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Simulation-Based Design of LTE Indoor Networks in High-Density Building Scenarios

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Abstract

The implementation of 5G mobile communication technology in Indonesia faces significant challenges due to limited infrastructure and coverage in several regions. Consequently 4G technology is still the favorite among the public. However, not all areas are covered by a good quality 4G long term evolution (LTE) network, especially inside buildings, because the signal from the eNodeB weakens due to the building construction. This study aims to determine the optimal antenna configuration to improve network quality inside the building, in this case in the XYZ building by implementing an indoor building solution (IBS) on the 4G LTE network using radiowave propagation simulator software. The IBS design uses two approaches, namely coverage dimensioning and capacity dimensioning. The simulation comparing the location of antenna placement in the center or edge building and the results show that placing the antenna in the center of the building is more optimal than placing it at the edge of the building. The average of received signal strength indicator (RSSI) values obtained from the ground floor to the 2nd floor are -46.67 dBm, -50.09 dBm, and -49.41 dBm, respectively. Meanwhile the average of signal to interference plus noise ratio (SINR) values obtained from each ground floor to the 2nd floor are 18.77 dB, 23.20 dB, and 27.77 dB, respectively. Both parameter values are included with an Excellent rating based on the RKX operator's key performance indicator (KPI) standards. Hopefully that the results of this research can be used as a reference, model, and implemented in other indoor locations so that 4G network coverage in Indonesia can be further expanded, especially indoors.

Keywords: Capacity Dimensioning, Coverage Dimensioning, Indoor Building Solution, 4G LTE Network.

I. INTRODUCTION

The development of technology, including mobile telecommunications systems, is point 9 of industry, innovation, and infrastructure in the sustainable development goals (SDGs) [1]**.** Implementing 5G mobile communication technology is one of Indonesia's efforts to support technological development. However, its implementation faces significant challenges, especially regarding infrastructure (frequency spectrum management, device investment, security and privacy issues) and geographical characteristics [2]. Based on the 2024 postal and information technology implementation data report released by the Ministry of Communication and Digital Affairs, the number of mobile subscribers in 2023 recorded an increase of 2.79% or an additional 9 million subscribers, and there were 373 5G infrastructures spread across 21 provinces in Indonesia in 2023. Meanwhile, there were 433,940 4G infrastructures spread across 34 provinces in Indonesia in 2023, and the growth of 4G long term evolution (LTE) in Indonesia was very rapid, with aggregate 4G growth in Indonesia reaching 12.58% from the previous year [3].

The data above shows that 4G technology is still popular among Indonesians. Although 4G infrastructure is now almost evenly distributed throughout Indonesia, not all places and areas are covered by a good quality 4G LTE network, outdoors, indoors [4]–[6], or in buildings [7]. In the case of indoor coverage, this is because the outdoor LTE network cannot reach certain areas due to the signal from the eNodeB being reduced or weakened (attenuation) by the building construction or construction materials [8]. To overcome this problem, indoor building solutions (IBS), a system with transmitters and receivers inside, is installed using the building internal network. Indoor network communication is applied inside buildings to assist outdoor network systems (macro and micro cell outdoor) [9]. IBS has two approaches in its planning, namely coverage and capacity dimensioning, but some studies only use one of these approaches [10][11]. Indoor building solution has been implemented in many places or locations, such as apartments [12][13],

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hospitals [14], campuses or universities [15], and recreational areas [16]. However, almost all previous research has not considered about the location of antenna placement in the building whereas this factor can affect performance and efficiency. Shopping centers should also have IBS [17] installed because high-speed data access is needed to support customer activities, whether shopping or just visiting [18]. The XYZ building is a shopping center that currently have experience indoor network issues and has not yet implemented an IBS network infrastructure.

The proposed study is implementating IBS network using a 4G LTE network using radiowave propagation simulator (RPS) software with the XYZ shopping center is used as model. The coverage and capacity dimensioning approach is used to determine the number of antennas/sites needed. Next, the antenna placement location will be compared and analyzed to get the best results (center or edge of the building) that cover the entire building area, avoiding interference and improving network performance. Meanwhile, the parameters to be measured are received signal strength indicator (RSSI) to determine the strength of the signal and signal to interference plus noise ratio (SINR) to assessing the quality signal intensity against the cumulative strength of interference and noise [19] using the key performance indicator (KPI) standard by the RKX operator. Hopefully that the results of this research can be used as a reference, model, and implemented in other indoor locations so that 4G network coverage in Indonesia can be expanded, especially indoors.

