Performance Analysis of 5G Stand Alone Inter-band Carrier Aggregation

Alfin Hikmaturokhman, Levina Anora, Solichah Larasati, Ari Sukarno, Rizky Syafrullah, and Khoirun Ni'amah

Telecommunication Engineering Institut Teknologi Telkom Purwokerto, Purwokerto 53147, Indonesia
Email: {alfin; 18101054; laras; 18101041; 18101066; irun}@ittelkom-pwt.ac.id

Abstract**—**Today, high data rate is the prior requirement to support services and applications. It is definitely a challenge for the 5G New Radio (NR) in providing high data rates, in order to support use cases, especially enhanced Mobile Broadband (eMBB). The objective of this research is to design a 5G network which has greater data rates employing carrier aggregation techniques. Carrier Aggregation (CA) is a way which is able to improve data rates by aggregate component carriers, hence, it can make a wider bandwidth. There are three modes of CA scenario that can be used: intra-band contiguous CA, intra-band non-contiguous CA, and inter-band non-contiguous CA. In this research, the 5G network planning with carrier aggregation on inter-band employing bandwidth 40 MHz at frequency 2300 MHz and bandwidth 100 MHz at frequency 3500 MHz was simulated in Mentum Planet software. The simulation implemented at Marunda Center Industrial Area in Bekasi used downlink outdoor-to-indoor (O2I) with Line of Sight (LOS) scenario. The parameters analyzed in this research employed three main parameters: SS-RSRP, SS-SINR and data rate, which resulted CA SS-RSRP increased by 0.14%, SS-SINR increased by 4.48%, and peak data rate increased up to 1412.26 Mbps from 312.872 Mbps.

Index Terms**—**5G NR Planning, Carrier Aggregation, Inter-band, Data Rate, Mentum Planet

I. Introduction

Recently, in the whole world, cellular technology has become an important necessity for human life and has grown rapidly. The development of cellular technology has enabled anyone to connect any device and exchange information via the internet [1].

5G New Radio (NR) technology is the latest generation of radio systems and network architecture released by the 3rd Generation Partnership Project (3GPP) which deliver enhanced Mobile Broadband (eMBB), Ultra-reliable and low Latency communication (uRLLC), and Massive network communication (mMTC) for humans and Internet of Things (IoT) communications [2].

In 2012, LTE-Advanced had been developed as the standard to include a new technique called Carrier Aggregation (CA). CA is a novel scheme combining multiple frequency spectrum to increase the bit rate. CA was first introduced in LTE-Advanced Release 10 (R10) [3].

To meet the data rate and capacity requirements of 5G technology, different carrier frequencies are combined, hence, a greater bandwidth value can be obtained. Carrier Aggregation (CA) enables the operators to extend the operational bandwidth by aggregating several component carriers (CC). The advantages of using carrier aggregation comprise of:

- Increasing peak data rate.
- More efficient use of spectrum compared to stand-alone carriers.
- Increasing user throughput.
- Efficient use of fragmented spectrum.
- Providing better and more consistent QoS to user with load-balancing across frequencies and systems. If a user is stuck in one band, the user becomes a scheduler at another frequency or system and has seamless access to the available unused capacity on other frequencies.
- Enabling interference management by intelligent allocation of resources [4].

One of the big problems that mobile operators encounter is how to deal with the growing demand for traffic. Carrier aggregation is a good solution because it provides a higher throughput on transmission path.

This study planned 5G NR network at frequency 2300 MHz and 3500 MHz employing Mentum Planet software planning. The objective of this study is to identify performance of 5G NR network planning using carrier aggregation technique. Using the same radio link budget, the result of network planning using carrier aggregation was compared without non-carrier aggregation.

The paper consists of the following sections. In section II, we describe the overview of 5G NR. Section III, it is discussed about what kind of configuration applied in 5G Network Planning followed by the method and calculations. Section IV, it is explained about the result of the simulation and the analysis. In Section V, we describe the conclusion of the research.

II. 5G Overview

A. 5G New Radio (NR)

5G New Radio is the fifth Generation of cellular technology defined by 3GPP after 4G LTE. Each generation provides performance enhancement, especially data rates. However, mobile broadband is not just the one being improved. There are three main use cases offered in 5G NR.

