carrier Aggregation

Implementation of Carrier Aggregation	
Carrier Aggregation	Inter-Band
Frequency	2300 MHz (with bandwidth 40 MHz) and 3500 MHz (with bandwidth 100 MHz)
Number of Site	10
Power	49 dBm
Class of CA configuration	Aggregation Class C
Antenna	Katherin_80020622 (for 2300 MHz) and Katherin_800250911 (for 3500 MHz)
Duplex	TDD_TDD

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C. Synchronization Signal Reference Signal Received Power (SS-RSRP)

SS-RSRP is a parameter used to measure signal strength. The range of values can be seen in Table VI.

TABLE VI
Range value of SS-SRPP

Range Value	Category	Color
SS-RSRP ≥ -85	Excellent	
-90 ≤ SS-RSRP < -85	Very good	
-95 ≤ SS-RSRP < -90	Good	
-100 ≤ SS-RSRP < -95	Normal	
-105 ≤ SS-RSRP < -100	Fair	
-110 ≤ SS-RSRP < -105	Bad	
-115 ≤ SS-RSRP < -110	Very Bad	

D. Synchronization Signal Signal to Noise and Interference Ratio (SS-SINR)

SS-SINR is the ratio between the average received power and interference plus noise. The range of values can be seen in Table VII.

TABLE VII
Range value of SS-SRPP

Range Value	Category	Color
SS-SINR ≥ 30	Very good	
15 ≤ SS-SINR ≤ 30	Good	
0 ≤ SS-SINR ≤ 15	Normal	
-10 ≤ SS-SINR ≤ 0	Bad	
SS-SINR ≤ --10	Very Bad	

III. RESULT AND DISCUSSION

In this research, we used two scenario, there are scenario 1 without carrier aggregation using 2300 MHz frequency, and scenario 2 with carrier aggregation using 2300 MHz and 3500 MHz frequencies.

A. Scenario 1 Non- Carrier Aggregation with frequency 2300 MHz

Scenario 1 was conducted by designing a 5G NR network on the n40 band with 2300 MHz frequency and 40 MHz bandwidth through simulation using Atoll 3.4 software. The number of site requirements in the planning area was obtained by calculating based on the propagation model and planning scenario, using the Urban Macro propagation model with O2O LOS downlink scenario. Based on the calculations, the number of site requirements for this planning area with an area of 13.9 km^2 is 10 sites.

Fig. 2 and 3 show simulation result and histogram of SS-RSRP. SS-RSRP value for scenario 1 is classified as excellent according to the RF 5G SS-RSRP parameter standard with an average value of -82.06 dBm.

Fig. 2. Simulation result of SS-RSRP in scenario 1

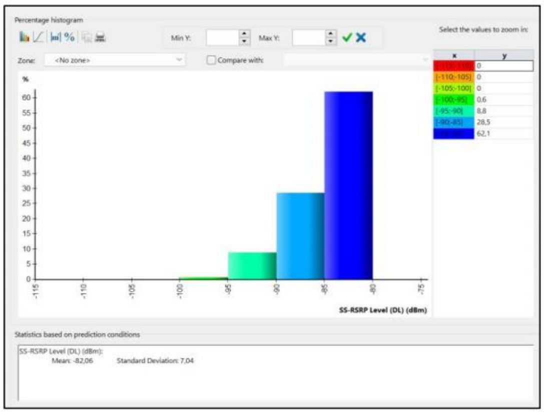

Fig. 3. Histogram of SS-RSRP in scenario 1

Based on the histogram in Fig. 4 and 5, it can be seen that the SS-SINR value for scenario 1 has the highest value in the range of 15 dB to 30 dB with a percentage of 50.97%. The mean value for this parameter is 4115.59 dB, which is classified as a good value.

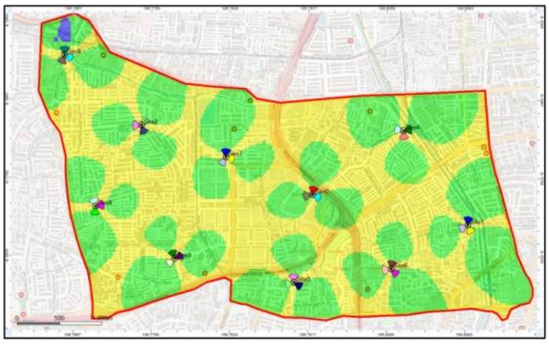

Fig. 4. Simulation result of SS-SINR in scenario 1

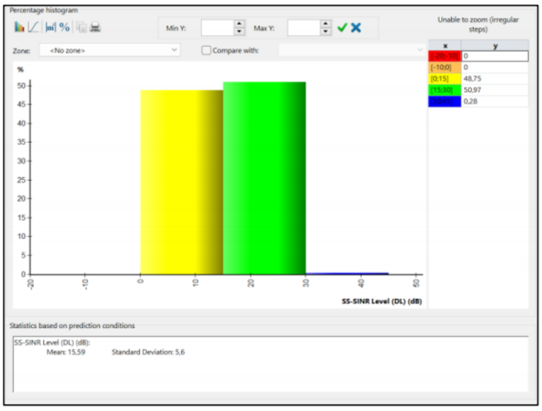

Fig. 5. Histogram of SS-SINR in scenario 1

The mean value of the data rate parameter is obtained at 235,447.99 Kbps or approximately 235.45Mbps, is shown in Fig. 6. According to the simulation results, the highest data rate value is obtained in the range of 0Mbps to 500Mbps with a percentage of 93.8%. The manual calculation previously conducted resulted in a data rate value of 453.7 Mbps, so the data rate value obtained from the Atoll 3.4 software simulation is approaching the manual calculation result, which may differ from the actual field conditions due to ideal conditions in the manual calculation.