II. Methods

The IBS design will use two approaches, namely coverage and capacity dimensioning. In contrast, the frequency used is band 40 (2300 MHz) due to the frequency has role as a capacity layer in LTE networks with supporting wider channel bandwidths for high indoor traffic demand. In comparison, lower-frequency bands such as 1800 MHz and 900 MHz offer better coverage and penetration characteristics but are generally more suitable for coverage oriented deployment. In addition, the operational frequency used by the reference operator considered in the network planning and simulation. Then for the size of cell uses a Femtocell because it is very effective for installation in buildings in terms of range and capacity and improves the network functionality and is relatively low-cost and can be stand alone (not dependent on outdoor networks). Then, for the antenna/site placement distribution system, passive distributed antenna system (DAS) is used because passive systems are relatively more straightforward to design, and the components and cables are robust if installed correctly. However, if the cable is disconnected, the base station will not send a voltage standing wave radio (VSWR) alarm due to high return loss [17]. The 4G propagation model for outdoor and indoor environments is different [20]. In indoor network design, the factors that affect propagation losses on a floor are the partitions of that floor, which are divided into hard and soft partitions [21]. For details of the entire system flowchart, coverage dimensioning flowchart and capacity dimensioning flowchart shown in Figure 1.

Therefore, the propagation model selected is Cost-231 Multiwall, because this propagation model is the most suitable model used for mobile communication design in indoor because this propagation model takes into account the material and thickness of the wall and other obstacles in signal propagation [9]. Compared to the ITU Indoor or Motley–Keenan models, which provide more generalized loss estimations, the Cost-231 Multiwall model enables more realistic representation of signal attenuation in complex indoor environments. The parameter to be measured is RSSI, which is the total power received by the radio channel or the measurement of the raw RF signal of the entire channel bandwidth. In the case of 4G, RSSI is the sum of all powers on active sub-carriers. Therefore, RSSI depends on the carrier bandwidth [22], [23]; the wider the bandwidth, the more sub-carriers will be transmitted [17], [24], and SINR is the ratio between signal strength and the sum of the average interference and noise strength [25]. Next, the final results will be compared with the location of antenna placement scenarios (center or edge of the building) to obtain optimal and efficient results to improve network performance.

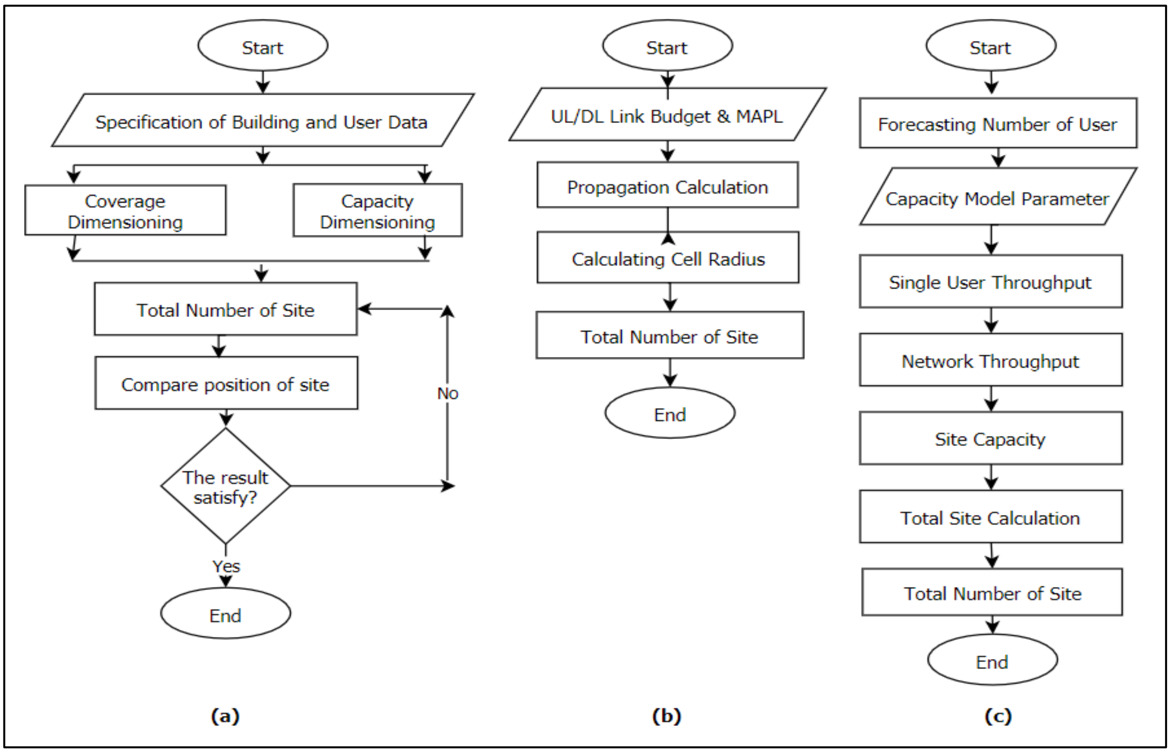


Figure 1. (a) Overall system, (b) coverage dimension, and (c) capacity dimensioning flowchart.