- Enhanced mobile broadband (eMBB): This use case provides greater data bandwidth which helps developing AR/VR, UltraHD streaming video, and many more.

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- Ultra-reliability and Low Latency Communications (uRLLC): This use case supports remote medical surgery, public protection, disaster relief, transportation safety, etc.
- Massive Machine Type Communications (mMTC): mMTC deployment handles of a huge number of devices. This use case supports to improve large implementation of IoT [5].

B. Stand Alone (SA) and Non-Stand Alone (NSA)

There are two types of architecture option in 5G. 5G NSA makes the 5G networks supported by the existing 4G LTE infrastructure. The access network is supported by the Evolved Packet Core (EPC). The EPC is employed for coverage to add the 5G carrier. The NSA architecture enables lesser cost to implement. This research basically used the SA architecture. 5G SA is a new core architecture defined by 3GPP that separating various network functions. 5G packet core is used in this architecture, which network slicing, virtualization, ultra-low latency, and others are built into this scenario. 5G SA is suitable to implement big data rates that do not use of the existing 4G LTE networks [6].

C. Carrier Aggregation

Nowadays, Mid-band and High band in Time Division Duplexing (TDD) are the most used frequency band in 5G NR deployment. These bands provide large capacity but lower propagation to current mobile frequency. Furthermore, these bands possess uplink limitations, therefore the coverage of 5G does not match with the 4G coverage made on the same site. In solving the problem, operators deploy the low band in the Frequency Division Duplexing (FDD) spectrum to increase coverage without adding new sites. However, NR capacity decreases and it is no different from LTE. In overcoming this, 5G NR carrier aggregation is completed to combine mid or high band TDD with Low band FDD, hence, bandwidth becomes larger and provides wider coverage. If so, uplink will be moved to FDD uplink channel where it is no longer limited and can optimize downlink throughput.

In order to achieve extreme data rate and high spectrum utilization in the 5G NR network, 3GPP specifies carrier aggregation technology to combine multiple contiguous or non-contiguous cc for User Equipment's (UEs). CA technology is divided into three modes, including intra-band Contiguous CA, intra-band Non-contiguous CA, and Inter-band Non-contiguous CA. Intra-band Contiguous CA and intra-band Non-contiguous CA modes combine cc in the same frequency band, each combines contiguous and non-contiguous CC. Inter-band Non-contiguous CA is enhanced with CCs placed in different frequency bands [7], [8]. Fig. 1 to Fig. 3 show the Intra-band and Inter band combination.

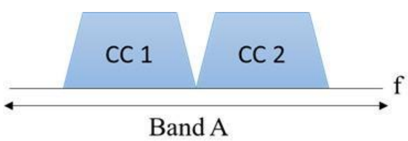

Fig. 1. Intra-band contiguous CA.

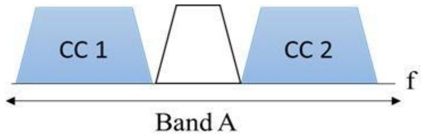

Fig. 2. Intra-band non-contiguous CA.

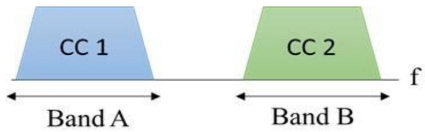

Fig. 3. Inter-band non-contiguous CA.

III. 5G NR Network Planning

A. CA Configuration Scenarios

The CA configuration used in this planning shown in the Table I.

TABLE I: 5G CA CONFIGURATION SCENARIOS

CA Configuration	NR-Band	Band Name	CC Bandwidth (MHz)	
			Pcell	Scell
non_CA-n40	n40	2300 +	40	-
non_CA-n78	n78	3500 +	100	-
CA_n40-n78	n40	2300 +	40	-
	n78	3500 +	-	100

This research used CA in 5G frequency at 2300 MHz with bandwidth 40 MHz based on the auction result from one of the telecommunication operators in Indonesia and frequency 3500 MHz with bandwidth 100 MHz. There are two types of serving cell in CA which are Primary Cell (Pcell) and Secondary Cell (Scell). Pcell is delivering the Primary Component Carrier (PCC) on downlink and uplink handling the connection of Radio Resource Control (RRC).

