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Enhanced Indoor Coverage with Femtocells in 5G Networks at 3500 Mhz Frequency using Radiowave Propagation Software

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***Abstract*--In the landscape of 5G mobile networks in Indonesia, one of the prominent frequency candidates is 3.5 GHz. The frequency is anticipated to be the initial choice for operators to deploy 5G networks. The research focuses on designing an indoor cellular network to address indoor network degradation issues using Small Cells, specifically Femtocells, within buildings such as schools, companies, hospitals, and airports. The design is implemented at PT. Sutanto Arifchandra Electronic (PT. SAE) based on the COST 231 Multi-Wall Propagation model using the Radiowave Propagation Simulator (RPS) 5.4 application. The required parameters for designing the indoor cellular network include residential building specifications and a Link Budget parameter to determine the number of Femtocell Access Points needed to cover all areas adequately. The coverage calculations determined that 2 Femtocell Access Points are required. The simulation uses three scenarios, with the optimal outcome observed in scenario 2 (employing 2 Femtocell Access Points positioned on the middle right and left sides of the walls). This scenario yields a signal power level of -25.60 dBm and a Signal to Interference Ratio (SIR) of 14.80 dB.**

***Keywords*: 5G Indoor, RPS, 3500 MHz, COST 231 Multi-Wall Propagation model**

I. Introduction

Currently, emerging network technologies offer higher data speeds and broader coverage areas. One such technology that is still in the research phase globally and in Indonesia is 5G technology. Introduced by telecommunications industries worldwide, 5G technology has already been implemented in several countries. In Indonesia, the Directorate General of Post and Informatics Resources (SDPPI) under the Ministry of Communication and Information Technology has allocated three frequencies, 3.5GHz, 26GHz, or 28GHz, for 5G deployment [1], [2], [3], [4], [5]. These frequencies are globally agreed upon for 5G technology, which is expected to be implemented around 2020, providing enhanced network services compared to the previous 4G LTE [6], [7], [8], [9].

The 5G technology boasts a data speed that is ten times faster, extensive bandwidth, and far-reaching coverage. In Indonesia, the 5G cellular network is anticipated to have significantly higher capacity and provide multi-gigabit per second data speeds for each user, supporting multimedia applications with stringent Quality of Service (QoS) requirements. In this research, the authors designs the coverage area of an indoor 5G network at PT. SAE which began its business in 1990 in Sokaraja, Banyumas, Indonesia. The company has two single-story buildings, front and rear. The authors focuses on the rear building, which has an area of 5545 m2. The selection of this case study is due to the large number of employees in PT. SAE (272 staff) and the frequent activities of the staff at the back of the building.

Despite the extensive coverage of 5G networks, signal attenuation can occur within buildings and tall structures due to factors such as microcell antennas that do not cover indoor areas and building materials that affect the signal [10], [11], [12], [13], for instance, at PT. SAE, a company in Sokaraja with large and tall buildings and many employees using cellular telecommunication services, may attenuate signals within the building, resulting in signal blank spots. Therefore, planning for indoor small cell network coverage is necessary to understand the coverage of 5G signals within the PT. SAE building, especially when 5G technology is expected to be implemented in the future in Indonesia.

The femtocell is an access point station that can

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be installed indoors, allowing users to connect directly to the network through the femtocell without relying on external macrocells. In the design of indoor or outdoor networks, a propagation model is required to determine the transmission losses in delivering signal quality. One suitable propagation model for indoor networks is the COST 231 Multi-Wall model [14], employed in the study within the PT. SAE building. The COST 231 Multi-Wall Model is employed for indoor propagation due to its ability to accurately estimate signal loss in complex environments with various obstacles. Its precision, flexibility, and strong empirical foundation make it a popular choice for indoor network planning, especially in modern applications like cellular networks in high-rise buildings and commercial settings [15], [16].

This research is an extension of a previous study [14]. The research explores the allocation of 1800 MHz and 900 MHz frequency selection using empirical models for indoor propagation models, specifically within an office environment. As an extension of the previous research, the authors conducted a study on the design of 5G Indoor Cellular Coverage Area at 3.5 GHz Frequency using Radiowave Propagation Simulator 5.4, with PT. SAE as the case study.

II. Method

A. Research Design

The design of the 5G network uses a working frequency of 3500 MHz with a bandwidth of 100 MHz, the Cost 231 Multi Wall Propagation model, and employs one of the small cell technologies, femtocell. The flowchart in Fig. 1 illustrates the general steps of the research design.