A. Coverage Dimensioning

Coverage dimensioning is a planning method based on area review, calculating the maximum allowed path loss (MAPL) value to obtain the coverage/radius of a cell from a single site/antenna. Once the cell radius value from one site is obtained, the number of sites required to cover the entire area inside the building can be determined. The main priority in coverage dimensioning is that all sides of the area inside the building are covered by the signal, without considering the throughput value obtained by each user. The overall steps of coverage dimensioning are shown in Figure 1(b).

Link budget (LB) is a fundamental calculation for the entire radio frequency (RF) link between the transmitter (Tx) and receiver (Rx). Effective isotropic radiated power (EIRP), commonly known as Rx-level, is the power radiated from the antenna into free space, which is the sum of Tx power and antenna gain, minus cable attenuation and propagation losses, as shown in (1) [17], [26].

$$Rxlev = TxPower\ (dBm) + Antena\ Gain\ (dB) - Cable\ Attenuation\ (dB) - Propagation\ losses \quad (1)$$

Maximum allowable path loss is the deviation between the desired transmit and receive power, including margin fading and body loss. In two-way calculations, there are two LB calculations, one for downlink (DL) and one for uplink (UL). The LB calculation results are the MAPL from the base station (eNodeB) to the mobile device on the downlink and the maximum allowable link loss on the reverse link, from the mobile device to the base station on the uplink. The calculations are presented in (2) for UL and in (3) for DL [17].

$$MALL = UETxPower + UEAG + OG - FM - IM - BL - PL1 - PL2 + EAG - CL - RSNB \quad (2)$$

Where,

MALL	= Maximum Allowable Link Loss permitted in signal propagation [dB]
UETxPower	= User Equipment Transmit Power [dBm]
UEAG	= UE Antenna Gain [dB]
OG	= Other Gain
FM	= Fading Margin [dB]
IM	= Interference Margin [dB]
BL	= Body Loss [dB]
PL1	= Penetration Loss [dB]
PL2	= Path Loss [dB]
EAG	= eNodeB Antenna Gain [dB]
CL	= Cable Loss [dB]
RSNB	= Receiver Sensitivity eNodeB [dBm]

$$MAPL = NBTxPower - CL + EAG + OG - FM - IM - PL1 - PL2 - BL + UEAG - RSUE \quad (3)$$

Where,

MAPL	= Maximum Path Loss permitted in signal propagation [dB]
NBTX Power	= eNodeB Transmit Power [dBm]
CL	= Cable Loss [dB]
EAG	= eNodeB Antenna Gain [dB]
OG	= Other Gain
FM	= Fading Margin [dB]
IM	= Interference Margin [dB]

PL1 = Penetration Loss [dB]

Calculation of cell area in planning using a hexagonal cell model [27]. In calculating cell area in indoor network planning, the scheme used is an omnidirectional antenna. The final step in calculating the number of required sites based on the coverage planning results is given in (4) [28].

$$LCell = 2{,}6\, x\, d^2$$
$$\sum LTECell = Area \,/\, Lcell \tag{4}$$

B. Capacity Dimensioning

Capacity dimensioning is a design method that estimates the services required to support the service and traffic offered. This requires an estimate of the number of users who will use the planned network, an estimate of the services that customers can access, and an estimate of the traffic density surge in handling the customers served simultaneously that can be covered in one cell. In capacity dimensioning, user behavior in an area is very crucial because user behavior is defined as the average usage during busy hours. One of the objectives is to determine the number of sites needed according to the required capacity [28].

Forecasting is a method for predicting the number of customers in a region within a certain period of time in year *n*, as expressed in (5), where Un is the number of customers in year *n*, U_o is the number of customers in the reference year, growth factor (GF) is the customer growth factor, and *n* indicates the year to be predicted.

$$Un = U_o\, x\, (1 + GF)n \tag{5}$$

The purpose of capacity dimensioning is to determine the number of sites required for the required traffic or capacity. In general, the capacity dimensioning calculation process is divided into two parts, namely single site dimensioning and total network throughput. The single-site dimensioning part of capacity dimensioning is a process of making an approach based on parameters such as duplex mode and bandwidth system, among others. The purpose of single-site dimensioning is to determine the capacity per site. Meanwhile, total network throughput dimensioning is a process based on the traffic and service model. The entire capacity dimensioning steps are shown in Figure 1(b). The single-user throughput and total network throughput can then be calculated by multiplying the number of target users by the single-user throughput value obtained. Determination of traffic parameters and service models used to find the single-user throughput value [29].