Meanwhile the Scell delivers the Secondary Component Carrier (SCC). This planning used frequency 2300 MHz as Primary Cell and 3500 MHz as Secondary Cell. The consideration is at frequency 2300 MHz having larger cell radius than 3500 MHz. The result of CA simulation is compared with non-CA at frequency 2300 MHz and 3500 MHz. The band combination is based on the standardization of 3GPP TS 138.101-1 in release 16 [9] .

In the simulation, the planning used downlink outdoor to indoor (O2I) with line of sight (LOS) scenario. This outdoor to indoor scenario is an essential scenario for UE coverage. The concept is the gNB is installed on the rooftop of the building, thus, it provides O2I coverage, especially in 5G SA [10].

B. Coverage Planning

The design based on coverage planning is conducted to estimate the number of sites needed to provide services to the area planning. Coverage planning considers the radio link budget and the propagation Model [11]. In general, the coverage planning focuses on downlink and uplink. However, in this study, we calculated only for downlink. After getting the pathloss value from the calculation of radio link budget, the cell radius is obtained from the calculation of propagation model. Moreover, the number of sites is discovered by calculating the coverage area and large of the area planning.

C. Radio Link Budget

Radio Link budget calculation is used for estimating the weakening between the mobile antenna and the mobile station antenna on the downlink and uplink called Maximum Allowable Pathloss Value (MAPL). In this study, the link budget focused on downlink based on the scenario employed. The MAPL value is inserted to the propagation model in finding the cell radius. (see Table II)

TABLE II: LINK BUDGET 5G NEW RADIO [12]-[15]

Comment Parameter	2300 MHz	3500 MHz
gNodeB Transmiter Power (dBm)	49	49
Resource block	106	273
Subcarrier quantity	1272	3276
gNodeB antenna gain (dBi)	18	17.5
gNodeB cable loss (dBi)	0	0
Penetration loss (dB)	23.41	26.85
Foliage loss (dB)	19.95	19.95
Body block loss (dB)	3	3
Interference margin (dB)	6	6
Rain/Ice margin (dB)	0	0
Slow fading margin (dB)	8	8
UT antenna gain (dB)	0	0
Bandwidth (MHz)	40	100
Konstanta boltzman (mWs/K)	1.38×10^{-20}	1.38×10^{-20}
Temperature (Kelvin)	293 °	293 °
Thermal noise power (dBm)	-157.91	-153.93
UT noise figure (dB)	9	9
Demodulation threshold SINR (dB)	22.9	22.9
Planning Area	5 km^2	5 km^2

The simulation uses system parameters summarized in Table III below:

TABLE III: MAIN SYSTEM PARAMETERS

Key Parameter	2300 MHz	3500 MHz
Technology template	NR	NR
Carrier frequency	2300 MHz	3500 MHz
Start frequency	2300 MHz	2400 MHz
End frequency	3300 MHz	3800 MHz
Bandwidth	40 MHz	100 MHz
Duplex	TDD	TDD
Antenna file	Kathrein	Kathrein

D. Propagation Model

The radius cell was calculated using the value of MAPL discovered from the link budget. Based on standardization of 3GPP 38.901 in 5G network planning, the propagation models used are Urban Micro (UMi), Urban Macro (UMa) and Rural Macro (RMa). In this study, we used the macro cell frequency and implemented in urban area, thus, we use the UMa propagation model. The formula of UMa propagation model for LOS scenario is [16]:

$$PL = 28.0 + 40\log(d_{3D}) + 20\log(fc) - 9\log((d'_{BP})^2 + (h'_{BS} - h'_{UT})^2 \quad (1)$$

where d_{3D} is the resultant of the distance between h_{BS} and h_{UT}, f_c is the frequency carrier, and d'_{BP} is breakpoint distance calculated by employing the formula :

$$d'_{BP} = 4 \times h'_{BS} \times h'_{UT} \times \frac{fc}{c} \quad (2)$$

which h'_{BS} value was obtained from the h_{BS} value minus the h_E value. Then the h'_{UT} value was obtained from the h_{UT} value minus h_E, h_{BS} represents the height of gNodeB, h_{UT} represents the height of the Transmission user height, and h_E represents the height of the equipment.

