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Network signal coverage expansion planning WLAN outdoor with 4-C scenario approach at Telkom University

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ABSTRACT

Enhancing internet accessibility on campus is vital for both academic purposes and general internet usage. This research aims to expand the outdoor WiFi coverage at Telkom University, taking into account wireless signal propagation, infrastructure, and network structure. The planning process includes conducting a walk test to evaluate signal coverage, simulating signal and interference, calculating the link budget (including pathloss, RSSI, and EIRP), and determining the Bill of Quantities (BoQ). The analysis of these simulations and calculations leads to informed planning recommendations. By applying the 4-C scenario approach, the study demonstrates that this method effectively covers the entire target area with a minimum RSSI of -75 dBm. There is no interference in the 2.4 GHz band, although co-channel interference occurs in the 5 GHz band. The RSSI consistently stays above -75 dBm, with the lowest measurement being -74 dBm over 200 meters in the 2.4 GHz band. EIRP values are within Indonesia's standard limit of 36 dBm, with a peak value of 33 dBm in the 5 GHz band. The total length of transmission cables used is 1628.3 meters, and the total BoQ amounts to Rp. 384,964,540.

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1. INTRODUCTION

In today's rapidly growing digital era, fast and reliable internet access is an important requirement for every individual to be able to explore the virtual world comfortably. One example of a group that requires internet access is students who use it for learning and social media purposes. At Telkom University, students can connect to the internet in all areas of campus, including in the canteen, lecture building, park, and surrounding areas. Students can access the internet via cellular networks or Wireless Local Area Network (WLAN) according to their needs. Telkom University has provided WLAN-based internet services, namely Wireless Fidelity (WiFi). WiFi is a technology that enables electronic devices to connect to the internet wirelessly through radio waves, with the connection strength determined by the device's signal output. It allows for internet access without the need for cables, and the quality of WiFi is typically evaluated by the speed, which is directly related to the signal strength, as in [1]. The main advantage of WiFi wireless network technology lies in its signal range, which generally reaches 100 meters, and has been tested to be able to cover open areas up to 500 meters, as in [2]. WiFi services can be accessed in almost all Telkom University locations, both indoors and outdoors.

Outdoor WiFi service is one of the options for students to connect to the internet network outdoors besides using cellular networks. This is due to the large number of student activities outdoors, such as association events, graduations, field research, and the number of Telkom University Bandung students which continues to grow every year. Based on data from PDDikti Kemendikbud, the number of Telkom University Bandung students increases every year. The following figure 1 is a graph of data on the number of students at the Telkom University Bandung campus in odd-numbered academic years 2020 to 2023.

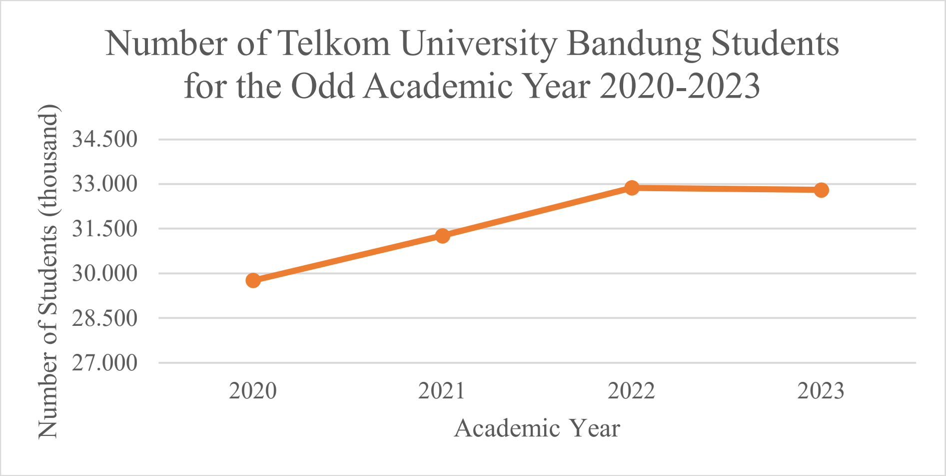


Figure 1. Number of Telkom University Bandung Students for the Odd Academic Year 2022-2023

Based on Figure 1, there is an increase in the number of students at Telkom University Bandung from the odd academic year 2020 to 2023. In 2020, the number of students reached 29,770 people. This number rose to 31,264 students in 2021, then increased again to 32,874 students in 2022. However, in 2023, there was a slight decrease in the number of students to 32,807 people.

Even so, there are still several locations in the Telkom University outdoor area that have not been covered by outdoor WiFi signals. This is due to the limited number of outdoor Access Point (AP) hardware, only 6 APs, and not evenly distributed in several locations where students do outdoor activities. To find out the coverage of existing outdoor WiFi signals, a Drive Test was conducted to see the signal coverage. The following figure 2 is the result of the drive test.

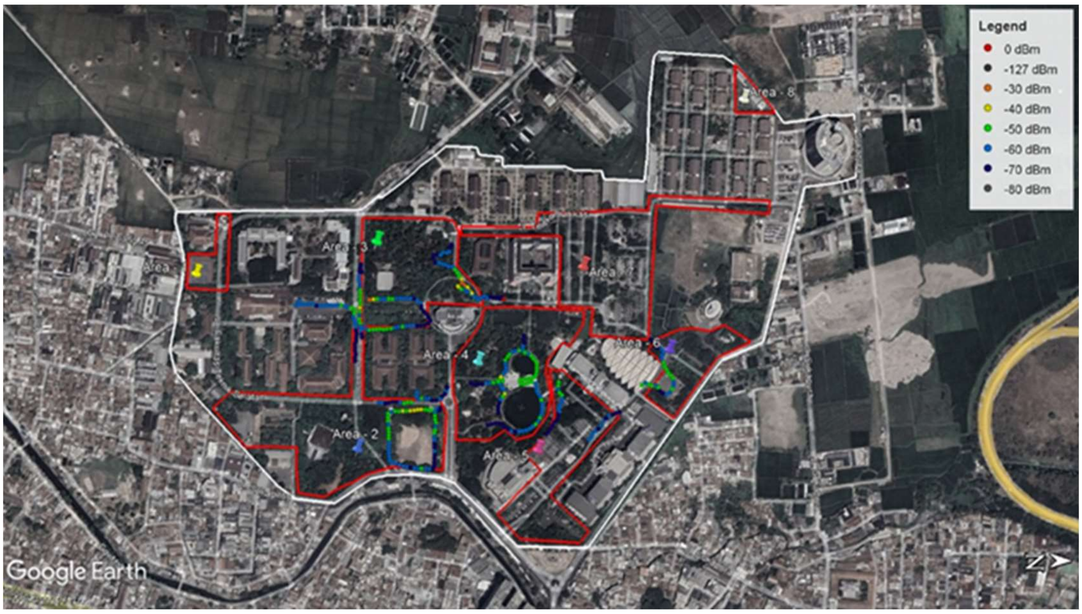


Figure 2. Drive Test Result

In the figure, there are dots that show the amount of RSSI value in the area. From the results of this Drive Test, it is known that there are several areas that have not been covered by outdoor WiFi signals, namely the canteen near the TULT Building, the front yard of the TULT dormitory, the GKU parking lot, Joglo, peacock cage, front yard of the Postgraduate Building, front yard of the Student Center Building, tennis court, and front yard of the Faculty of Communication and Business Building. These areas are frequently visited by students because they are places to gather and do outdoor activities, and have facilities that support students' outdoor needs.