In (6), Session Time is the duration of the point to point protocol (PPP) session, session duty ratio is the data transmission ratio of the PPP session, block error rate (BLER), while bearer rate is the service application layer (IP) bearer rate.

$$Throughput/Session\ (Kbit) = (Bearer\ Rate\ x\ PPP\ Session\ Time\ x\ PPP\ Session\ Duty\ Ratio)/(1 - BLER) \tag{6}$$

The traffic model indicates how the UE behaves daily (UE behaviors). The parameters in the traffic model are penetration ratio and busy hour service attempt (BHSA). The penetration ratio is the penetration proportion for each service. Meanwhile, BHSA is the number of service access attempts made by a single user in one hour. After obtaining the throughput/session and traffic model results, the following process is to find the single user throughput (SUT) value, which is the total throughput of several service types for one user/customer. SUT can be calculated based on the throughput value per session, traffic model, and peak-to-average ratio, as given in (7). The peak to average ratio value is an estimate or margin in a traffic surge. The selection of the peak to average ratio value depends on the morphology of the area [30].

$$Single\ User\ Throughput = (\sum (Throughput\ per\ Session\ x\ BHSA\ x\ Penetration\ Ratio))\ x\ (+Peak\ Average\ Rat \,/\, 3600 (Kbps) \tag{7}$$

Total network throughput is the total throughput that must be provided by the network to serve the target number of users, as given in (8). Network throughput can be obtained by multiplying the number of users by the single-user throughput value [30].

$$Total\ Network\ Throughput (Kbps) = Single\ User\ Throughput (Kbps)\ x\ Total\ User\ Target \tag{8}$$

The value of total network throughput obtained from the calculation is the throughput at the IP layer. This throughput must be converted to throughput at the MAC layer because single-site capacity throughput is throughput at the MAC layer, and the throughput that will be obtained by the user is throughput at the MAC/Phy layer. The conversion from the IP layer to the MAC layer accounts for a relative efficiency of 98.04% [30]. Therefore, the MAC layer throughput is calculated using (9).

$$MAC\ layer\ throughput = IP\ layer\ throughput \,/\, 98{,}04\ \% \tag{9}$$

Single site capacity or cell average throughput is the capacity of a single site. The purpose of calculating site capacity is to determine the number of sites needed to serve users based on the total network throughput obtained. To determine site capacity or cell average throughput, information about cell radius and SINR distribution is required. Cell capacity calculations are performed on both sides, namely the downlink (DL cell throughput) and uplink (UL cell throughput), as shown in (10) and (11), respectively.

$$
\begin{aligned}
&DL\ cell\ Capacity + CRC \\
&= (168 - 36 - 12) \times (Code\ bits) \\
&\times (Coderate) \times Nrb \times C \times 1000
\end{aligned} \tag{10}
$$

$$
\begin{aligned}
&UL\ cell\ Capacity + CRC = \\
&(168 - 24) \times (Code\ bits) \times (Coderate) \\
&\times Nrb \times C \times 1000
\end{aligned} \tag{11}
$$

Where,

CRC	= Cyclic Redundancy Check, 24
168	= Number of Resource elements in 1 ms
36	= Number of control channels on the Resource element in 1 ms
12	= Number of reference signals on the Resource element in 1 ms on the downlink
24	= Number of reference signals on the Resource element in 1 ms on the uplink
Code bits	= Modulated bit
Code rate	= Channel coding rate
Nrb	= Number of Resource Blocks
C	= MIMO Antena Mode

Then calculate the number of sites required from the capacity dimensioning side by dividing the total network throughput by the single site capacity, as given in (12).

$$
\begin{aligned}
&Number\ of\ site\ (UL/D)) \\
&= UL/DL\ Total\ Network\ Throughput\ /\ UL \\
&/DL\ Single\ Site\ Capacity
\end{aligned} \tag{12}
$$

III. Result and Discussion

To start the simulation, the first step is to understand the design and spesifications of the building where Indoor Building Solutions will be implemented. After obtaining the design and spesifications of the XYZ shopping center building, a layout is created using RPS software, as shown in Table 1 and Figure 2. This design considers the materials utilized in the building and the meaning of color in design shown the material that used as shown in Table 2.