From the propagation model calculated previously, the d_{3D} was discovered. Then, the cell radius value (d_{2D}) was obtained by using:

$$Cell\ Radius\ (d_{2D}) = \sqrt{(d_{3D})^2 - (h_{BS} - h_{UT})^2} \quad (3)$$

$$Site\ Coverage\ area = 2.6 \times {d_{2D}}^2 \quad (4)$$

After obtaining the cell radius and the site coverage area, the number of gNodeB needed was calculated by using:

$$Number\ of\ Sites = \frac{Total\ Large\ of\ Area}{Size\ Coverage\ Area} \quad (5)$$

Data rate is one of the parameters in this study. The data rate has to be calculated in identifying how much data rate that can be achieved by the network. The formula employed to calculate the data rate value in 5G based on the 3GPP TS 38.306 used [17]:

$$\text{Data Rate (Mbps)} = 10^{-6} \cdot \sum_{j=1}^{J} \left(v_{Layers}^{(j)} \cdot Q_m^{(j)} \cdot f^{(j)} \cdot R_{\max} \cdot \frac{N_{PRB}^{BW(j),\mu} \cdot 12}{T_s^{\mu}} \cdot \left(1 - OH^{(j)}\right) \right) \quad (6)$$

Which J represents the Component Carrier, $v_{Layers}^{(j)}$ represents the number of layers, $Q_m^{(j)}$ represents the Modulation Order, $f^{(j)}$ represents the Scaling Factor, N_{PRB} represents the Number of RB, and $OH^{(j)}$ represents the Overhead.

The data rate calculation result can be seen in the Table IV below:

TABLE IV: DATA RATE CALCULATION

Parameters	Symbol	2300 MHz	3500 MHz	CA 2300 & 3500 MHz
Bandwidth	-	40 MHz	100 MHz	140 MHz
Subcarrier Spacing	-	30 KHz	30 KHz	30 KHz
Component Carrier	J	1	1	2
Modulation Order	$Q_m^{(j)}$	4	4	4
Number of Layer	$v_{Layers}^{(j)}$	4	4	4
Scaling Factor	$f^{(j)}$	1	1	1
Numerology	µ	1	1	1
Number of RB	N_{PRB}	106	273	379
Overhead	$OH^{(j)}$	0.14	0.14	0.14
Data Rate (in Mbps)	NR_{Thr}	453.7	1168.5	3244.4

E. Marunda Center Industrial Estate

The simulation of 5G NR network planning depicted in Marunda Center industrial area is show in Fig. 4.

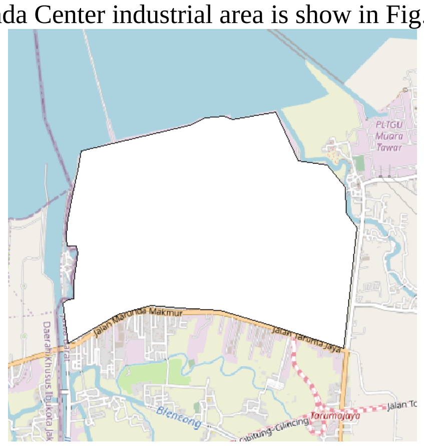

Fig. 4. Area planning in mentum planet.

This location is along the coastline of Tanjung Priok Port. This industrial area has large of area by 5 km^2 and it is suitable for 5G deployment since it improves efficiency in industrial digitalization. Based on the calculation, the site needed in Marunda Center is 5 sites. This number of sites was plotted using Automatic Site Placement (ASP) in Mentum Planet planning software.

IV. RESULT AND ANALYSIS

A. Link Budget Calculation Result

The result of the link budget calculation based on coverage planning can be seen in the Table V below.