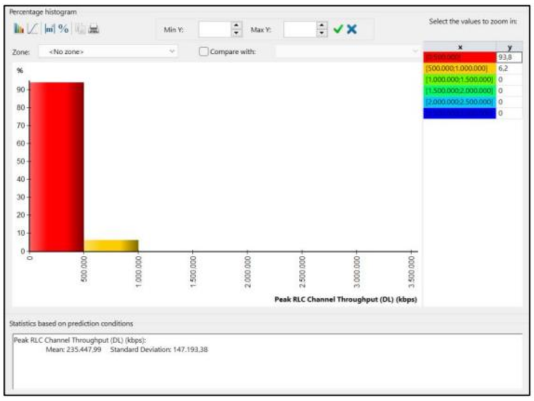

Fig. 6. Histogram of data rate in scenario 1

B. *Scenario 2 Interband- Carrier Aggregation with frequency 2300 MHz and 3500 MHz*

In scenario 2 planning, an inter-band carrier aggregation configuration was added to scenario 1. Scenario 2 combinedband n40 with a 40MHz bandwidth as the PCell and band n78 with a 100MHz bandwidth was used as the SCell. The simulation results of implementing the inter-band carrier aggregation configuration were displayed using Atoll 3.4 software.

Fig. 7 and 8 show the simulation result and histogram of SS-RSRP in scenario 2. The highest SS-RSRP value was obtained within the range of -85 dBm to -80 dBm, with a percentage of 62.4%. The mean value for this parameter was -82.02 dBm, which falls under the "excellent" category in the 5G RF SS-RSRP parameter standard.

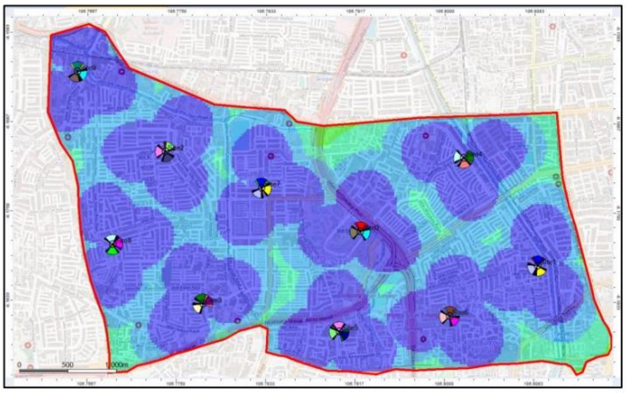

Fig. 7. Simulation result of SS-RSRP in scenario 2

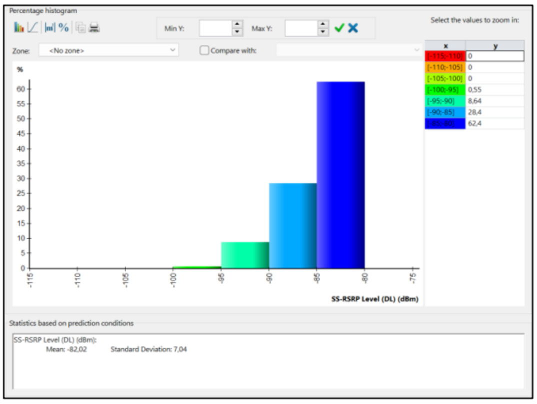

Fig. 8. Histogram of SS-RSRP in scenario 2

Fig. 9 and 10 show simulation result and histogram of SS-SINR scenario 1. The histogram shows that the highest SS-SINR value was obtained in the range of 15dB to 30dB, with a percentage of 51.6%. The mean value for this parameter was 15.71dB, which falls under the "good" category.