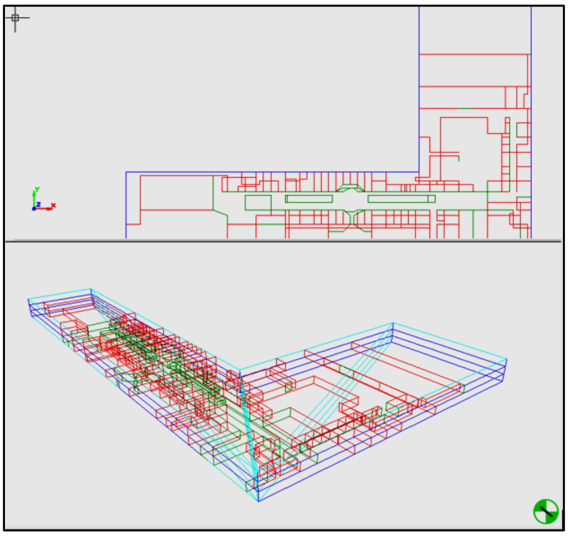


Figure 2. 2D & 3D layout design of XYZ shopping center building in RPS.

TABLE 1
SPESIFICATION OF XYZ SHOPPING CENTER BUILDING

BUILDING AREA	42000M2
NUMBER OF FLOORS	3 FLOOR
BUILDING HEIGHT	12 METER
AREA OF EACH FLOOR	14200 M2

TABLE 2
SYMBOL MATERIAL IN RPS

MATERIAL	SYMBOL
FLOOR	
CEILING	
INNER WALL	
OUTER WALL	
GLASS	

Meanwhile, details of the transmission losses including coaxial cables serving as the backbone and the passive components utilized like jumpers, splitters, connectors, and combiners, are presented in the Table 3.

TABLE 3
CABLE LOSS ON EACH FLOOR

FLOOR	GROUND FLOOR	1ST FLOOR	2ND FLOOR
ΣLFEEDER 1/2" (DB)	13.71	13.71	13.71
ΣLFEEDER 1 5/8" (DB)	0.7385	0.633	0.527
ΣLSPLITTER 2-WAY (DB)	3.02	3.02	3.02
ΣLTAPPER (DB)	3.2	7.6	6
ΣLCOMBINER (DB)	2.5	2.5	2.5
ΣLCONNECTOR (DB)	2.1	1.8	1.8
ΣCABLE LOSS (DB)	15.26	29.26	27.55

TABLE 4
PROPAGATION LOSS ON EACH FLOOR

FLOOR	MATERIAL TYPE	LOSS (DB)	AMOUNT	TOTAL LOSS (DB)
GROUND FLOOR	Brick	3.5	9	31.5
	Wood	2.8	2	5.6
	Glass	0.8	3	2.4
	Indoor Loss Ground Floor			39.5
1ST FLOOR	Brick	3.5	7	24.5
	Wood	2.8	2	5.6
	Glass	0.8	5	4
	Indoor Loss 1st Floor			34.1
2ND FLOOR	Brick	3.5	7	24.5
	Wood	2.8	2	5.6
	Glass	0.8	7	5.6
	Indoor Loss 2nd Floor			35.7

TABLE 5
NUMBER OF SITE COVERAGE DIMENSIONING ON EACH FLOOR

FLOOR	CELL AREA	NUMBER OF SITES	NUMBER OF SITE COVERAGE
GROUND FLOOR	3339.72 m^2	4.2518	**4**
1ST FLOOR	4614.84 m^2	3.0770	**3**
2ND FLOOR	**4729.46 M^2**	**3.0024**	**3**

TABLE 6
NUMBER OF SITE CAPACITY DIMENSIONING ON EACH FLOOR

FLOOR		GROUND FLOOR	1ST FLOOR	2ND FLOOR
TOTAL USER		521	347	289
NETWORK THROUGHPUT (MAC) (MBPS)	UL	18.93	12.62	10.51
	DL	168.6	112.4	93.66
SINGLE SITE THROUGHPUT (MAC) (MBPS)	UL	15.2	15.2	15.2
	DL	38.001	38.001	38.001
SITE CALCULATION	UL	1.245	0.83	0.691
	DL	4.436	2.957	2.464
TOTAL SITE CAPACITY		4	3	3

The propagation model employed in this study is the Cost-231 Multiwall model, which accounts for building dimensions, material characteristics, and multipath fading. This model is therefore considered the most suitable for estimating path loss caused by indoor materials, commonly referred to as indoor loss. Consequently, the calculated results are used to adapt the network design to the actual conditions of the building in the field as shown in Table 4.

Based on the calculations that have been carried out, it was found that coverage dimensioning requires a total of 4,3,3 antennas from the ground floor to the 2nd floor, as shown in Table 5. Capacity dimensioning also requires a total of 4,3,3 antennas, as shown in Table 6.