TABLE V: RESULT OF LINK BUDGET CALCULATION

Comment Parameter	2300 MHz	3500 MHz
Pathloss (dBm)	101.61	89.93
d_{3D} (m)	652.14	331.05
Cell radius / d_{2D} (m)	651.71	330.21
Coverage Area (Km^2)	1.1	0.28
Total Large of Area (Km^2)	5	5
Number of site	5	79

This planning focused on throughput enhancement, thus, the reference for the number of site requirements is at frequency 2300 MHz as the primary cell. It is because the frequency 2300 MHz has a larger cell radius than frequency 3500 MHz as a secondary cell.

B. SS-RSRP Parameters

Synchronization Signal - Reference Signal Received Power (SS-RSRP) is an average power (Watt) in total time measured at User Equipment (UE) from secondary synchronization signal (SS) added with cell transmitter. This parameter is the same as RSRP in 4G LTE. It indicates the signal power received by the user. The range of SS-RSRP is presented in Table VI.

TABLE VI: SS-RSRP RANGES [18]

Range SS-RSRP	Category
SS-RSRP ≤ -130	Very bad
-130 ≤ SS-RSRP ≤ -110	Bad
-110 ≤ SS-RSRP ≤ -90	Normal
-90 ≤ SS-RSRP ≤ -70	Good
RSRP ≥ -70	Very Good

Based on the simulation on Mentum Planet software, the result of SS-RSRP non-CA at frequency 2300 MHz and 3500 MHz and after using CA is displayed in Fig. 5 to Fig. 7 below.

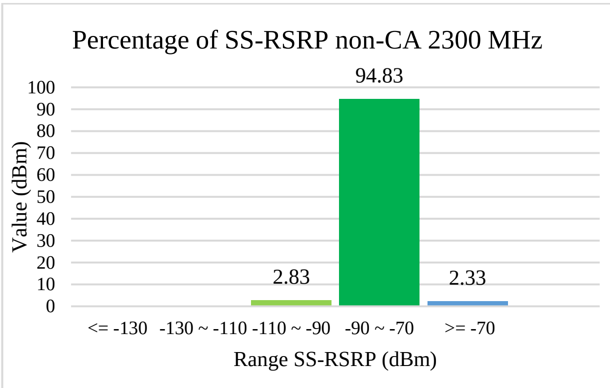

Fig. 5. Graph of SS-RSRP parameter non-CA 2300 MHz.

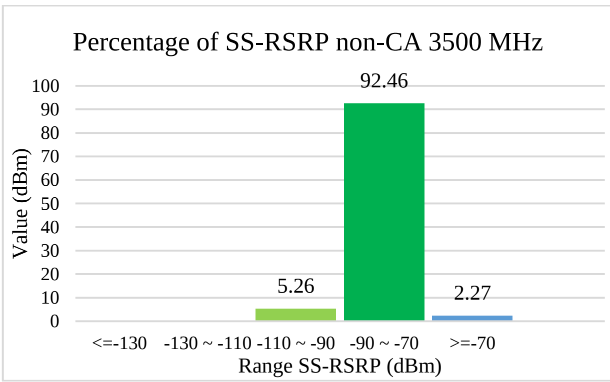

Fig. 6. Graph of SS-RSRP parameter non-CA 3500 MHz.

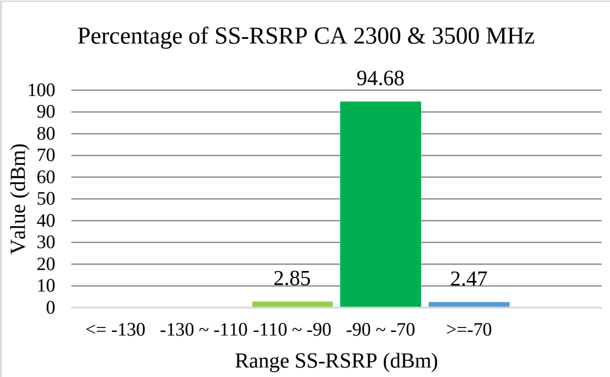

Fig. 7. Graph of SS-RSRP Parameter CA.