Therefore, a plan to expand outdoor WiFi coverage in areas identified as lacking signal is being carried out to ensure these areas receive outdoor WiFi coverage. This planning involves simulating signal coverage and interference, calculating link budget parameters, measuring and mapping transmission cable routes, and performing a Bill of Quantities (BoQ) calculation for the implementation. The result of this planning includes the planning specifications for the 4-C scenario, such as transmit power, frequency, and channel frequency, as well as the coordinates for AP placement and the BoQ required for implementation.

However, there are several things that need to be considered in its design, such as aspects of wireless network propagation, infrastructure, and wireless network architecture such as Access Point (AP), coverage area, Free Space Loss, and RSSI, as in [3]. This is important because there are several factors that can affect the quality of WiFi networks, such as distance, obstructions, and interference with other radio devices.

2. METHOD

For easier comprehension of the following sections, Table 1 outlines the notations used throughout the paper.

Table 1. List of Notations Used in Paper

Notation	Description
RSSI	Received Signal Strength Indikator (dBm)
EIRP	Effective Isotropic Radiated Power (dBm)
BoQ	Bill of Quantity
DHCP	Dynamic Host Configuration Protocol
DNS	Domain Name System
P_L	Pathloss (dB)
d	Distance between AP and receiver (Km)
f	Frequency (MHz)
P_{TX}	AP Transmission Power (dBm)
G_{TX}	AP Antenna Gain (dBi)
G_{TX}	UE Antenna Gain (dBi)
L_T	Loss Transmitter (dB)

In planning the expansion of WiFi network coverage, a simulation was carried out with a 4-C scenario approach. Scenario 4-C is a scenario that involves increasing the number of APs and replacing the old versions of APs used, namely RG-AP630 IODA and RG-AP630 IDA2 with 802.11ac or WiFi 5 standards, to RG-AP680 CD and RG-AP680 O (V3) with 802.11ax or WiFi 6 standards. with the 4-C scenario approach, then calculated the pathloss value with 2 different pathloss models, namely the Free Space Loss model and the Huawei model, the average Received Signal Strength Indicator (RSSI) value from a distance of 10 meters, 50 meters, 100 meters, 150 meters and 200 meters, Effective Isotropic Radiated Power (EIRP) and Bill of Quantity (BoQ) values for scenario 4-C.

2.1 Planning System Architecture

In the planning system architecture, there are several elements used, namely Access Points, transmission cables, Power over Ethernet (PoE) switches and network servers located in the Panambulai Building on the Telkom University campus. Figure 3 is the planning system architecture used.

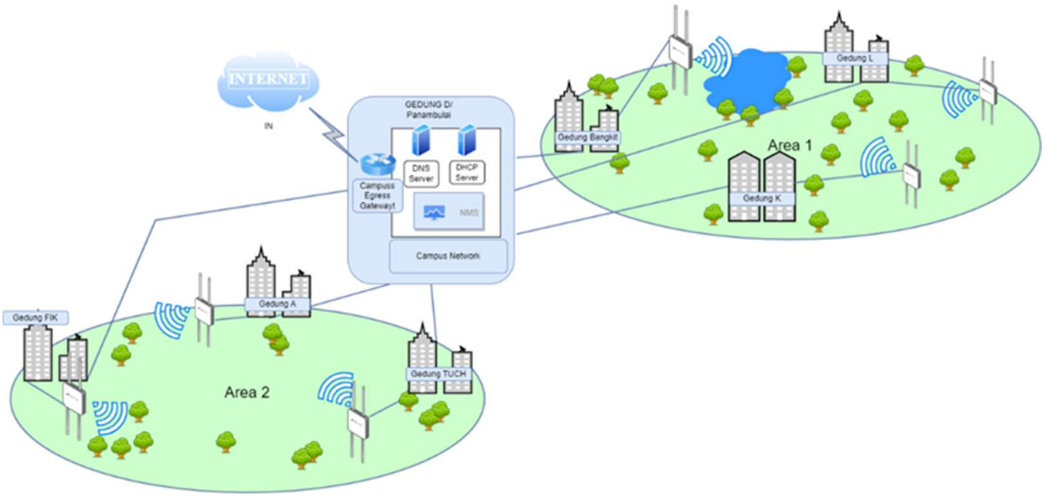


Figure 3. Planning System Architecture

Figure 3 illustrates the architecture of the system used for planning. In this system, several stages are involved for a device to access the internet through the installed Access Points (APs). The process begins with the campus Egress Gateway, which controls the network traffic from external sources, such as the internet. For a device to connect to the internet, a DHCP server is needed to assign an IP address to the device, enabling it to communicate over the internet. The intermediary between the device and the internet is the Access Point. The Access Point broadcasts a signal in a specific direction, allowing devices to capture the signal, and the DHCP server assigns an IP address to the device for internet communication.

Once the device is connected to the internet, it can access websites or information available online, which is identified through domain names using the DNS server. The DNS server translates domain names from websites or information into the correct IP addresses, enabling the device to access those websites or information. To connect the servers to the Access Points, UTP Cat6 cables and FO Multimode fiber optics are used as transmission cables.

2.2 Areas of Research

The research area was conducted around the outdoor area Telkom University Bandung. There are several areas that into the planning area, which is as follows.

1. Area 1 includes the tennis court, basketball court and the surroundings of the Student Center Building.
2. Area 2 includes the neighborhood around Syamsul 'Ulum Mosque and the jogging track.
3. Area 3 includes the biopore forest environment, joglo and peacock aviary.
4. Area 4 covers the neighborhood around Lake Galau.
5. Area 5 covers the neighborhood around the Faculty of Creative Industries, Faculty of Economics and Business and Faculty of Applied Sciences.
6. Area 6 includes the field in front of the Telkom University Convention Hall and the Bandung Techno Park building.
7. Area 7 includes the parking lot and the front yard of the Public Lecture Building.
8. Area 8 covers the canteen neighborhood near Telkom University Landmark Tower.