From the results of the coverage and capacity dimensioning calculations, it was found that the number of antennas or sites for each floor was the same. Recommendations for antenna placement should consider placing hotspot antennas and maximizing data performance, efficiency for saving costs, isolating buildings, and filling gaps (blank spots). Therefore, a comparison was made between was made between the location of antenna placement in the center and on the edge of the building to observe network performance and efficiency. The parameters measured were RSSI and SINR.

The RSSI and SINR value threshold levels adopted and follow the KPI standards defined by the RKX operator. The RSSI thresholds, are defined as follows: Excellent (> −44 dBm), Good (−45 to −59 dBm), Intermediate (−60 to −74 dBm), Poor (−75 to −89 dBm), and Bad (−90 to −104 dBm). In addition, the SINR thresholds are categorized as Excellent (> 12 dB), Good (6–12 dB), Intermediate (3–6 dB), Poor (−3–3 dB), and Bad (−20 to −3 dB). Based on RSSI simulation comparation between antenna center placement and antenna edge placement on the ground floor until 2nd floor as shown in Table 7. On the ground floor, the results are equally good between antenna placement in the center or on the edge. There are no results in the very poor category. However, antenna placement in the center has a better percentage value. On the first floor, which uses a three-antenna design, the results of RSSI also show that placing the antenna in the center is better, as evidenced by the sum of the very good and good categories reaching 85% of the area and the very poor category only around 0.1%. The simulation results conducted on the 2nd floor also using three-antenna like 1st floor showed better values for antenna placement in the center. For the excellent category, the difference in percentage values was almost 10%. Although for the good category, the percentage of antenna placement at the edges was greater, for the poor category, the percentage values produced were quite large.

Meanwhile, based on the SINR parameter value, comparation between antenna center placement and antenna edge placement on the ground floor until 2nd floor shown in Table 8. On the ground floor, balanced value is obtained. However, when placing the antenna at the edge, there is very poor category even though the percentage value is small. The reason why the antenna placement value at the edge is not optimal is likely because the transmission is blocked by an obstacle, resulting in limited coverage. Better values also apply to the SINR parameter on the 1st floor. As can be seen in Table 6, the very good category achieved a value of 74.71%. The SINR produced by placing the antennas in the middle had fairly good value because the distance between them was just right so that antenna does not interference with each other. For the SINR parameter results for 2nd floor, the results of placing antenna in the center and on the edge have the same good values. However, placing the antenna on the edge yields slightly better results. This is likely because placing the antenna in the center is slightly affected by interference from other antennas. This impact can be reduced by placing the antennas a little further apart.

TABLE 7
RSSI SIMULATION COMPARATION BETWEEN ANTENNA CENTER & EDGE PLACEMENT LOCATIONS

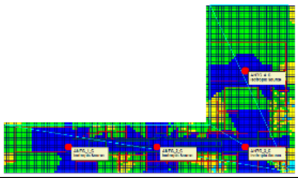
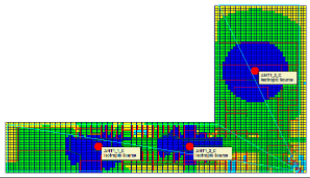
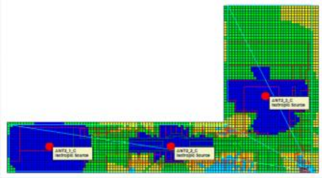
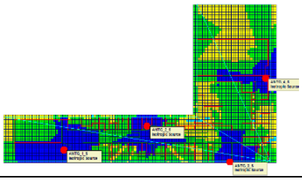
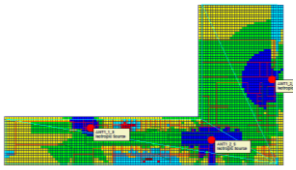
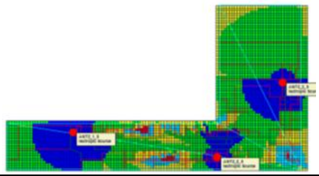
	Ground Floor			1st Floor			2nd Floor		
RSSI Simulation (Center)									
	Category	Range	Percentage	Category	Range	Percentage	Category	Range	Percentage
	Excellent	>-44	45.65	Excellent	>-44	29.41	Excellent	>-44	39.64
	Good	-45 to -59	45.19	Good	-45 to -59	55.55	Good	-45 to -59	45.17
	Intermediate	-60 to -74	8.57	Intermediate	-60 to -74	13.91	Intermediate	-60 to -74	12.89
	Poor	-75 to -89	0.59	Poor	-75 to -89	1.02	Poor	-75 to -89	2.28
	Bad	-90 to -104	0	Bad	-90 to -104	0.10	Bad	-90 to -104	0.02
RSSI Simulation (Edge)									
	Category	Range	Percentage	Category	Range	Percentage	Category	Range	Percentage
	Excellent	>-44	30.51	Excellent	>-44	15.60	Excellent	>-44	30.41
	Good	-45 to -59	48.34	Good	-45 to -59	52.61	Good	-45 to -59	52.07
	Intermediate	-60 to -74	20.74	Intermediate	-60 to -74	25.06	Intermediate	-60 to -74	12.66
	Poor	-75 to -89	0.41	Poor	-75 to -89	6.29	Poor	-75 to -89	4.45
	Bad	-90 to -104	0	Bad	-90 to -104	0.43	Bad	-90 to -104	0.41

