Increasing the LTE-Advanced Network Capacity Using Inter-band Carrier Aggregation (Downlink Side) Method

Fadli Kusuma[1], Hasanah Putri[2*]

[1,2]Diploma of Telecommunication Engineering, Telkom University
[1,2]Jl. Telekomunikasi No. 1, Terusan Buah Batu, Bandung 40257, Indonesia
*Corresponding Email: hasanahputri@tass.telkomuniversity.ac.id

Abstract — According to the identification of the Operating Support System (OSS) by the Smartfren cellular operator in the Central Bandung area, six sites are found to have high traffic capacity with the physical resource block (PRb) percentage of 82.6 %. The use of PRb > 80 % is included in the warning indicator 2 based on the operator's standards. It is also strengthened by the condition of the existing sites with the average Reference Signal Receive Power (RSRP) of -103.3 dBm, Signal to Interference Noise Ratio (SINR) of 6.28 dB, and throughput of 27.78 Mbps, thus resulting in non-optimal network performance in the area. Therefore, in this study, the inter-band Carrier Aggregation (CA) was applied by combining the 40 Time Division Duplex (TDD) band (2300 MHz) and band 5 Frequency Division Duplex (FDD) (850 MHz). One of the advantages of applying this method is that it can increase the user network capacity by maximizing the resources owned by the operator. The predetermined scenario taking into account the initial network condition indicated a decrease in the PRb percentage by 44.50 % and an increase in the average RSRP value by 12.8 dBm, SINR by 5.14 dB, and throughput by 34.59 Mbps.

Keywords – LTE-Advanced, inter-band carrier aggregation, physical resource block, throughput, RSRP, SINR

I. INTRODUCTION

Cellular service users tend to measure a network based on the speed of uploading and downloading data. The faster the upload and download, the better the service of the cellular operator. To provide high-speed data services, a wide bandwidth is necessary [1], [2]. This leads to the development of 4G LTE-Advanced cellular technology that provides very high data speeds with high capacity and high mobility. However, the use of wide bandwidth takes up the frequency spectrum, which is a problem for cellular operators who have limited frequency resources, and if the cellular operator has excess frequency resources, the use of Long-Term Evolution (LTE) networks can only use a maximum bandwidth of 20 MHz for LTE release 8 [3], [4]. This is the background of an international standardization body, the 3rd Generation Partnership Project (3GPP), to serve as the LTE network developer. In March 2008, the 3GPP began a study to further develop LTE towards LTE-Advanced by targeting the IMT-A requirements set by the International Telecommunication Union (ITU). The study results produce a new set of radio features such as carrier aggregation in release 10, which is a solution to the limitation of frequency use [5], [6].

Based on the results of the survey and identification of OSS conducted by a cellular operator in the Central Bandung area, there are six sites with high traffic capacity, i.e., the physical resource block percentage of 82.6 % with an average throughput of 27.78 Mbps, the RF parameter (RSRP) value of -103.3 dBm, and the SINR value of 6.28 dB. Two of the six sites are in a warning condition, including ZBDG_4393, with the physical resource block percentage of 88 % and ZBDG_4417 with the physical resource block percentage of 72.21 %. A percentage of use of physical resource block (PRb) > 70 % is included in the warning indicator 1, > 80 % is included in the warning indicator 2, and > 90 % is included in the warning indicator 3, so the LTE network performance in the Central Bandung area is not maximum. The high percentage of PRb usage is the background of the use of the inter-band CA method to increase the user capacity in the planning

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area by maximizing the bandwidth owned by the cellular operator [7], [8].

In this study, the application of inter-band CA was done to increase network capacity by optimizing bandwidth usage owned by the cellular operator, which combined the Band 5 FDD (850 MHz) and the Band 40 TDD (2300 MHz). There are several parameters to be analyzed, namely RSRP, SINR, throughput, and the percentage of PRb usage [9], [10].

For a better understanding, the rest of this paper is organized as follows. Section II discusses the research methodology, while the results of the inter-band carrier aggregation application are discussed in section III. Lastly, the conclusion is presented in section IV.

II.   RESEARCH METHOD

A. Carrier Aggregation Method

Carrier aggregation is a technology that allows 4G networks to run on two different frequencies by combining several Component Carriers (CC) to achieve a peak data rate. The component carriers can have a bandwidth of 1.4, 3, 5, 10, 15, or 20 MHz, and a maximum of five CC can be combined with a maximum bandwidth of 100 MHz [11]. This CA is also able to maintain the compatibility between UE release 8 and UE release 9 or what is called "backward compatibility". The LTE release 8 can only be a maximum of 20 Mhz [12].