These areas were chosen as research areas because these areas are not covered by outdoor WiFi signals as evidenced by the drive test results in Figure 2. In addition, these areas are areas usually used by students to carry out outdoor activities, such as sports, research and organizational events. These activities are supported by the facilities in these areas. so that these areas become research areas. To see these areas more clearly, the following figure 4 is a mapping of research areas bounded by red lines and Telkom University areas bounded by white lines.

Figure 4. Areas of Research

2.3 Research Flowchart

Figure 5 is a flowchart of this research. The research starts from making field observations to calculating the total BoQ required. The following figure 5 is a flowchart of the research.

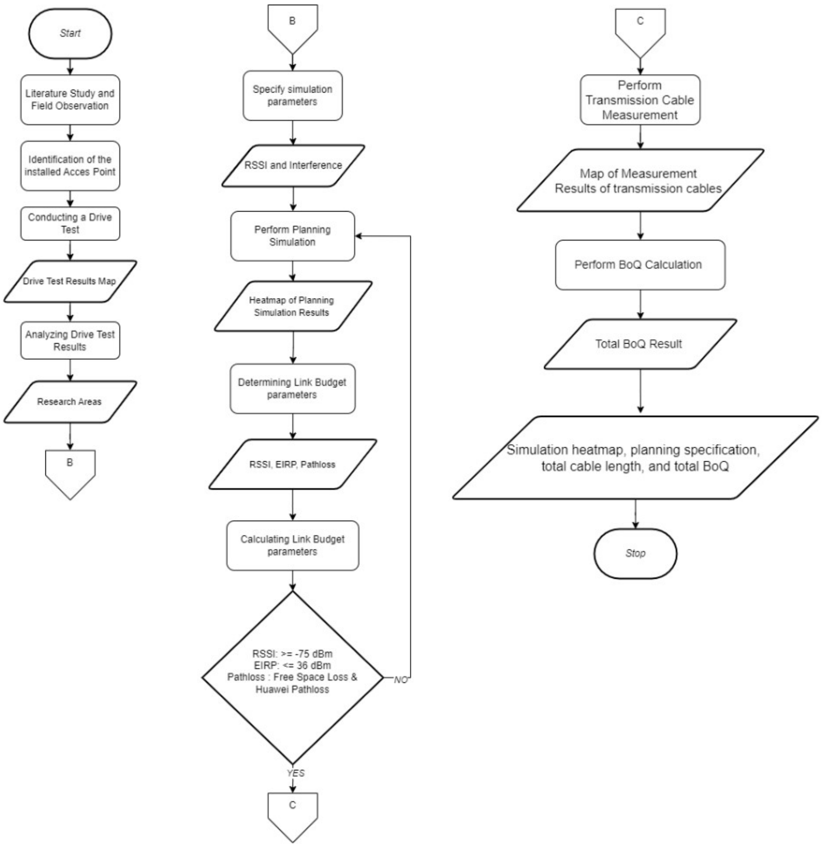


Figure 5. Research Flowchart

The research begins with field observations to identify the study areas and determine the location and signal coverage of each Access Point (AP) that has been installed, using a drive test procedure. The drive test results are then analyzed by examining the signal points distributed across the outdoor area of Telkom University. Areas where signal points are absent are identified as lacking outdoor WiFi coverage. This analysis produces a map highlighting the research areas.

Once the study areas are determined, planning simulations are conducted within these areas using the 4-C scenario. The simulations include both signal coverage and interference analyses. In the signal coverage simulation, the Received Signal Strength Indicator (RSSI) value is a key parameter, and for this research, the RSSI is set at -75 dBm. This value falls within the “GOOD” category according to the RSSI standard set by TIPHON. The interference simulation generates a heatmap to identify two types of interference: Co-Channel interference and Adjacent Channel interference.

Following the simulations, a link budget calculation is performed. Key parameters such as path loss, RSSI, and Effective Isotropic Radiated Power (EIRP) are calculated using variables from the planning simulation, including the transmission power of each AP and the frequency in use. The link budget calculation aims to determine the average RSSI value in the 4-C scenario and ensure that the EIRP remains within regulatory limits.

After the link budget calculation, transmission cable measurements are taken for each planned AP. Two types of transmission cables are used: Unshielded Twisted Pair (UTP) Cat6 and Fiber Optic, selected based on the distance between the AP and the switch. Following the cable measurements, a Bill of Quantities (BoQ) calculation is performed, covering the total cost of tools, materials, and services required for the planning and implementation. The final outcomes of this research include a map of the simulation results, detailed planning specifications, the total transmission cables required, and the complete BoQ.

2.4 Simulation

Simulation were conducted using the Wiscloud website Ruijie. The simulation carried out is a simulation of signal coverage coverage simulation with a minimum RSSI value of -75 dBm and interference simulation in the 2.4 GHz and 5 GHz frequency bands. interference simulations in the 2.4 GHz and 5 GHz frequency bands. There are 2 types of interference that can occur in the simulation, namely Co-channel and Adjacent channel. Co-channel interference occurs when two signals overlap and have the same the same channel, as in [4], while Adjacent channel interference happens when a signal in one channel interferes with another signal in a nearby channel due to the power from the adjacent signal, as in [5]. Simulation results in the form of heatmap of simulated signal coverage and interference. Before the simulation, we added obstacles around the Telkom University area to get better simulation results. The following table 2 which is a description of the types of obstacles in scenario planning 4-C.

Table 2. Obstacles Type

Obstacle	Thick (Meter)
Concrete	0.15
Brick	0.1
Window	0.01

The thickness of the obstacle is obtained from the minimum thickness used in the standard of building construction in Indonesia with SNI 2847 2019, SNI 15-2609-2006 and SKh-5.9.3. Obstacles are added based on the type of obstacle that most envelops the buildings, such as the TULT Building whose sides are enveloped by glass.

2.5 Link Budget

In the calculation of the link budget, there are 3 parameters to be calculated, namely Pathloss, Received Signal Strength Indicator (RSSI) and Effective Isotropic Radiated Power (EIRP). The calculation of these parameters is calculated based on the specifications in the planning simulation, namely the transmit power and frequency used. The frequencies used in this research are 2.4 GHz and 5 GHz, Each frequency band has a different channel range according to the standards of the International Telecommunication Union (ITU). In the 2.4 GHz frequency band, there are channels 1 to 14 covering frequencies from 2,401 MHz to 2,484 MHz. While in the 5 GHz frequency band, the channels range from 36 to 165 with a frequency range of 5,170 MHz to 5,835 MHz and the planning will use dual band frequencies. The purpose of link budget calculation is to get the average value of RSSI based on mathematical equations and get the EIRP value in accordance with the standards set. The following table 3 is a specification of the link budget parameters for this design.