B. Determination of Research Object

In this research, the authors designs an indoor 5G network, one of the candidates to be implemented in Indonesia, specifically at 3500 MHz indoors in PT. SAE. The selection of this case study is due to the low network access at the company. If the 5G network at 3500 MHz begins implementation, this indoor design will address the access issues as the company has many users relying on cellular networks. Hence, designing a communication network is necessary to support communication network access with good coverage.

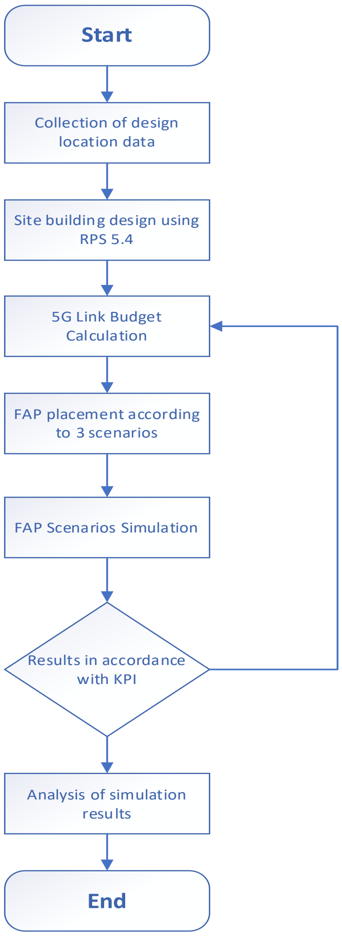

Fig. 1. Flowchart Design of 5G Indoor Coverage

C. Indoor Cellular Communication

Indoor cellular communication systems have a primary characteristic known as multipath, where signals bounce due to interference between the transmitter and receiver. Multipath is more prevalent in indoor networks compared to outdoor networks. Indoor communication systems function within a building to support outdoor network systems (macro and micro outdoor cells) to enhance cellular and wireless network services. Planning indoor cell areas involves coverage area planning according to area needs, traffic capacity according to requirements, providing satisfactory signal quality to customers, and minimizing interference. Indoor cellular communication offers advantages such as improving coverage area, enhancing customer signal quality, and providing wireless connectivity.

D. Small Cell Concept

A small cell is a small base station access point subdividing a cell site into smaller units. Small

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Cells are categorized into pico, macro, and femtocells. Small Cells connect to the network provider through broadband services such as Optic, Ethernet, or DSL (Digital Subscriber Line). With a macro cell base station having a single pipeline into the network, Small Cells can divide this pipeline into multiple ones, improving network capacity at the edge of the macro cell with speed and efficiency [17], [6]

E. Link Budget Coverage Calculation

1. Effective Isotropic Radiated Power (EIRP) is a measure indicating the transmitting power of an antenna and can be calculated using the formula [7], [8]:

$$EIRP = P_{tx} + G_{tx} - L_{tx} \quad (1)$$

   P_{tx} is the power transmitted by the source or transmitter (transmitter power) measured in decibel-milliwatts (dBm).
   G_{tx} is the gain of the antenna measured in decibels relative to an isotropic antenna (dBi).
   L_{tx} is the loss or attenuation that occurs in the system, such as cable and connector losses, measured in decibels (dB).
2. Receive Signal Level (RSL) is the received signal level more significant than the device's sensitivity minus attenuation. The RSL value can be calculated using the equation [9], [10]:

$$RSL = EIRP - L_{propagation} + G_{rx} - L_{rx} \quad (2)$$

   EIRP is Effective Isotropic Radiated Power
   $L_{propagation}$: This refers to the loss of signal strength as it propagates through the medium (e.g., air, space). Propagation loss is influenced by factors such as distance, obstacles, and environmental conditions that attenuate the signal as it travels from the transmitter to the receiver.
   G_{rx}: This is the gain of the receiving antenna, measured in decibels (dB). It reflects the antenna's ability to focus the received signal power in a specific direction, effectively increasing the received signal level.
   L_{rx}: These are the losses associated with the receiving equipment, such as losses in cables, connectors, or any other components between the antenna and the receiver.
3. The COST 231 Multi-Wall propagation model considers all walls in the vertical plane between the transmitter and receiver. Table 1 shows for each obstacle, the materials' properties are taken into account.