TABLE VII: COMPARISON SS-RSRP NON-CA AND CA

Statistic Parameters	SS-RSRP Value (dBm)		
	non-CA 2300	non-CA3500	CA 2300 & 3500
Minimum	-93.46	-96.35	-93.46
Maximum	-40.62	-47.5	-40.62
Mean	-81.31	-80.51	-80.37

Based on the results of the data obtained, the SS-RSRP value in the scenarios of carrier aggregation belongs to the good category that can be seen in the Table VII. Around 94.68% is in the range -90 to -70 dBm. Looking at the non-CA 2300 MHz and 3500 MHz, the non-CA 2300 MHz has a higher percentage of the signal level compared to the non-CA 3500 MHz. In the statistics parameter, the non-CA 2300 MHz and CA have the same value in the minimum and the maximum SS-RSRP. Otherwise, it can be identified that CA implementation affects the average value of SS-RSRP where the value is increased by 0.94 dBm. By increasing the SS-RSRP value, it means that the performance is getting more optimal after using CA.

C. SS-SINR Parameters

Synchronization-Signal Signal-to-Noise and Interference Ratio (SS-SINR), is a linear average over the power contribution (in Watt) of the resource elements delivering secondary synchronization signals divided by the linear average of the noise and interference power contribution (in Watt). In 4G LTE, these parameters is identified as Signal-to-Noise and Interference Ratio Power (SINR). Basically, this parameter is the same because it indicates the signal power divided with noise and interference received by user. The range of SS-SINR will be used is in Table VIII.

TABLE VIII: SS-SINR RANGES [18]

Range SS-SINR	Category
SS-SINR ≤ -10	Very bad
-10 ≤ SS-SINR ≤ 0	Bad
0 ≤ SS-SINR ≤ 15	Normal
15 ≤ SS-SINR ≤ 30	Good
SS-SINR ≥ 30	Very Good

The result of SS-SINR based on the simulation result in Mentum Planet software can be seen in Fig. 8 to Fig. 10 below:

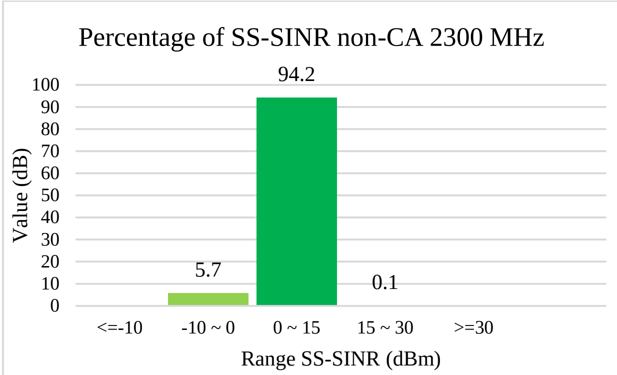

Fig. 8. Graph of SS-SINR Parameter non-CA 2300 MHz.

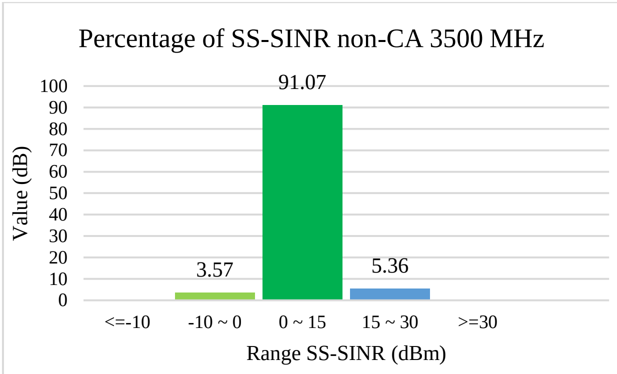

Fig. 9. Graph of SS-SINR Parameter non-CA 3500 MHz.

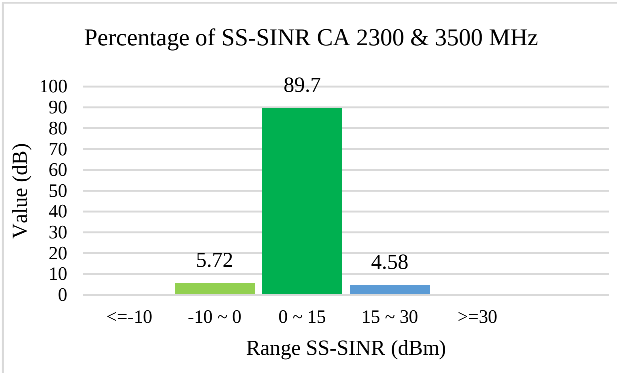

Fig. 10. Graph of SS-SINR Parameter CA.