Table 3. Link Budget Parameter Specifications

Parameter	Spesification
Model Path*loss*	*Free Space Loss* Huawei
RSSI	>= (-75) dBm
EIRP	<= 36 dBm

2.5.1 Pathloss

Pathloss is the signal power lost between the transmitter and the receiver in units of dB, as in [2]. In WLAN networks, there are several pathloss models that can be used, such as Free Space Loss, Cost 231, Huawei, Okumura and Hata. These models can be used in accordance with the specifications of the network design being carried out, such as the design environment and the frequency used in the design. In this plan, 2 pathloss models are used, namely the Free Space Loss and Huawei models. These models can be used for planning using frequencies of 2.4 GHz and 5 GHz. The following equation (1) is a mathematical equation for the Free Space Loss pathloss model, as in [6].

$$PL_{FSL} = 20\, Log_{10}(d) + 20\, Log_{10}(f) + 32.45 \quad (1)$$

The following equation (2) is a mathematical equation for the Huawei pathloss model [2].

$$\mathrm{PL_H} = 42.6 + 26\mathrm{Log_{10}(d)} + 20\mathrm{Log_{10}(f)} \quad (2)$$

2.5.2 Received Signal Strength Indicator

Received Signal Strength Indicator or RSSI is a value to measure the signal strength received by the device with dBm units. RSSI is commonly used to measure the signal strength of WiFi networks, the higher the RSSI value or the value towards 0 dBm, the good network quality, the smaller the RSSI value or the RSSI value towards -100 dBm, the poor network quality, as in [3]. In this research, the TIPHON standard is used to analyze the quality of the calculated RSSI. The following table 4 is the RSSI standard set by TIPHON, as in [7].

Table 4. TIPHON Standard RSSI Range

Category	**RSSI (dBm)**
Very Good	> -70
Good	-70 s/d -85
Moderate	-86 s/d -100
Bad	-100

In Table 3, RSSI is divided into categories based on RSSI values in a certain range. RSSI in the “Very Good” category has an RSSI value above -70 dBm. RSSI with the “Good” category has an RSSI value between -70 dBm to -85 dBm. RSSI with “Moderate” category has RSSI value between -86 dBm to -100 dBm and RSSI with “Bad” category has RSSI value below -100 dBm, as in [8]. The following equation (3) is a mathematical equation for calculating RSSI, as in [2].

$$RSSI = PT_x + GT_x - P_L - \text{Attenuation} + GR_x \quad (3)$$

2.5.3 Effective Isotropic Radiated Power

Effective Isotropic Radiated Power or EIRP is the total transmission power of the transmitting antenna, as in [2]. The total transmission power released by the transmission antenna can be influenced by several parameters, such as transmission power, transmission antenna gain and transmitter loss. EIRP is limited in each country, in Indonesia the maximum tolerated EIRP limit is 36 dBm or 4 watts in accordance with KOMINFO ministerial policy number 1 of 2019, as in [9]. The following equation (4) is the mathematical equation for calculating EIRP, as in [10].

$$EIRP = P_{tx} + G_{tx} - L_t \tag{4}$$

2.6 Transmission Cable

The transmission cables used in scenario 4-C planning are Unshielded Twisted Pair or UTP and Fiber Optic or FO transmission cables. Transmission cable measurements are taken from the AP to the PoE switches available in several buildings at Telkom University. The tool for taking measurements is a measuring wheel meter and a google earth application to display the transmission cable route after measurement.

2.7 Bill of Quantiy

Bill of Quantity or BoQ is calculated based on the number of tools and materials used to perform 4-C scenario planning, including APs, transmission cables and others. In addition, the cost for implementation is also calculated in order to get a BoQ that matches the planning. The costs listed can change over time, so before the implementation is carried out, the necessary costs are rechecked so as not to exceed the required costs.

3. RESULTS AND DISCUSSION

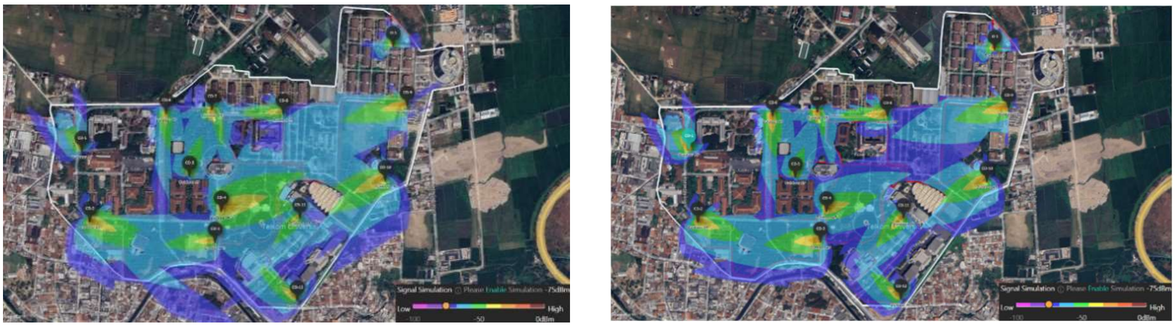
There are several results obtained from this planning, namely simulation results, the results of the calculation of link budget parameters, the results of transmission cable measurements and the calculation of the required BoQ. The simulation results consist of signal coverage simulation results and interference simulation results in the 2.4 GHz and 5 GHz frequency bands. The results of the calculation of link budget parameters consist of pathloss, RSSI and EIRP calculations in the 2.4 GHz and 5 GHz frequency bands. The results of transmission cable measurements consist of the total length of transmission cables required and a map of the distribution of transmission cable installation locations. The results of the BoQ calculation consist of the costs required to purchase installation tools and materials and service fees.

3.1. Simulation Result

The simulation results consist of signal coverage and interference simulation results. The simulation results are in the form of a heatmap of the planning simulation, so that it will be seen that the signal coverage is in accordance with the planning and will be seen if interference occurs.

3.1.1 Signal Coverage Simulation Result

Figure 6 (a) and (b) are heatmaps of the simulated signal coverage results in scenario 4-C. In this simulation, the RSSI value that must cover the entire research area is a maximum of -75 dBm. If there are research areas that have not been covered by the signal, new APs will be installed in these areas.



(a) (b)

Figure 6. Heatmap of Simulated Signal Coverage in Frenquency Band (a) 2.4 GHz and (b) 5 GHz

In Figures 6 (a) and (b), it can be seen that the entire area bounded by the red line is covered by signals from the planned APs. The entire area is covered with signals that have a maximum RSSI value of -75 dBm marked by blue signal emission in the 2.4 GHz and 5 GHz frequency bands. In this signal coverage simulation, the number of APs that must be installed to meet the simulation objectives is 13 APs with the RG-AP680(CD) and RG-AP680(O) V3 series. In addition, APs with Omnidirectional and Directional radiation patterns were used to fulfill the simulation objectives. The signal coverage simulated by each AP varies. This is due to the presence of obstacles that were previously added. These obstacles can cause the signal to diffract or reflect, resulting in different signal coverage for each AP transmission.