In the 3GPP release 8 specification, this criterion has not been fulfilled because it only reaches 300 Mbps, so LTE release 8 can be called 3.9 G, whereas in the 3GPP release 10 the LTE-A has reached a peak data rate of above 1 Gbps. The LTE-Advanced uses the CA, which can combine up to five CCs with each bandwidth reaching 20 MHz, depending on the spectrum availability and the EU capability.

B. Carrier Aggregation Spectrum Scenario

The CA can be used on both FDD and TDD technologies. The carrier aggregation arrangement can be implemented either on the same or different band and bandwidth frequencies. In general, CA has three different features, as shown in Fig. 1.

a. Intra-band contiguous carrier aggregation: A form of carrier aggregation which uses a single band. It is the simplest form of LTE operator to carry out aggregation. The frequencies owned by the cellular operator are adjacent to each other. The Increasing the LTE-Advanced Network Capacity Using Inter-band Carrier Aggregation (Downlink Side) Method.

b. Intra-band non-contiguous carrier aggregation: A form of carrier aggregation that aggregated in the same band but is non-contiguous. There is a band distance between the first and second CCs.

c. Non-contiguous inter-band: The aggregated form of carrier aggregation lies in different

bands. The first and second CCs are not contiguous and have different frequency bands (inter-band).
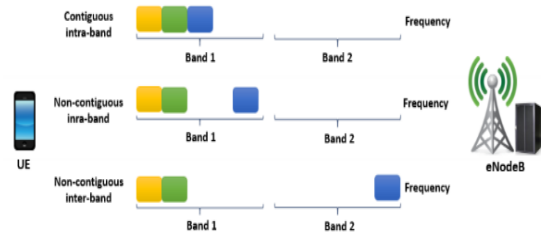

Fig. 1. Carrier Aggregation's Features [13]

C. Carrier Aggregation Bandwidth Configuration

The CA combination defined in 3GPP TS 36.101 shows that the E-UTRAN frequency band combination according to the CA bandwidth class. A combination of the operating frequency band owned by the Smartfren operator is band 40 (2300 MHz) with a bandwidth of 30 MHz and band 5 (850 MHz) with a bandwidth of 10 MHz. CA bandwidth class depends on the number of PRb and the number of CC. The CA configuration shows the combination of LTE operating band and CA bandwidth class [14][15].

Table 1 illustrates the CA bandwidth class that shows the combination of the maximum Aggregated Transmission Bandwidth Configuration (ATBC) and the maximum number of CC, where ATBC is the combined bandwidth configuration that is equal to the total PRb aggregate. The application of three CCs is already available; meanwhile, the four CCs is expected to subsequently available since it is currently in the status of For Further Study (FFS).

D. Area Identification

Figure 2 indicates an area that is the object of research on the application of inter-band CA. Six sites have quite high traffic in the area and have a good potential market. The focus zone (green line) shows the boundary area for the application of inter-band CA, while the computation zone (red line) shows the area around the site coverage.

Table 1. Aggregated Transmission Bandwidth Configuration

CA Bandwidth Class	Aggregated Transmission Bandwidth Configuration	Maximum CC Number
A	NRb agg. < 100	1
B	25 < NRb agg. < 100	2
C	100 < NRb agg. < 200	2
D	200 < NRb agg. < 300	3
E	300 < NRb agg. < 400	FFS
F	400 < NRb agg. < 500	FFS

[*]NRb agg. = Number of Resource Block Aggregated

Based on the evaluation of these sites, several sites have quite high traffic. The average percentage of PRb at ZBDG_4416 site is 54.85 %, that at ZBDG_4417