TABLE 8
SINR SIMULATION COMPARATION BETWEEN ANTENNA CENTER & EDGE PLACEMENT LOCATIONS

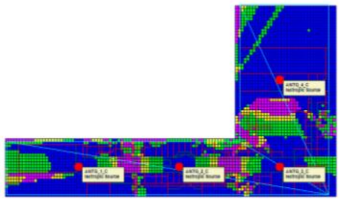
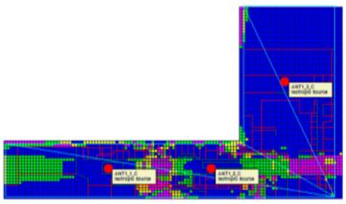
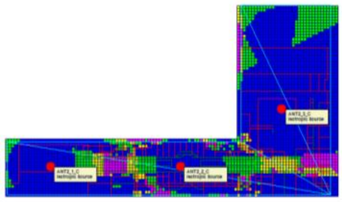
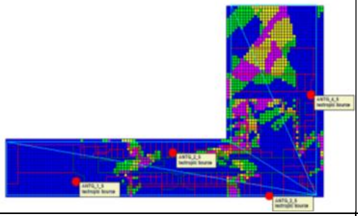
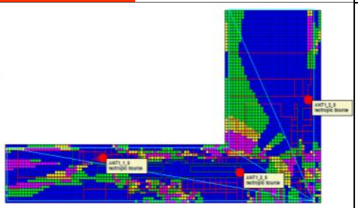
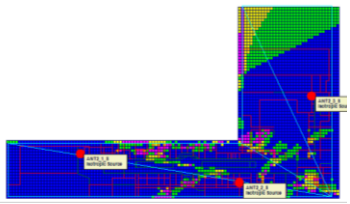
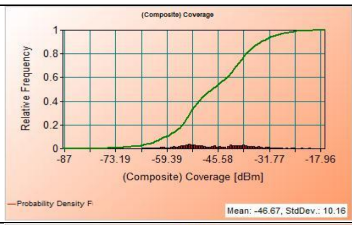
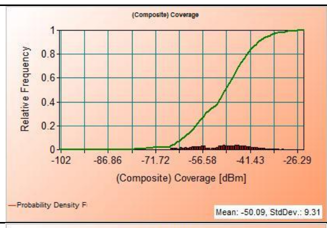
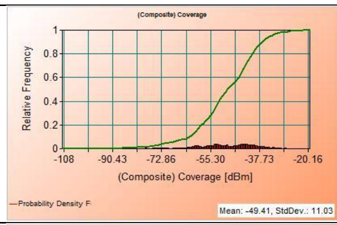
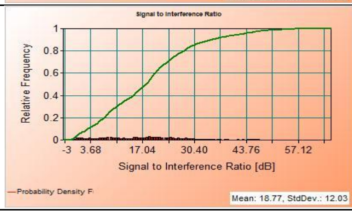
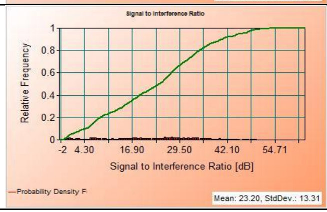
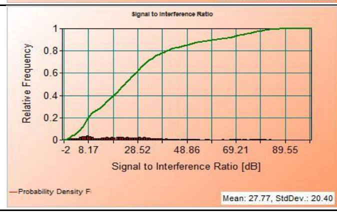
	Ground Floor			1st Floor			2nd Floor		
SINR Simulation (Center)									
	Category	Range	Percentage	Category	Range	Percentage	Category	Range	Percentage
	Excellent	>12	68.08	Excellent	>12	74.71	Excellent	>12	70.31
	Good	6 to 12	14.45	Good	6 to 12	11.79	Good	6 to 12	17.52
	Intermediate	3 to 6	6.19	Intermediate	3 to 6	5.29	Intermediate	3 to 6	5.47
	Poor	-3 to 3	11.28	Poor	-3 to 3	8.21	Poor	-3 to 3	6.70
	Bad	-20 to -3	0	Bad	-20 to -3	0	Bad	-20 to -3	0
SINR Simulation (Edge)									
	Category	Range	Percentage	Category	Range	Percentage	Category	Range	Percentage
	Excellent	>12	69.41	Excellent	>12	56.78	Excellent	>12	68.08
	Good	6 to 12	13.48	Good	6 to 12	25.70	Good	6 to 12	14.45
	Intermediate	3 to 6	5.91	Intermediate	3 to 6	5.04	Intermediate	3 to 6	6.19
	Poor	-3 to 3	11.15	Poor	-3 to 3	12.48	Poor	-3 to 3	11.28
	Bad	-20 to -3	0.05	Bad	-20 to -3	0	Bad	-20 to -3	0