In Figure 6 (a) and (b), the simulated signal coverage results appear different. In Figure 6 (a), the signal coverage is broader and can cover more area because it uses the 2.4 GHz frequency band, whereas in Figure 6 (b), the coverage is smaller due to the use of the 5 GHz frequency band. This occurs because of the frequency band used; the higher the frequency, the smaller the signal coverage, as higher frequencies are more susceptible to interference, and vice versa. Additionally, the transmit power of each AP affects the simulated signal coverage. The greater the transmit power used, the larger the signal coverage.

3.2.1 Interference Simulation Result

Figure 7 (a) and (b) are heatmaps of the simulated interference results in scenario 4-C. The results were simulated in the 2.4 GHz and 5 GHz frequency bands. There are two types of interference that can occur, namely Co-Channel interference and Adjacent interference. If Co-Channel interference occurs in an area, the area is colored red, if Adjacent interference occurs in an area, the area is colored yellow, if no interference occurs, the area is colored green.

(a) (b)

Figure 7. Heatmap of Simulated Interference in Frequency Band (a) 2.4 GHz and (b) 5 GHz

Figure 7 (a) shows that the result of the interference simulation in the 2.4 GHz frequency band is no interference, as indicated by the green area in the heatmap. This can happen because the frequency channels have been configured so that there are no similar and adjacent channels. Figure 7 (b) shows that the simulation result of interference in the 5 GHz frequency band is Co-Channel interference with red color area on the heatmap. This can happen because there are still the same frequency channels and their signal beams overlap, resulting in Co-Channel interference, as in [4].

Table 5. AP Spesification for Scenario 4-C

AP Type	AP Code	2.4 GHz Frequency Band			5 GHz Frequency Band			Coordinate (Lat, Long)
		Transmit Power (dBm)	Frequency (MHz)	Frequency Channel	Transmit Power (dBm)	Frequency (MHz)	Frequency Channel	
RG-AP680(CD) Directional	CD-1	6	2412	1	23	5745	149	-6.976466, 107.630252
	CD-2	14	2462	11	28	5765	153	-6.976921, 107.631474
	CD-3	9	2437	6	28	5785	157	-6.974892, 107.631474
	CD-4	19	2412	1	28	5805	161	-6.974508, 107.631492
	CD-5	7	2412	1	20	5825	165	-6.974508, 107.631492
	CD-6	6	2462	11	25	5805	161	-6.975702, 107.629569
	CD-7	10	2437	6	22	5745	149	-6.973480, 107.630175
	CD-8	7	2412	1	26	5765	153	-6.973198, 107.629443
	CD-9	12	2412	1	28	5825	165	-6.9609039, 107.628156

AP Type	AP Code	2.4 GHz Frequency Band			5 GHz Frequency Band			Coordinate (Lat, Long)
		Transmit Power (dBm)	Frequency (MHz)	Frequency Channel	Transmit Power (dBm)	Frequency (MHz)	Frequency Channel	
	CD-10	15	2462	11	28	5745	149	-6.970477, 107.630315
	CD-11	6	2462	11	24	5765	153	-6.971593, 107.631078
	CD-12	9	2437	6	23	5825	165	-6.972317, 107.633339
RG-AP680(O)V3 Omnidirectional	O-1	11	2437	6	26	5745	149	-6.9609039, 107.628156

Table 5 shows the transmit power used by the APs to achieve signal coverage that can cover the entire study area with a minimum RSSI value of -75 dBm. According to Table 5, the highest transmit power is 28 dBm at the 5 GHz frequency band, while the lowest transmit power is 6 dBm at the 2.4 GHz frequency band. The highest transmit power is used at the 5 GHz frequency band because higher transmit power is needed to achieve a larger signal coverage area. As the frequency increases, the signal is more susceptible to diffraction, reflection, and interference from other radio signals. In contrast, the 2.4 GHz frequency band, with its lower frequency, is less prone to diffraction, reflection, and interference, resulting in a lower transmit power compared to the 5 GHz band. Table 4 also shows the frequency and frequency channels used by each AP. These channels are configured differently to reduce the likelihood of interference between the APs. Additionally, the coordinates of the AP locations are provided, making implementation easier.

3.2 Link Budget Calculation

Pathloss and RSSI parameters are calculated with varying distances between the AP and receiver, starting from 10 meters, 50 meters, 100 meters, 150 meters and 200 meters. While the EIRP parameter is not affected by the distance between the AP and the receiver.

3.2.1 Pathloss Calculation

The pathloss calculation uses 2 different pathloss models, namely the Free Space Loss and Huawei models. The following table 6 is the result of the pathloss calculation in the Free Space Loss model.

Table 6. Pathloss Model Free Space Loss at 2.4 GHz and 5 GHz Frequency Bands

Frequency (MHz)	Pathloss Value at Transmitter to Receiver Distance (dBm)				
	10 Meter	50 Meter	100 Meter	150 Meter	200 Meter
2,412	60	74	80	84	86
2,437	60	74	80	84	86
2,462	60	74	80	84	86
5,745	68	82	88	91	94
5,765	68	82	88	91	94
5,785	68	82	88	91	94
5,805	68	82	88	91	94
5,825	68	82	88	91	94

Table 6 shows the results of the Free Space Loss model pathloss calculation in the 2.4 GHz and 5 GHz frequency bands. The frequency used is different in certain frequency bands, because the frequency is the center frequency in each frequency channel used. At a frequency of 2.412 MHz is the center frequency for channel 1 in the 2.4 GHz frequency band, while at a frequency of 5.745 MHz is the center frequency for channel 149 in the 5 GHz frequency band. The largest pathloss value is 94 dBm, obtained at frequencies 5.745 MHz, 5.765 MHz, 5.785 MHz, 5.805 MHz and 5.825 MHz at a distance of 200 meters. While the smallest pathloss value is 60 dBm at frequencies of 2,412 MHz, 2,437 MHz and 2,462 MHz. The further the distance between the AP and the receiver, the greater the pathloss value. The following table 7 is the result of the pathloss calculation in the Huawei model.