site is 72.71 %, while ZBDG_4393 site has the highest traffic with an average PRb of 88 %. Fig. 3 illustrates the percentage of resource block usage accessing the ZBDG_4393 site. The observations were taken for one week starting from April 19, 2019 to April 25, 2019.
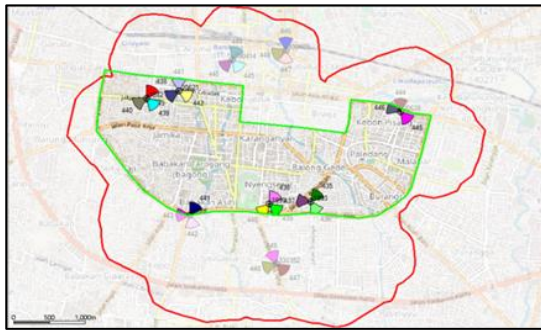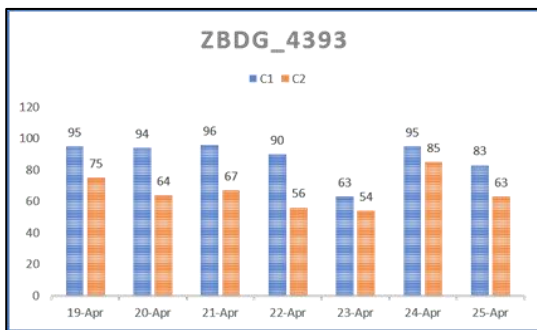

Fig. 2. Planning Area

Fig. 3. PRb Percentages of ZBDG_4393

*C1 = PRB TDD & C2 : PRB FDD

E. Carrier Aggregation Configuration

In this article, CA is implemented with CA configuration using a combination of the operating frequency band owned by the cellular operator, namely band 40 (2300 MHz) with a bandwidth of 30 MHz and band 5 (850 MHz) with a bandwidth of 10 MHz. This configuration affects the LTE network itself. Table 2 shows the CA configurations applied in this study.

Table 2 shows the four CA configurations in two scenarios. Scenario 1 indicates the configuration of CA_40A-5A with 2 CCs and CA_40C-5A with three CCs. The scenario 1 uses a CA configuration based on frequency band 40 (2300 MHz) as the Primary CC (PCC) or main carrier and band 5 (850 MHz) as the Secondary CC (SCC) or second carrier. Then, scenario 2 indicates the CA_5A-40A configuration with two CCs and CA_5A_40C with three CCs. Scenario 2 uses CA configuration based on frequency band 5 (850 MHz) as the PCC or main carrier and band 40 (2300 MHz) as the SCC. The CC from CA_5A has one carrier with a total NRb <100 so that it belongs to CA Bandwidth Class A with a bandwidth of 10 MHz and a total NRb of 50. The CC from CA_40A has one carrier with a total NRb <100 so it belongs to CA Bandwidth Class A with a bandwidth of 20 MHz and a total NRb of 100. Meanwhile, the CC from CA_40C has two carriers with a total NRb between >100 to <200 so that

it belongs to CA Bandwidth Class C with 10 MHz and 20 MHz bandwidths and a total NRb of 150. The distribution of the CA Bandwidth Class can be seen in Table 1.

In this inter-band CA, different resources between TDD Frame and FDD Frame are important things to consider for the CA application. The cellular operator can allocate resources on request where the TDD resources are asymmetrical. It is an advantage for the application of inter-band CA, which can allocate uplink (UL) and downlink (DL) resources according to the operator. In this study, the Resource Block (RB) allocation is based on duplex and bandwidth, as shown in Table 3. The value used in this process is the fixed value of the smartfren operator, depending on the use of bandwidth for the calculation of UL & DL PRb. FDD is 1:1 symmetrical between DL & UL, while asymmetric TDD depends on the configuration it uses [5].

Table 2. Carrier Aggregation Configuration

Type of CA & Duplex	CA Configuration	Maximum Aggregated Bandwidth (MHz)	Maximum Number of CC
Inter-Band CA TDD – FDD	CA_40A-5A	30	2
Inter-Band CA TDD – FDD	CA_40C-5A	40	3
Inter-Band CA FDD – TDD	CA_5A-40A	30	2
Inter-Band CA FDD - TDD	CA_5A-40C	40	3

Table 3. Resource Block Calculation According to Duplex and Bandwidth

Duplex	Bandwidth (MHz)	Configuration	RB UL	RB DL
TDD	20	2	20	60
TDD	10	2	10	30
FDD	10	-	25	25

Next, a resource block calculation is performed for the application of inter-band CA, which can be seen in Table 4.