TABLE 1
Obstacle *Loss Materials*

Materials	**dB**
Glass	0.8
Wood	0.3
Brick	3.5
Floor/concerate	4

As the signal passes through more walls, wall attenuation decreases, making the COST 231 Multi-Wall model suitable for conditions within a room. This study employs the COST 231 Multi-Wall Model [17], [12].

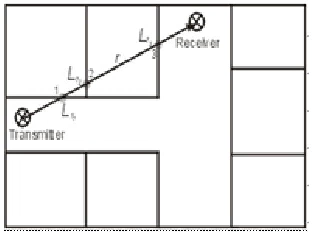

Fig. 2. COST 231 Multi Wall Model Appearance Prediction

$$L_t = LFSL + LC + \sum_{i=1}^{M} nmwi.Lwi + nf^{\left[\frac{nf+2}{nf+2}b\right]+Lf} \quad (3)$$

LFSL is *Loss Free Space*, LC is *Constant Loss* (37dB), nwi is *number of wall crossed by the direct path*, Lwi is *Wall type loss* I = 1,2,..n. To determine the coverage area of the femtocell access point, the calculation is performed using the following formula [13], [14]:

$$L = 2{,}6\ x\ d^2 \quad (4)$$

L is the coverage area of the Femtocell Access Point and d is the radius of the coverage area. Thus, to calculate the number of Femtocell Access Points (FAP) needed in the coverage area planning, this study uses the following formula [15]:

$$\text{Number of FAP} = \frac{Planned\ area}{Cell\ Coverage\ Area} \quad (5)$$

Table 1 and 2 show the information regarding the Reference Signal Received Power (RSRP) and Signal to Interference Ratio

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(SIR) parameter, as per the Key Performance Indicator (KPI).

TABLE 1
RSRP Categories [18]

Value	Informations
(-45) dBm to (-10) dBm	Very Good
(-70) dBm to (-46) dBm	Good
(-90) dBm to (-71) dBm	Normal
<=(-100) dBm	Bad

TABLE 2
SINR Categories [19]

Value	Informations
(21) dBm to (40) dBm	Very Good
(9) dBm to (20) dBm	Good
(1) dBm to (9) dBm	Normal
<=(0) dBm	Bad

F. *Object Research Information*

(a) Side View (b) Front View
Fig. 3. PT. SAE Company

The cellular network connectivity within the building is still not optimal, with specific areas experiencing blank spots. Therefore, network communication planning is needed to support good coverage of communication network access.

III. Result and Discussion

A. *Results of Coverage Calculation*

After calculating the MAPL, COST 231 Multi-Wall Propagation, and sel coverage area, values for the area size, cell coverage area, and calculation results were obtained. The determination of the number of Femtocell Access Points (FAP) uses the equation (5).

$$\text{Number of FAP} = \frac{5545}{164048.9096} = 0.033800895$$

It was assumed to be 1 FAP.

B. *Simulation result*

In the placement of FAP in this thesis research, it is divided into three scenarios in placing Femtocell Access Points (FAP), where the simulation results from the Radiowave Propagation Simulator are based on Reference Signal Received Power (RSRP) and Signal to Interference Ratio (SIR).