TABLE IX: COMPARISON SS-SINR NON-CA AND CA

Statistic Parameters	SS-RSRP Value (dBm)		
	non-CA 2300	non-CA3500	CA 2300 & 3500
Minimum	-3.76	4.73	-3.76
Maximum	15.94	19.32	19.23
Mean	4.73	6.58	5.65

From the data obtained, it is implied that the SINR received by the three scenarios has the most value in 0 dB to 15 dB in which this value falls into the normal category. The highest percentage is owned by non-CAs 2300 MHz, and the lowest percentage is owned by CA. From the comparisons presented in table IX, there is a difference in the maximum and mean value between non-CA 2300 MHz and CA in which the maximum CA value is higher by 3.29 dB. It affects the average value where the average CA value is 0.92 dB higher than the non-CA 2300 MHz.

D. Data Rate Parameters

Data rate is the key parameter of this study, because this CA scenario aims to increase the data rate. CA aggregates the carrier bandwidth, thus, the data rate of each carrier is summed. The data rate value of 2300 MHz has smaller data rate than 3500 MHz because the limitation of bandwidth. Hence, the frequency 3500 MHz with more bandwidth aggregates in 2300 MHz to get wider bandwidth and increases data rate. The result of the data rate is described in Table X below.

TABLE X: COMPARISON DATA RATE NON-CA AND CA

Statistic Parameters	SS-RSRP Value (dBm)		
	non-CA 2300	non-CA3500	CA 2300 & 3500
Minimum	14.34	43.12	14.34
Maximum	312.87	1.104.51	1.412.26
Mean	89.33	365.17	372.44

From the results in Table X, it can be identified that the data rate of non-CA 2300 MHz has smaller value than non-CA 3500 MHz. It happens because smaller frequency has smaller bandwidth in which the bandwidth in the simulation at frequency 2300 MHz used bandwidth 40 MHz and at frequency 3500 MHz are using bandwidth 100 MHz. Compared to non-CA 2300 MHz, CA has the same minimum data rate but different maximum data rate. It happens because the result of the data rate is the sum of the maximum values of non-CA 2300 MHz and non-CA 3500 MHz. If we observe closer, we can see that without using CA, it will only obtain data rates up to 312 Mbps. While using CA, the data rate becomes bigger up to 1412 Mbps or 1.412 Gbps. From the mean value, it can be identified that the data rate value of non-CA 2300 MHz is tremendously supported by the aggregating with non-CA 3500 MHz.

E. Comparison before CA and After CA

This simulation used some main system parameters summarized in Table XI which was assumed by following previous research.

TABLE XI: SUMMARY BEFORE CA AND AFTER CA

Parameters	**Before CA**		**After CA**
	2300 MHz	**3500 MHz**	**2300 + 3500 MHz**
Percentage SS-RSRP >= -70 dBm	2.33 %	2.27 %	2.47 %
Mean SS-RSRP (dBm)	-81.315\	-80.51	-80.37
Percentage SS-SINR >=15 dB	0.1 %	5.36 %	4.58%
Mean SS-SINR (dB)	4.73	6.58	5.65
Peak Data Rate (Mbps)	312.87	1.104.51	1.412.26
Mean Data Rate (Mbps)	89.33	365.17	372.44

After analyzing the research parameters, it can be identified that implementing CA can obtain better performance than non-CA. The SS-RSRP with range >= 70 dB increased by 0.14%, the average SS-RSRP increased by 0.939 dBm, the SS-SINR in range >=15 dB increased by 4.48%, the average SS-SINR increased by 0.92 dB, and the main objective of CA, which specificaly increased the data rate, was proven by increasing the data rate to 1412 Mbps from 312 Mbps and the average increased to 372.441 Mbps from 89.333 Mbps. In this case, CA is compared to non-CA 2300 Mhz because it is the primary cell, while 3500 MHz is the secondary cell aggregated with the primary to increase wider bandwidth and obtaining more data rate. The data rate value is different from calculation which has been calculated. It is because in calculation, we were calculating in ideal condition without considering the obstacle, environment etc. The plotting parameters of the SS-RSRP and SS-SINR are presented in the Fig. 11 and Fig. 12 below:

Fig. 11. Plotting of SS-RSRP Parameter CA in Google Earth.