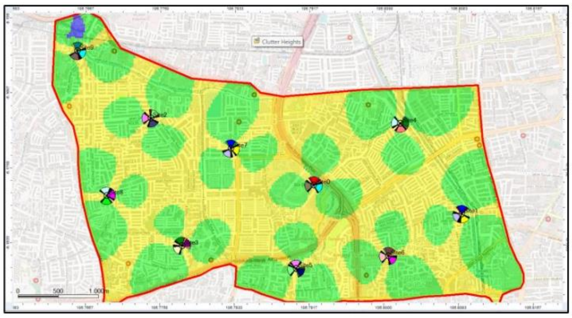

Fig. 9. Simulation result of SS-SINR in scenario 2

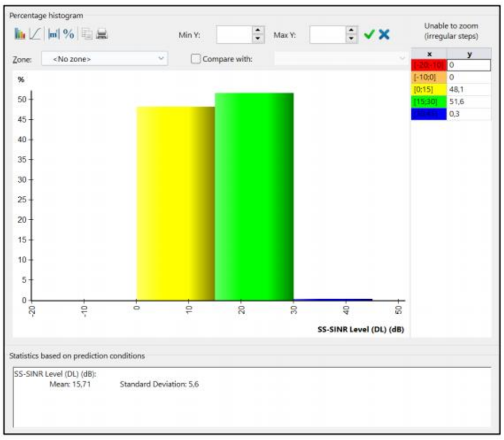

Fig. 10. Histogram of SS-SINR in scenario 1

Based on the calculation, the data rate value for the carrier aggregation method reached 1622.2 Mbps, which falls within the range of 1500 Mbps to 2000 Mbps in the simulation, with a coverage plot result percentage of 9.14% as shown in Fig. 11.

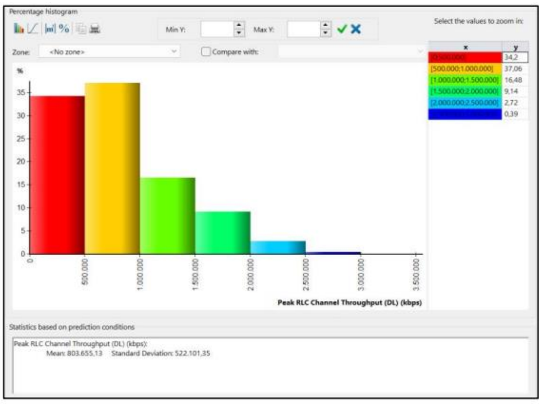

Fig. 11. Histogram of data rate in scenario 1

The simulation results from this study show an increase in the average value for each parameter, including SS-RSRP, SS-SINR, and data rate, after applying the inter-band carrier aggregation method as shown in Table VIII, IX, X, and XI. Specifically, the SS-RSRP parameter shows a 0.05% increase in the average value with a value of -82.02 dBm, which falls under the "excellent" category in the 5G RF parameter standard for SS-RSRP. Meanwhile, the SS-SINR parameter shows a 0.77% increase in the average value with a value of 15.71dB, which falls under the "good" category in the 5G RF parameter standard for SS-SINR.

The data rate parameter, there was a significant increase in the average value between non-CA and CA implementation, with an average value of 235.45 Mbps and 803.66 Mbps, respectively. The percentage increase in data rate was 241.33%. This significant increase was achieved by combining the component carriers between PCell and SCell on frequencies of 2300MHz and 3500MHz with a total bandwidth of 140MHz. The combination of component carriers can increase the usage of bandwidth and affect the increasing number of resource blocks generated, resulting in a higher data rate.

TABLE VIII
Simulation Result of SS-RSRP Parameters

Value (dBm)	Non-CA 2300 MHz	CA 2300 and 3500 MHz
SS-RSRP ≥ 85	62.1 %	62.4 %
-90 ≤ SS-RSRP < -85	28.5 %	28.4 %
-95 ≤ SS-RSRP < -90	8.8%	8.64%
-100 ≤ SS-RSRP < -95	0.6 %	0.55 %

TABLE IX
Simulation Result of SS-SINR Parameters

Value (dB)	Non-CA 2300 MHz	CA 2300 and 3500 MHz
SS-SINR ≥ 30	0.3 %	0.3 %
15 ≤ SS-SINR < 30	50.97 %	51.6 %
0 ≤ SS-SINR < 15	48.75 %	48.1 %

TABLE X
Simulation Result of Data Rate Parameters

Data Rate (Mbps)	Non-CA 2300 MHz	CA 2300 and 3500 MHz
2500 ≤ Data Rate < 3000	0	0.39 %
2000 ≤ Data Rate < 2500	0	2.72 %
1500 ≤ Data Rate < 2000	0	9.14 %
1000 ≤ Data Rate < 1500	0	16.48 %
500 ≤ Data Rate < 1000	6.2 %	37.06 %
0 ≤ Data Rate < 500	93.8 %	34.2 %

TABLE XI
Simulation Result of Scenario 1 and Scenario 2

Parameter	Scenario 1	Scenario 2	Increase
SS-RSRP	-82.06 dBm	-82.02 dBm	0.05 dBm
SS-SINR	15.59 dB	15.71 dB	0.77 dB
Data Rate	235.45 Mbps	803.66 Mbps	241.33 Mbps

IV. Conclusion

The analysis of the average values obtained from the simulation results show that there was an increase in the average value for each parameter after the implementation of the inter-band carrier aggregation method in the network planning process. Specifically, there was a 0.05% increase in the SS-RSRP parameter, a 0.77% increase in the SS-SINR parameter, and a significant improvement in the data rate parameter, reaching up to 241.33%. This proves that the implementation of the inter-band carrier aggregation method can be a solution to increase network capacity, especially in terms of data rate, by combining component carriers to maximize the usage of bandwidth and resource blocks.

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