1. First Scenario, places 2 Femtocell Access Points in the front area inside the PT. SAE building.

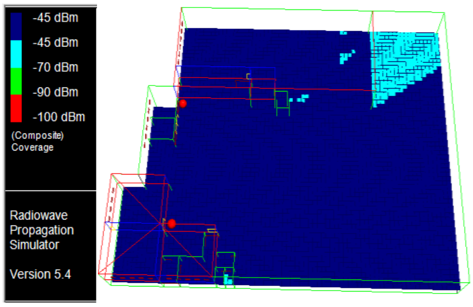

Fig. 4. Composite coverage result in 3D view

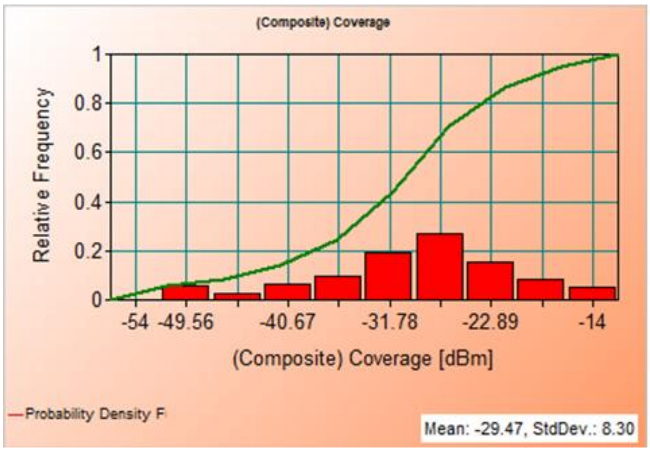

Fig. 5. Histogram of coverage in first scenario one

Based on the simulation results of scenario one, the composite coverage in Fig. 4, with a 3D view, shows the distribution pattern of the femtocell access point FAP signal according to the color indicator. Composite coverage plays a vital role in modern telecommunications by ensuring that users experience reliable and continuous connectivity across different areas, whether in cities or rural locations. It leverages the combined strength of multiple cells to provide a robust and seamless communication experience. The coverage simulation inside the PT. SAE building is considered very good because almost the entire area is covered. In Fig. 5, the histogram of the simulation results of composite coverage in scenario 1 shows the average signal value in histogram form, with an average received signal of -29.47 dBm.

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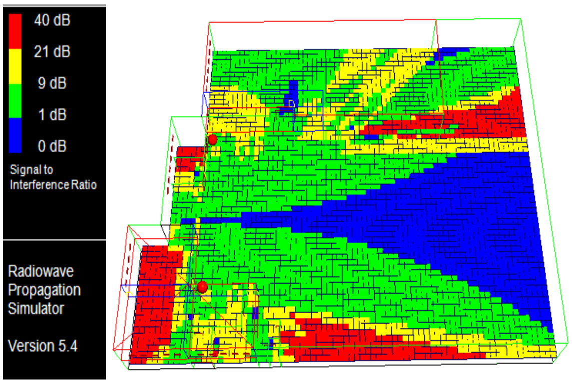

Fig. 6. SIR simulation result in first scenario in 3D view

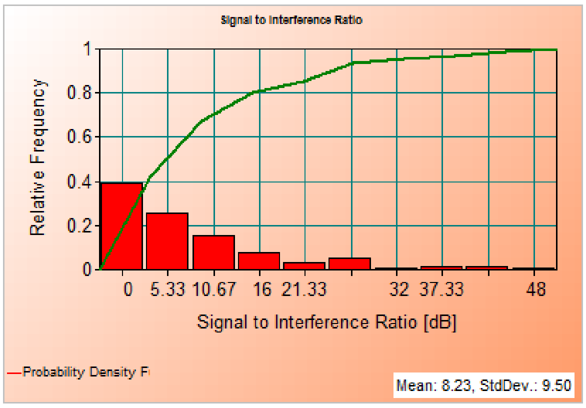

Fig. 7. Histogram of SIR results in first scenario

Similar to before, the SIR parameter in 5G technology still refers to the LTE network according to Key Performance Indicators. SIR indicates the minimum power where a user can still access call signals in a network. The Interference Ratio value is obtained from the SIR histogram simulation in scenario one. The range of (21) to (40) indicates perfect conditions, and users get a Signal-to-signal-to-interference ratio presentation in the simulation results of 25.81534%. Thus, on average, users obtained a Signal-To-Interference Ratio with a good presentation of 8.23 dB in scenario one.

2. Second Scenario, places FAP on the middle side walls inside the PT. SAE building.

Fig. 8 and 9 above show the composite coverage results in second scenario. These figures show the distribution pattern of the FAP signal to areas inside the building according to the color indicator. The coverage simulation is considered good because there are still areas where the coverage is average, but almost the entire area is covered. In Fig. 9, the histogram of the simulation results of composite coverage in second scenario shows the average signal value in histogram form, with an average received signal of -25.60 dBm.