Table 7. Pathloss Model Huawei at 2.4 GHz and 5 GHz Frequency Bands

Frequency (MHz)	Pathloss Value at Transmitter to Receiver Distance (dBm)				
	10 Meter	50 Meter	100 Meter	150 Meter	200 Meter
2,412	58	76	84	89	92
2,437	58	77	84	89	92
2,462	58	77	84	89	92
5,745	66	84	92	96	100
5,765	66	84	92	96	100
5,785	66	84	92	96	100
5,805	66	84	92	96	100
5,825	66	84	92	96	100

Based on table 7, the largest pathloss value in the Huawei model is 100 dBm at frequencies of 5,745 MHz, 5,765 MHz, 5,785 MHz, 5,805 MHz and 5,825 MHz at a distance of 200 meters. The smallest pathloss value in the Huawei model is 58 dBm at frequencies of 2,412 MHz, 2,437 MHz and 2,462 MHz at a distance of 10 meters. The further the distance between the AP and the receiver, the greater the pathloss value.

Based on Tables 6 and 7, there is a difference in the pathloss calculation results between the two models. In the Free Space Loss model, the maximum pathloss value is 94 dBm, while in the Huawei model, the maximum pathloss value is 100 dBm. This difference is because, in the Free Space Loss model, the environment is assumed to be obstacle-free when the signal is transmitted, resulting in a lower pathloss value compared to the Huawei model. The highest pathloss values, 94 dBm in the Free Space Loss model and 100 dBm in the Huawei model, were observed at the 5 GHz frequency band. This is because higher frequencies are more prone to diffraction, reflection, and interference with other radio signals. On the other hand, the lowest pathloss values, 60 dBm in the Free Space Loss model and 58 dBm in the Huawei model, were observed at the 2.4 GHz frequency band, as the 2.4 GHz band has a lower frequency compared to the 5 GHz band.

3.2.2 RSSI Calculation

There is a variable in the RSSI equation obtained from the simulation results, which is the transmit power of the AP. AP transmit power varies depending on the planning simulation, so the RSSI value of each AP will vary. In addition, in calculating RSSI, 2 pathloss models are used that have been previously calculated, namely Free Space Loss and Huawei and 2 frequency bands, namely 2.4 GHz and 5 GHz. The following table 8 is the result of the calculation of the average value of RSSI in the Free Space Loss model.

Table 8. Average RSSI Value of Free Space Loss Model at 2.4 GHz and 5 GHz Frequency Bands

Distance between AP and receiver (Meter)	RSSI Value (dBm)	
	2.4 GHz	5 GHz
10	-42	-56
50	-56	-49
100	-62	-55
150	-66	-51
200	-68	-61

Based on Table 8, it can be seen that the highest RSSI value in the Free Space Loss pathloss model is -42 dBm at a distance of 10 meters using the 2.4 GHz frequency band. Then the lowest RSSI value is -68 at a distance of 200 meters using the 5 GHz frequency band. Based on Table 8, it can be seen that the RSSI value is influenced by the distance between the transmitter or AP to the receiver and the frequency band used. The highest RSSI value is obtained using the 2.4 GHz frequency band and the lowest RSSI value is obtained using the 2.4 GHz frequency band.

Based on Table 8, the calculated RSSI values in the 5 GHz frequency band show differences as the distance between the AP and the device increases. This can be observed in the distance ranges of 10 meters to 50 meters and 100 meters to 150 meters. At a distance of 10 meters, the RSSI value is -56 dBm, whereas at 50 meters, the RSSI value is -49 dBm, indicating an increase of 7 dBm. At a distance of 100 meters, the RSSI value is -55 dBm, while at 150 meters, it is -51 dBm, showing an increase of 4 dBm. This variation can occur due to the path loss model and the transmit power used. In the 5 GHz frequency band, a higher transmit power is used compared to the 2.4 GHz band, leading to varying RSSI values.

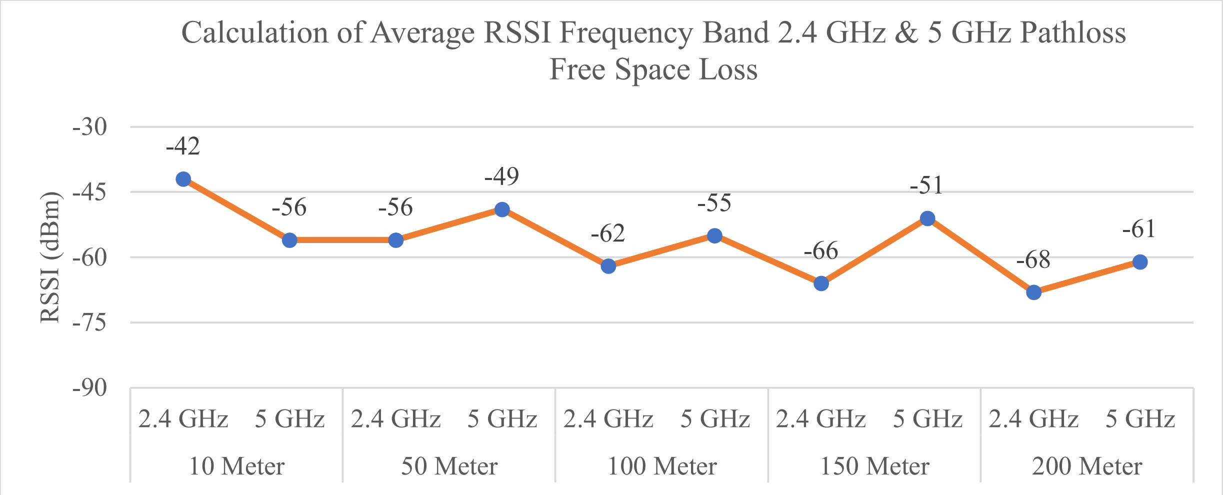


Figure 8. Graph of Average RSSI Value of Free Space Loss Model at 2.4 GHz and 5 GHz Frequency Band

Based on Figure 8, we can see the graph of the RSSI calculation in the Free Space Loss model. The RSSI value decreases as the distance between the transmitter and receiver increases. This happens because the greater the distance between the AP and the receiver, the weaker the emitted signal will be due to diffraction, reflection and interference from surrounding radio signals.

Table 9. Average RSSI Value of Huawei Model at 2.4 GHz and 5 GHz Frequency Bands

Distance between AP and receiver (Meter)	**RSSI Value (dBm)**	
	2.4 GHz	**5 GHz**
10	-41	-33
50	-59	-51
100	-67	-59
150	-71	-63
200	-74	-67

Based on Table 9, it can be seen that the highest RSSI value in the Huawei pathloss model is -33 dBm at a distance of 10 meters using the 5 GHz frequency band. Then the lowest RSSI value is -74 at a distance of 200 meters using the 2.4 GHz frequency band. Based on Table 9, it can be seen that the RSSI value is influenced by the distance between the transmitter or AP to the receiver and the frequency band used. The highest RSSI value is obtained using the 5 GHz frequency band and the lowest RSSI value is obtained using the 2.4 GHz frequency band.