Table 4. Calculation of CA Configuration

CA Configuration	Bandwidth (MHz)	Maximal of CC	RB UL	RB DL
CA-40A_5A	30	2	45	85
CA-40C_5A	40	3	55	115
CA-5A_40A	30	2	45	85
CA-5A_40C	40	3	55	115

F. Coverage Dimensioning

At this stage, the calculation of the link budget and cell radius is done. Table 5 shows the Maximum Allowed Path Loss (MAPL) value based on the morphology of urban areas with propagation modeling, i.e., the Cost-231 Model. We use this empirical model because it has frequency specifications from 800 MHz to 2000 MHz.

Table 5. Calculation of MAPL

Link Budget	Calculation	UL	DL
Transmitter			
Max power (dB)	A	43	23
RB to distributed	B	60	3
Subcarrier to distributed power	C=12*B	720	36
Subcarrier power (dBm)	D=A-10*Log C	14.4266	7.496
Tx antenna gain (dBi)	E	16.2	0
Tx cable loss (dB)	F	0	0
Tx body loss (dB)	G	0	0
EIRP per subcarrier (dBm)	H=D+E-F-G	30.6266	7.4369
Receiver			
SINR (dB)	I	-4	-4
Noise Figure (dB)	J	7	3.5
Rx sensitivity (dBm)	K=I+J-174+10 Log (15*1000)	-139.2390	-142.7390
Rx antenna gain (dBi)	L	0	16.2
Rx cable loss (dB)	M	0	0.5
Rx body loss (dB)	N	0	0
Interference margin (dB)	O	8	2
Min. signal reception strength (dBm)	P=K-L+M+N+O	-131.2390	-125.1390
Indoor penetration loss (dBm)	Q	16	16
Shadow fading margin (dB)	R	8	4
Maximum allowed pathloss (dB)	S	137.8657	130.1760

The next step is to calculate the cell radius, which is determined by the value of the link budget's results, i.e., the smallest MAPL between the downlink and uplink. The calculation results can be seen in Table 6.

Table 6. Cell Radius

eNodeB	Height (m)	Cell Radius (km)
ZBDG_4393	25	0.501
ZBDG_4416	17	0.442
ZBDG_4394	26	0.508
ZBDG_4418	22	0.582

eNodeB	Height (m)	Cell Radius (km)
ZBDG_4417	22	0.582
ZBDG_4485	17	0.442

In this calculation, it is known that the antenna height is based on the existing conditions assuming the user height is 1.5 meters, and the working frequency is 2300 MHz. The calculation employs (1) and (2).

$$P_L = 46.33 + 33.9 Log(h_b) - a(h_m) +$$

$$[44.9 - 6.55 \log (h_b)] \log d \qquad (1)$$

Where P_L is a pathloss (dB), h_b is a height of eNode B (m), $a(h_m)$ is an UE antenna correction factor, and d is a radius (km).

$$a(h_m)urban = (1.1 \log f - 0.7)h_m - (1.56 \log f - 0.8) \qquad (2)$$

Where P_L is a pathloss (dB), f is a frequency (MHz), h_b is a height of eNode B (m), h_m is a height of UE (m), d is a radius (km), and $a(h_m)urban$ is an UE antenna correction factor for urban areas.

The next step is to calculate the forecasting user. The calculation employs (3).

$$Future\ Population = p_o\ [(1 + GF)]^n \qquad (3)$$

Where P_o is a current population, GF is a grow factor, and n is a number of forcasting years.

The next process is to calculate the forecasting user number of LTE-Advanced operator with the following steps.

- Future Population
  $346,820\ [(1 + 0.5)]^5 = 354,341$ peoples
- Productive age
  345,341 x 70.17 % = 248,039 peoples
- Market share
  248,039 x 3 % = 7441 peoples
- LTE operator
  7441 x 60 % = 4465 peoples
- LTE-A operator
  4465 x 40 % = 1786 peoples

The calculation results can be seen in the following Table 7.

Table 7. Forecasting User

Growth Factor	0.43 %
Future Population	354,341
Productive Age	248,039
Market share	7441
Total user	7441
LTE operator 60%	4465
LTE-Advanced operator 40%	1786

The next step is to calculate cell average throughput in one cell according to the bandwidth used. This calculation uses (4) and (5).