Fig. 12. Plotting of SS-SINR Parameter CA in Google Earth.

The results shown in Fig. 11 and Fig. 12 are the plotting parameters depicted from Google Earth. We are able to identify that the displayed colors are mostly dark green which is categorized as good range. This color represents the range of -90 dBm until -70 dBm in SS-RSRP and the range of 0 dBm until 15 dBm in SS-SINR. The light blue is the color which appears the least in the figure. This color represents the very good range of the parameters which is usually shown near the sites.

V. CONCLUSION

In this research, the number of sites plotted in Marunda Center Industrial Area for non-CA and CA were five sites, since the site reference needed was from primary cell 2300 MHz with a larger cell radius. Based on performance analysis of 5G NR network planning simulation result, it can be concluded that inter-band CA in 5G can be effectively implemented. CA which increased the SS-RSRP of the network means that CA can provide larger coverage area than non-CA. CA increased SS-SINR, hence, CA has much better signal performance than non-CA 2300 MHz as the primary cell. The peak data rate also increased. For non-CA 2300 MHz, it was obtained 312.872 Mbps with average value 89.33 Mbps and after using CA inter-band with 3500 MHz the peak data rate increased up to 1412.26 Mbps with average value was 372.441 Mbps. Thoroughly, CA provides better performance to 5G NR if implemented.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Levina Anora and Rizky Syafrullah did the simulation of the CA 5G network planning remotely. Ari Sukarno did the simulation of the CA 5G network planning directly, Levina Anora, Ari Sukarno, and Rizky Syafrullah wrote the paper cooperatively. Alfin Hikmaturokhman, Solichah Larasati and Khoirun Ni'amah have been lead and give any recommendation about the paper and checked the paper. All authors had approved the final version.

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Alfin Hikmaturokhman received the Bachelor's degree in Electrical Engineering from University of Gadjah Mada (UGM), Yogyakarta, Indonesia, in 2002, and the Master's degree in Electrical Engineering from Telkom University (Tel-U), Bandung, Indonesia, in 2011. He has published many journal papers and conference proceedings. He is currently a lecturer at Faculty of Engineering, Institut Teknologi Telkom Purwokerto-Indonesia. His research interests are mobile and wireless communication technology, both concerning technical research and regulatory policy management.

Levina Anora was born in Purwokerto, Indonesia, in 2000. She is a student from Institut Teknologi Telkom Purwokerto, Indonesia, in Telecommunication Engineering. She is a member of Hexacomm Cellular Communication Laboratory and a laboratory assistant of Electro and Digital Technique laboratory.

Solichah Larasati received the S.T. and M.T. degrees in telecommunication engineering from Institut Teknologi Telkom Purwokerto and Telkom University Bandung, Indonesia in 2016 and 2018, respectively. Her current research interests include channel coding, information theory, and wireless communication.

Ari Sukarno was born in Klaten, Indonesia, in 2000. He is a student from Institut Teknologi Telkom Purwokerto, Indonesia, in Telecommunication Engineering, and a member of Hexacomm Cellular Communication Laboratory.

Rizky Syafrullah was born in Jakarta, Indonesia, in 2000. He is a student from Institut Teknologi Telkom Purwokerto, Indonesia, in Telecommunication Engineering. He is a member of Hexacomm Cellular Communication Laboratory and a laboratory assistant of Physics laboratory.

Khoirun Ni'amah graduated from master's degree (M.T) of Electrical Engineering (Telcomunication) from Telkom University, Bandung. She is a lecturer of telecommunication engineering at Institut Teknologi Telkom Purwokerto. Her research interest is on wireless communications.