Based on Table 9, it is observed that the RSSI value decreases from a distance of 10 meters to 200 meters in both the 2.4 GHz and 5 GHz frequency bands. This decrease in RSSI value is due to the increasing distance between the AP and the receiver. For instance, at a distance of 10 meters in the 2.4 GHz band, the RSSI value is -41 dBm, while at a distance of 200 meters, the RSSI value is -74 dBm, resulting in a decrease of 33 dBm. This occurs because, as the signal propagates, it may experience diffraction, reflection, or interference from radio signals of other devices. The decrease in RSSI values in the Huawei model is clearly visible in Figure 9, which shows the RSSI value calculation graph for the Huawei model in the 2.4 GHz and 5 GHz frequency bands.

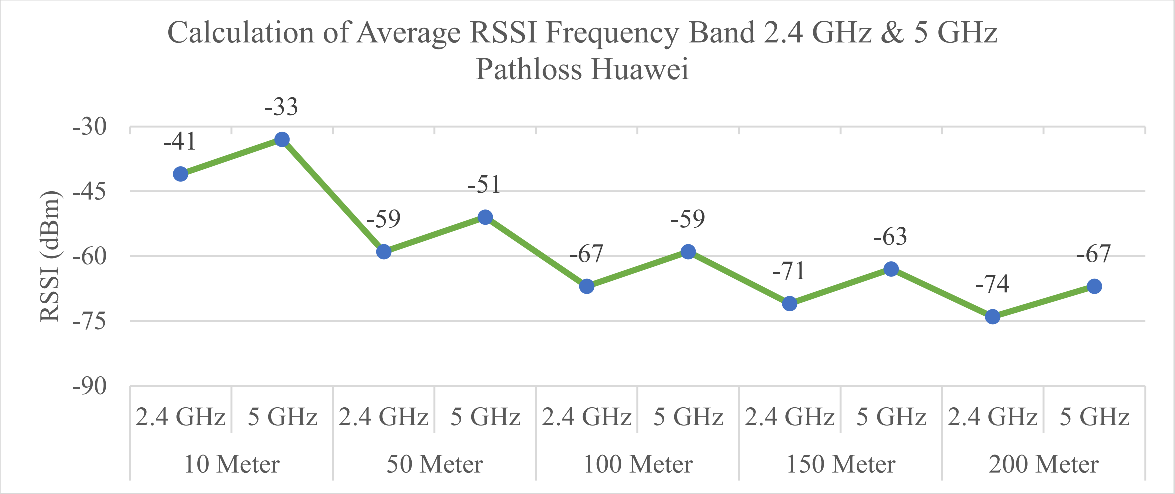


Figure 9. Graph of Average RSSI Value of Huawei Model at 2.4 GHz and 5 GHz Frequency Band

Based on Figure 9, we can see the graph of the RSSI calculation in the Huawei model. The RSSI value decreases as the distance between the transmitter and receiver increases. This happens because the greater the distance between the AP and the receiver, the weaker the emitted signal will be due to diffraction, reflection and interference from surrounding radio signals.

3.2.3 EIRP Calculation

EIRP calculation is obtained from equation (4) with transmission power obtained through simulation results at each AP. The antenna gain value is obtained from the type of AP used. In this plan, the antenna gain used is 7.9 dBi for the RG-AP680 CD series AP and 4 dBi for the RG-AP680 O(V3) series AP. The transmitter loss value is left at 0 because to get the transmitter loss value, direct implementation must be done, but this planning does not do direct implementation. The following table 8 is the result of the EIRP calculation in the 2.4 GHz and 5 GHz frequency bands along with the EIRP limits in Indonesia.

Table 10. EIRP Calculation Results at 2.4 GHz & 5 GHz Frequency Bands

EIRP Calculation Results at 2.4 GHz & 5 GHz Frequency Bands			
Parameter	2.4 GHz	5 GHz	EIRP Standard Limit
EIRP Value (dBm)	18	33	36

Based on Table 10, it can be seen that the highest EIRP value is 33 dBm in the 5 GHz frequency band, while the lowest EIRP value is 18 dBm in the 2.4 GHz frequency band. The EIRP value obtained does not exceed the EIRP standard limit set, which is 36 dBm. The EIRP value depends on the transmit power used; the higher the transmit power, the greater the EIRP value, and vice versa. The highest EIRP value is achieved in the 5 GHz frequency band because, in this band, a high transmit power up to 28 dBm is used. In contrast, the maximum transmit power in the 2.4 GHz frequency band is 19 dBm, as shown in Table 5. Therefore, the highest EIRP value is obtained using the 5 GHz frequency band, while the lowest EIRP value is obtained using the 2.4 GHz frequency band.

3.3 Transmission Cable Measurement

Transmission cable planning is done by adjusting the location of the AP and the location of the existing switch. There are 2 types of transmission cables used, namely UTP cat6 and Fiber Optic. The following figure 10 is the distribution of transmission cables for scenario 4-C.

Figure 10. Scenario 4-C Transmission Cable Distribution Map

Based on Figure 10, we can see the distribution of transmission cables used. The pink line is a Fiber Optic transmission cable, while the light green one is a Cat6 UTP transmission cable. The following table 11 is the total length of the transmission cable used for scenario 4-C planning.

Table 11. Total length of Transmission Cable

Total Length of Transmission Cable (Meter)		
Parameter	Transmission Cable Type	
	UTP	FO
Length	286.5 m	1341.8 m
Total	1628.3 m	

Based on table 11, the total length of UTP transmission cable required is 286.5 meters, while for Fiber Optic is 1341.8 meters. The total length of the overall transmission cable is 1628.3 meters. When measuring transmission cables, attention is also given to the routing of the cables. The cable routing should not obstruct walkways or hang over buildings, ensuring a tidy installation. Additionally, if the distance between the AP and the switch exceeds 100 meters, fiber optic cables are used. For distances less than 100 meters, UTP Cat6 cables are used. But the length can change if the cable placement is readjusted, so it needs to be re-measured.

3.4 BoQ Calculation Result

The Bill of Quantity (BoQ) obtained is based on the number of tools and materials used and the estimated cost of services. The following table 12 is a detailed BoQ for scenario 4-C.