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Cell Capacity (UL) $= [(168-24) \times$ *Code Bits $\times$ CodeRate $\times$ Nrb $\times$ C $\times$ 1000] – CRC*   (4)

Cell Capacity (DL) $= [(168-36-12) \times$ *Code bits $\times$ Code rate $\times$ Nrb $\times$ C $\times$ 1000] – CRC*   (5)

Table 8. The Calculation of Cell Average Throughput of DL

Modulation	Code Bit	Code Rate	Number of RBs	MIMO	SINR (min)(dB)	SINR Probability (Pn)	Cell Throughput (bps) (Rn)	Cell Average Throughput (kbps)
QPSK 1/3	2	0.3	105	2	-1.5 – 0.3	0.29	15119976	4384.79304
QPSK 1/2	2	0.43	105	2	0.3 - 2	0.27	21671976	5851.43352
QPSK 3/5	2	0.58	105	2	2 – 4.5	0.19	29231976	5554.07544
16 QAM 1/3	4	0.36	105	2	4.5 - 6	0.15	36287976	5443.1964
16 QAM 1/2	4	0.47	105	2	6 – 8.5	0.14	47375976	6632.63664
16 QAM 3/5	4	0.6	105	2	8.5 – 10.8	0.09	60479976	5443.19784
64 QAM 1/2	6	0.45	105	2	10.8 – 12.5	0.06	68039976	4082.39856
64 QAM 3/5	6	0.65	105	2	12.5 – 13.5	0.05	98279976	4913.9988
Cell Average Throughput								42305.7302
Site Capacity								126917.191

Table 9. The Calculation of Cell Average Throughput of DL

Modulation	Code Bit	Code Rate	Number of RBs	MIMO	SINR (min)(dB)	SINR Probability (Pn)	DL Cell Throughput (bps) (Rn)	DL Cell Average Throughput (kbps)
QPSK 1/3	2	0.3	115	2	-1.5 – 0.3	0.29	16559976	4802.39304
QPSK 1/2	2	0.43	115	2	0.3 - 2	0.27	27863976	7523.27352
QPSK 3/5	2	0.58	115	2	2 – 4.5	0.19	37583976	7140.95544
16 QAM 1/3	4	0.36	115	2	4.5 - 6	0.15	46655976	6998.3964
16 QAM 1/2	4	0.47	115	2	6 – 8.5	0.14	60911976	8527.67664
16 QAM 3/5	4	0.6	115	2	8.5 – 10.8	0.09	77759976	6998.39784
64 QAM 1/2	6	0.45	115	2	10.8 – 12.5	0.06	87479976	5248.79856
64 QAM 3/5	6	0.65	115	2	12.5 – 13.5	0.05	126359976	6317.9988
Cell Average Throughput								53557.8902
Site Capacity								160673.671

Based on Tables 8 and 9, it is known that in the 30 MHz bandwidth, the average throughput value in one uplink direction cell is 10.878 Mbps, whereas, in the downlink direction, it is 42.305 Mbps. In the 40 MHz bandwidth, the average throughput value in one cell in the uplink direction is 13.296 Mbps, while the average throughput value in one cell in the downlink is 53.557 Mbps. Then, it can be seen that for LTE 30 MHz bandwidth, the site capacities for the uplink and the downlink are 32.635 Mbps and 126.917 Mbps, while for LTE 40 MHz bandwidth, the site capacities for the uplink and the downlink are 39.888 Mbps and 160.673 Mbps.

III. RESULT

The inter-band CA simulation was done by taking into account: the initial network condition and two predefined scenarios. First scenario: performed according to the configuration schemes of CA_40A-5A with two CCs and CA_40C-5A with three CCs. The second scenario: performed according to the configuration schemes of CA_5A-40A with two CCs and CA_5A-40C with three CCs.

The simulation is based on a research area limited by the focus zone (green line) and the computation zone (red line), which is the site coverage area around the CA application. After that, the evaluation is performed by taking into account the RSRP parameters, SINR, throughput, and the percentage of

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PRb based on cellular provider standards. Fig. 4 - 9 indicates the results of predictions of the application of inter-band CA from both scenarios. Table 10 illustrates the summary of planning results by comparing the initial conditions of the network using scenarios 1 and 2.