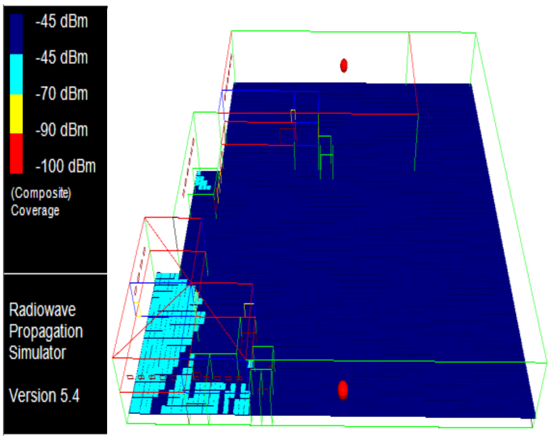

Fig. 8. Composite coverage result in second scenario in 3D view

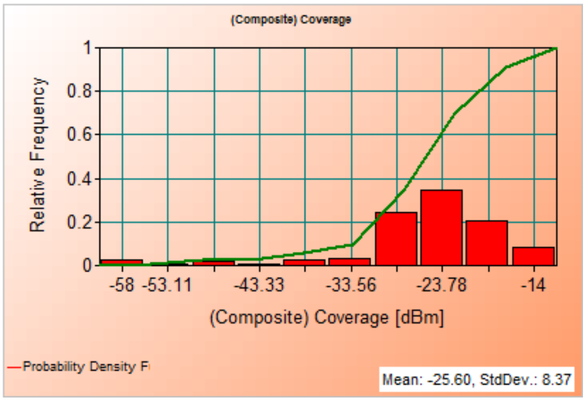

Fig. 9. Histogram of composite coverage in second scenario two

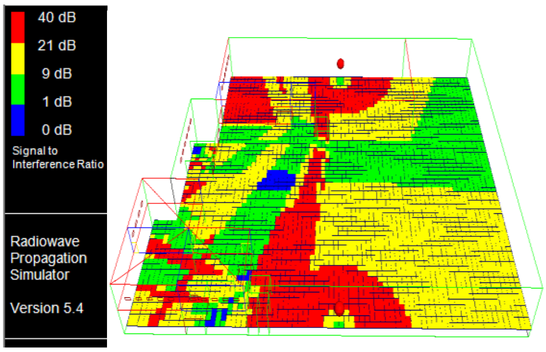

Fig. 10. SIR simulation result in second scenario in 3D view

Fig. 10 shows the Signal-to-Interference Ratio simulation results in a 3D view in scenario two, where the results can be seen in the area inside the PT. SAE covers all areas receiving signals from the Femtocell Access PointFAP. Fig. 11 is the histogram of the simulation results of Signal Interference Ratio (SIR) scenario 2, which shows the average signal value in histogram form, with an average received signal of 14.80 dBm.

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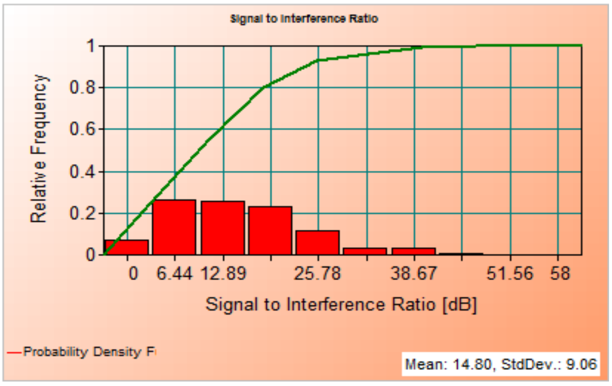

Fig. 11. Histogram of SIR results in second scenario

3. Third Scenario, places Femtocell Access Points in the rear area inside the PT. SAE building, in the back corners, namely the right and left corners. PT. SAE building, with simulation discussions, still uses the same parameters as the previous scenarios discussed above.