Table 12. Bill of Quantity Skenario 4-C

NO	Description	Unit	Volume	Unit Price	Total Cost
A			Material		
1	Acces Point RUIJIE (RG-AP680(CD)	Pcs	13	Rp. 14.139.000	Rp. 183.807.000
2	Fiber Optic Cable (Drop Core)	Roll (50 m)	2	Rp. 300.000	Rp. 600.000
3	Fiber Optic Cable (Drop Core)	Roll (100 m)	1	Rp. 250.000	Rp. 250.000
4	Fiber Optic Cable (Drop Core)	Roll (150 m)	3	Rp. 350.000	Rp. 1.050.000
5	Fiber Optic Cable (Drop Core)	Roll (200 m)	1	Rp. 480.000	Rp. 480.000
6	Fiber Optic Cable (Drop Core)	Roll (300 m)	2	Rp. 700.000	Rp. 1.400.000
7	UTP CAT 6 Cable	Roll (300 m)	3	Rp. 2.950.000	Rp. 8.850.000
8	LC Connector	Pcs	22	Rp. 4.500	Rp. 99.000
9	RJ-45 Connector	Pcs	3	Rp. 557.500	Rp. 1.672.500
10	Power Adapter	Pcs	9	Rp. 260.700	Rp. 2.346.300
11	PoE Adapter	Pcs	3	Rp. 499.000	Rp. 1.497.000
12	SFP Modul	Pcs	17	Rp. 400.000	Rp. 6.800.000
13	Pole	Pcs (7 Meter)	11	Rp. 4.600.000	Rp. 50.600.000
		Total Material			Rp. 259.451.800
B			Services		
1	Acces Point Installation	LOT	13	Rp. 582.983	Rp. 7.578.779
2	Fiber Optic Single Mode 2 Core Drop Cable Installation	KM	2	Rp. 463.925	Rp. 927.950
3	LC Adapter Installation	LOT	10	Rp. 32.727	Rp. 327.270
4	UTP Cable Withdrawal	M	3	Rp. 18.979	Rp. 56.937
5	3 Meter Iron Pole Installation	AU	11	Rp. 2.672.995	Rp. 29.402.945
6	Excavation of Garden Soil Path Withdrawal	M	1022.1	Rp. 85.333	Rp. 87.218.859
		Total Services			Rp. 125.512.740
		Overall Total			Rp. 384.964.540

4. CONCLUSION

Based on this planning result, it can be concluded that Scenario 4-C successfully serves as the outdoor WiFi expansion planning scenario. This is indicated by all planning areas achieving a minimum RSSI value of -75 dBm, as shown in Figures 6 (a) and (b), and an RSSI measurement with a minimum value of -74 dBm as detailed in Table 8. Additionally, the obtained EIRP value does not exceed the standard limit, with a maximum EIRP value of 33 dBm, while the standard limit is 36 dBm, thus confirming the success of the planning. The planning results, including simulation images, simulation specifications, cable placement, and BoQ requirements, can serve as references for implementing the plan.

Based on the link budget parameters, the RSSI value is not less than the RSSI calculation target of -75 dBm with the smallest RSSI value of -74 dBm in the Huawei pathloss model in the 2.4 GHz frequency band at a distance of 200 meters. The EIRP value obtained also does not exceed the EIRP standard limit in Indonesia which is 36 dBm with the highest EIRP value is 33 dBm in the 5 GHz frequency band, while the smallest EIRP value is 18 dBm in the 2.4 GHz frequency band. The total length of the transmission cable used is 1628.3 meters and the total BoQ obtained is Rp. 384,964,540.

Based on this planning result, there are still some limitations that can be investigated in future studies. Specifically, the number of users that an AP can support is not known, as this study focused solely on signal coverage. Future research could aim to calculate the number of users that an AP can accommodate under various conditions. In addition, future research can use different path loss models, in addition to Free Space Loss and Huawei, to obtain a lower path loss value compared to the smallest path loss value achieved, which is 58 dBm. In the simulation of interference in the 5 GHz frequency band, interference still occurs, so in future research, frequency configuration can be done so that interference does not occur.

REFERENCES

[1] A. Aileen, A. D. Suwardi, and F. Prawiranata, “WiFi Signal Strength Degradation Over Different Building Materials,” *Engineering, MAthematics and Computer Science (EMACS) Journal*, vol. 3, no. 3, pp. 109–113, Oct. 2021, doi: 10.21512/emacsjournal.v3i3.7455.

[2] “Network Planning Guide,” 2023. [Online]. Available: https://e.huawei.com

[3] S. Nauvaldi, F. T. Pontia, and N. Tjahjamooniarsih, “Analysis of Wi-Fi Network Quality In Tanjungpura University Library Building,” *Telecommunications, Computers, and Electricals Engineering Journal*, vol. 1, no. 1, p. 13, Jun. 2023, doi: 10.26418/telectrical.v1i1.69799.

[4] A. A. Rabbany, R. Munadi, Syahrial, E. D. Meutia, B. Devanda, and A. Bahri, “Analisis Pengaruh Co-Channel Interference Terhadap Kualitas Wi-Fi Pada Frekuensi 2,4 GHz,” *KITEKTRO: Jurnal Komputer, Teknologi Informasi, dan Elektro*, vol. 6, no. 2, pp. 31–35, 2021.

[5] T. Oyedare, V. K. Shah, D. J. Jakubisin, and J. H. Reed, “Interference Suppression Using Deep Learning: Current Approaches and Open Challenges,” 2022, *Institute of Electrical and Electronics Engineers Inc.* doi: 10.1109/ACCESS.2022.3185124.

[6] N. J. Ayidu and V. O. Elaigwu, “Pathloss Prediction Model In Wlan Propagation,” *Fudma Journal Of Sciences*, vol. 7, no. 3, pp. 1–5, Jul. 2023, doi: 10.33003/fjs-2023-0703-1822.

[7] F. A. Karima and A. M. Shiddiqi, “Optimization of Access Point Positioning on Wi-Fi Networks Using the K-Means Clustering Method,” *IPTEK The Journal for Technology and Science*, vol. 33, no. 1, p. 13, May 2022, doi: 10.12962/j20882033.v33i1.12402.

[8] D. Jaisinghani, N. Gupta, M. Maity, and V. Naik, “Adaptive ViFi: A dynamic protocol for iot nodes in challenged WiFi network conditions,” in *Proceedings - 2020 IEEE 17th International Conference on Mobile Ad Hoc and Smart Systems, MASS 2020*, Institute of Electrical and Electronics Engineers Inc., Dec. 2020, pp. 147–155. doi: 10.1109/MASS50613.2020.00028.

[9] Menteri Komunikasi dan Informatika Indonesia, “Permen Kominfo Nomor 1 Tahun 2019,” 2019. Accessed: Aug. 13, 2024. [Online]. Available: https://peraturan.bpk.go.id/Details/149081/permenkominfo-no-1-tahun-2019

[10] B. Yamamoto *et al.*, “Received signal strength indication (RSSI) of 2.4 GHz and 5 GHz wireless local area network systems projected over land and sea for near-shore maritime robot operations,” *J Mar Sci Eng*, vol. 7, no. 9, Sep. 2019, doi: 10.3390/jmse7090290.