Table 10 shows the comparison of the forecasting results of the initial network condition, scenario 1, and scenario 2. The optimal result is found in scenario 1 with the inter-band CA configuration of CA_40C_5A with 3 CCs.
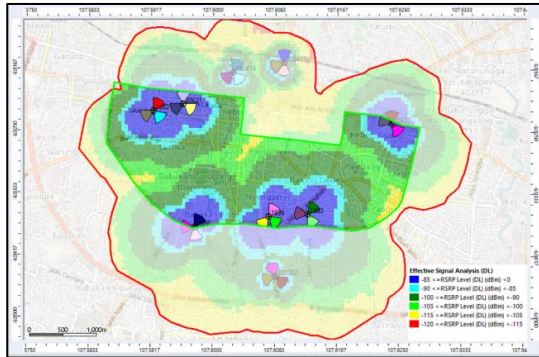
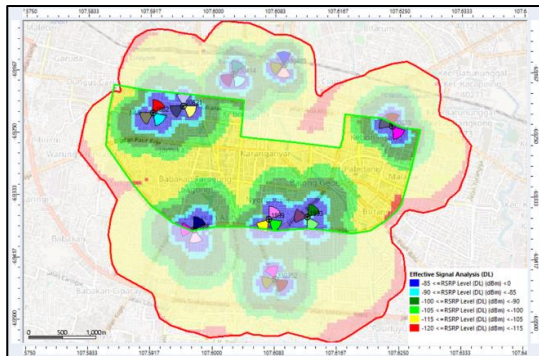

Fig. 4. Coverage Plot for RSRP Scenario 1

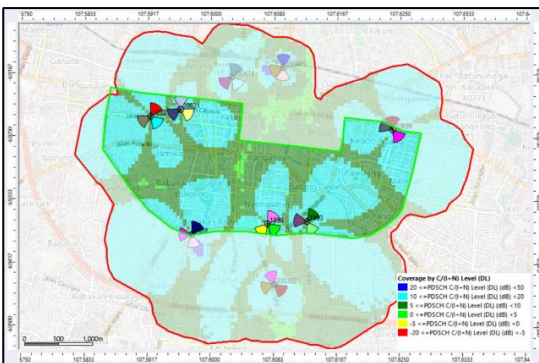Fig. 5. Coverage Plot for RSRP Scenario 2

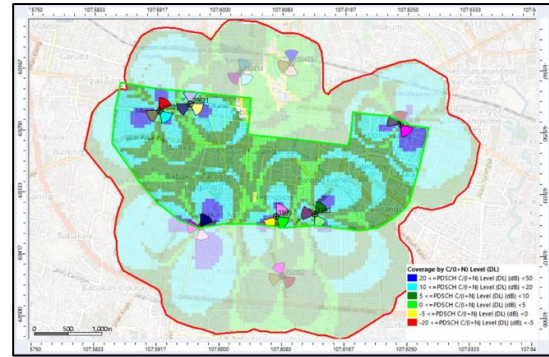

Fig. 6. Coverage Plot for SINR Scenario 1

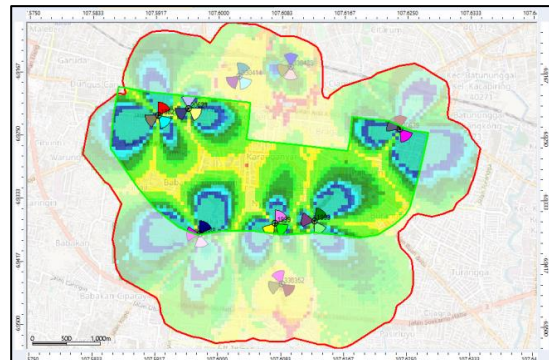Fig. 7. Coverage Plot for SINR Scenario 2

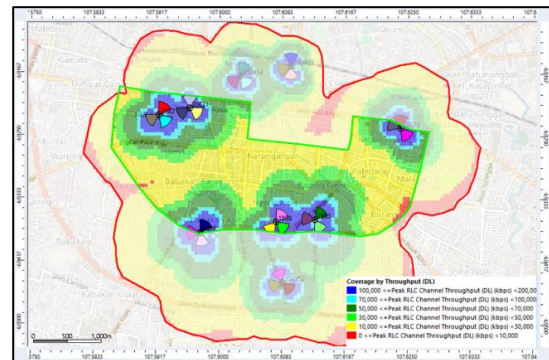

Fig. 8. Coverage Plot for Throughput Scenario 1

Fig. 9. Coverage Plot for Throughput Scenario 2

IV. DISCUSSION

Table 11 shows a decreased traffic load percentage of the physical resource block usage in the application of inter-band CA compared to the initial network condition that has high traffic.