TABLE 9
HISTOGRAM OF THE BEST DESIGN OF ANTENNA PLACEMENT LOCATION ON EACH FLOOR FOR ALL RSSI AND SINR PARAMETERS

	Ground Floor	1st Floor	2nd Floor
SINR Histogram			
SINR Histogram			

Hence from the result of RSSI and SINR, the antenna design selected for the ground floor is the antenna placed in the center, which has an average RSSI value of -46.67 and a standard deviation of 10.16. This indicates that most of the signals are around -46 dBm with a variation ±10 dB, and the average SINR value has an average of 18.77 and a standard deviation of 12.03 dBm, seen around 3.68 dB, with the green curve ≈ 0.2, meaning that 20% of the area has a SINR ≤ 3.68 dB, as shown in Table 9. Both parameter values fall into the excellent category for the RKX operator's KPI parameters. The antenna design selected for the 1st floor is also placed in the center, which has an average RSSI value of -50.09 dBm, a standard deviation of 9.31, and an average SINR parameter value of 23.20 with a standard deviation of 13.31. Both parameter values fall into an excellent category for the RKX operator's KPI parameters too. The design chosen for the 2nd floor differs slightly from the previous two floors. This is because, in terms of the RSSI parameter, placing the antenna in the center is better, but in terms of the SINR parameter, placing the antenna at the edge is better. However, the chosen design is to place the antenna in the center because the SINR parameter values are not too far apart. This design has an average RSSI value of -49.41 dBm, a standard deviation of 11.03, while the SINR parameter has an average value of 27.77 and a standard deviation of 20.40. Table 9 shows the histogram of the best design of antenna placement on each floor for all RSSI and SINR parameters. The next step in the research process is to conduct more in-depth simulations, such as analyzing other 4G LTE KPI parameters, comparing with other frequencies and propagation models, and involving artificial intelligence (AI) in the process of determining antenna placement locations.

IV. CONCLUSION

Based on the simulation and analysis results, it was found that the number of sites required for the XYZ shopping center building is four antennas on the ground floor, three antennas on the first floor, and three antennas also on the second floor. This number is consistent in terms of both coverage and capacity dimensioning. The simulation results show that placing antennas in the center of building is more optimal than placing them at the edges of the building because it producess more even signal distribution, minimizes blankspots, interference, and provides better performance values. Overall, the average RSSI values obtaines were -46.67 dBm on the ground floor, -50.09 dBm on the first floor, and -49.41 dBm on the second floor. Meanwhile, the average SINR value was recorded at 18.77 dB on the ground floor, 23.20 dB on the first floor, and 27.77 dB on the second floor. All of these values fall into the Excellent rating based on the RKX operator's KPI standards. Thus, the implementation of IBS using antenna placement in the center of the building and the number of sites according to the calculation results. Has proven to be able to provide even signal coverage, adequate capacity, and optimal network performance in the XYZ shopping center. It is hoped that the results of this research can be used as a reference, model, and implemented in other indoor locations so that 4G network coverage in Indonesia can be further expanded, especially indoors.

DECLARATIONS

Conflict of Interest

The authors have declared that no competing interests exist.

CRediT Authorship Contribution

Ryan Prasetya Utama: Conceptualization, Methodology, Software, Writing – Original Draft; Regina Leonnie: Supervision, Investigation, Validation, Project Administration; Selvi Melani: Writing – Review & Editing, Visualization, Formal Analysis; Riska Amanda: Writing – Review & Editing, Visualization, Formal Analysis; Achmad Shivan: Visualization, Resources, Data Curation; Faiz Husnayain: Validation, Supervision, Writing – Review & Editing.

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