Table 11. Decreased PRb Usage Compared to Initial Network Condition

Simulation	Configuration	Physical Resource Block	
		Initial (%)	Final (%)
Scenario 1	CA-40A_5A	82.6	72.80
	CA-40C_5A	82.7	44.50
Scenario 2	CA-5A_40A	82.8	74.36
	CA-5A_40C	82.9	58.58

Table 11 shows the percentage of PRb usage where the testing is performed under the same traffic load (DL) condition. In the initial column, (%) shows a high percentage of PRb at the initial network condition, while in the final column, (%) shows a lower percentage of PRb after application of the inter-band CA method. The application of inter-band CA can maintain high traffic to remain stable under the cellular operator's warning with an increase in the network capacity side. Table 12 shows the percentage of each target parameter according to the operator's Key Performance Indicator (KPI) standard.

Table 12 shows the final simulation results of the inter-band carrier aggregation application. It indicates an increase in the percentage of KPI targets in the focus zone and an increase in the computation zone. An optimal forecasting result can be found in scenario 1 with an inter-band CA configuration of CA_40C_5A with 3 CCs.

Based on the results of capacity increase simulations, this study recommends the application of inter-band CA using CA_40C_5A configuration with three CCs to be implemented by the operator in the Central Bandung area. This is due to the consideration of initial network condition and efficiency in the use of operator resources, as well as better performance in terms of coverage with an average RSRP of -90.5 dBm, better network quality with an average SINR of 11.42 dB. In addition, in the term of capacity, it increases with an average throughput of 62.37 Mbps and at a percentage of PRb of 44.50 %.

Table 10. Comparison of Forecasting Results

Final Forecasting Results					
Simulation	**RSRP (dBm)**		**SINR (dB)**		**Throughput (Mbps)**
	Focus Zone	**Computation Zone**	**Focus Zone**	**Computation Zone**	**Focus Zone**	**Computation Zone**
Initial condition	-103.3	-104.71	6.28	8.44	27.78	29.46
CA-40A_5A	-90.5	-96.86	13.12	11.03	38.12	34.96
CA-40C_5A	-90.5	-96.48	11.42	10.39	62.37	56.90
CA-5A_40A	-99.36	-102.74	10.73	9.62	37.32	31.67
CA-5A_40C	-99.36	-102.74	10.7	9.56	47.55	39.92

Table 12. The Final Result of Inter-band CA Application

Final Results According to KPI Targets					
Simulation	**RSRP (dBm) > -105 dBm (%)**		**SINR (dB) > 5 dB (%)**		**Throughput > 5 Mbps (%)**
	Focus Zone	**Computation Zone**	**Focus Zone**	**Computation Zone**	**Focus Zone**	**Computation Zone**
Initial condition	49.41	49.50	74.64	74.64	100	100
CA-40A_5A	97.38	97.4	90.88	90.86	99.96	99.96
CA-40C_5A	97.33	97.4	99.03	98.97	100	100
CA-5A_40A	59.95	60.06	87.86	87.84	99.5	99.5
CA-5A_40C	59.95	60.06	87.9	87.63	99.6	97.6

V. CONCLUSION

According to the simulation results, scenario 1 with the CA-40A-5A configuration with two CCs can increase the average throughput capacity of 38.12 Mbps with the traffic load percentage of PRb usage of 72.80 %. This value improves the traffic percentage of high PRb usage in the initial network condition, which is 82.6 %, and improves the quality of RF parameters such as RSRP with an average of -90.5 dBm, and SINR with an average of 13.12 dB. Meanwhile, the use of 3 CCs increases the average capacity more on the throughput wherein scenario 1 with CA-40C-5A configuration, it can be more optimally obtained with an average throughput of 62.37 Mbps with the load traffic percentage of PRb usage of 44.50 %. This value improves the percentage of high PRb usage traffic by 82.6 % at the initial network condition, that at SINR by 11.42 dB, and that at RSRP by -90.5 dBm.

Furthermore, scenario 1 suggests an increase in RSRP value > -105 dBm by 97 %, that in SINR value > 5 dB by 90 %, and that in throughput value > 5 Mbps by 100 %. Scenario 2 indicates an increase in RSRP value > -105 dBm by 59 %, that in SINR value > 5 dB by 87 %, and that in throughput value > 5 Mbps by 99 %.

The inter-band CA application of CA-40C_5A configuration with 40 MHz bandwidth is more optimal to be implemented because it can increase capacity by maximizing available resources.

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