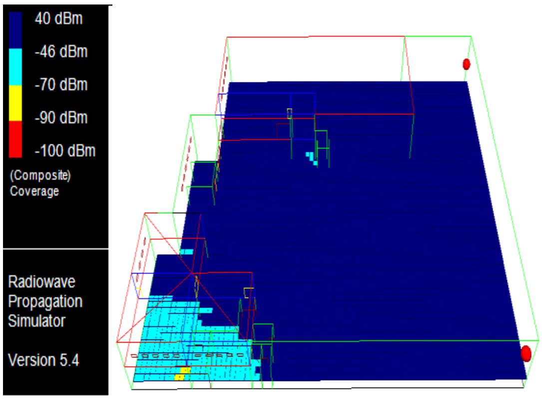

Fig. 12. Composite coverage result in third scenario in 3D view

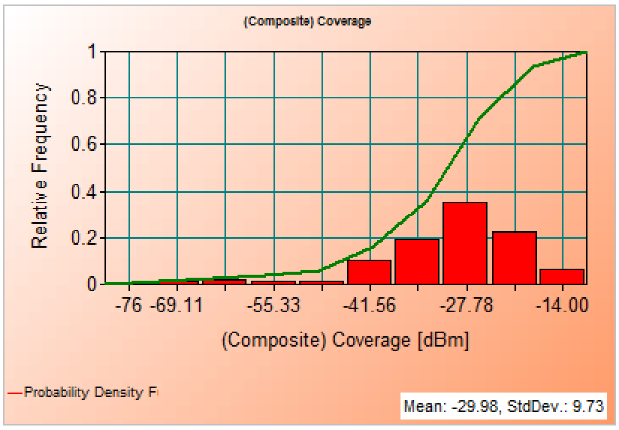

Fig. 13. Histogram of composite coverage in third scenario

From the simulation results in third scenario in Fig. 12, the composite coverage result with a 3D view, the figure shows the pattern of signal distribution from the Femtocell Access Point (FAP) according to the color indicator. In the signal spread in the PT. SAE building, it is very good, but there are still areas where the signal spread is within standard conditions. Fig. 13, the histogram of the simulation results of composite coverage in scenario 1, shows the average signal value in histogram form, with an average received signal of -29.98 dBm. Composite coverage in the very good category means values ranging from (-45) to (-10) in this simulation, presenting a very good percentage of 94.2384%.

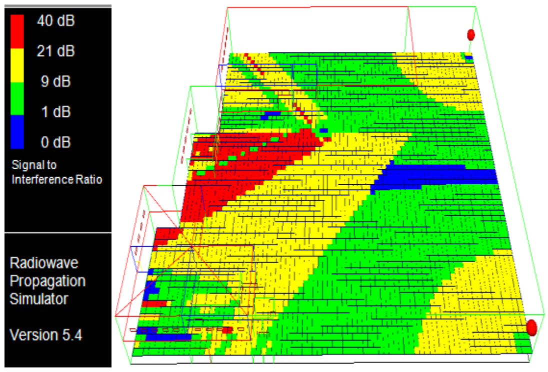

Fig. 14. Simulation results of the three SIR scenarios in 3D display

Fig. 14 shows the simulation results of the Signal to Interference Ratio (SIR) for the third scenario. The information regarding the Signal to Interference Ratio (SIR) parameter, as per the Key Performance Indicator (KPI), still refers to the LTE network in Table 1 and 2.

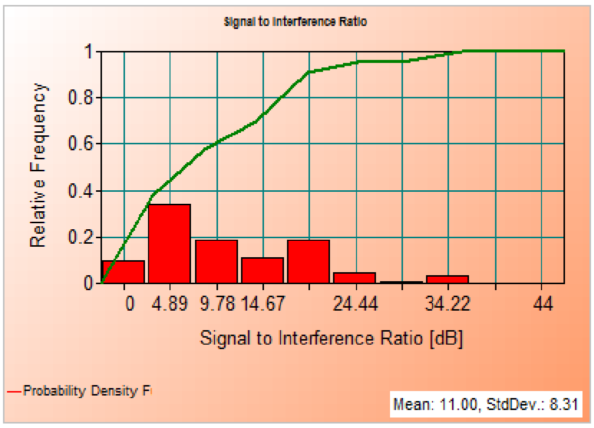

Fig. 15. Histogram of SIR results for the third scenario

The information on the Signal to Interference Ratio (SIR) parameter, as per the Key Performance Indicator (KPI), indicates that the values are excellent, ranging from (21) to (40). The obtained percentage is 47.16585%, showing that many users achieve a Signal to

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Interference Ratio classified as very good. As a result, the average user experiences a Signal-to-Interference Ratio with a good percentage.

4. Simulation of one Femtocell Access Point (FAP) placed at the front side inside the PT. SAE building.

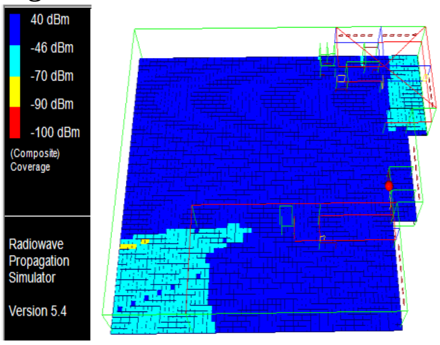

Fig. 16. 3D display composite coverage 1 FAP simulation results

In Fig. 16, the simulation results depict the utilization of a single Femtocell Access Point (FAP) positioned at the front area inside the building. The simulation, presented in 3D view, illustrates uniform signal distribution; however, small areas are not well-covered.

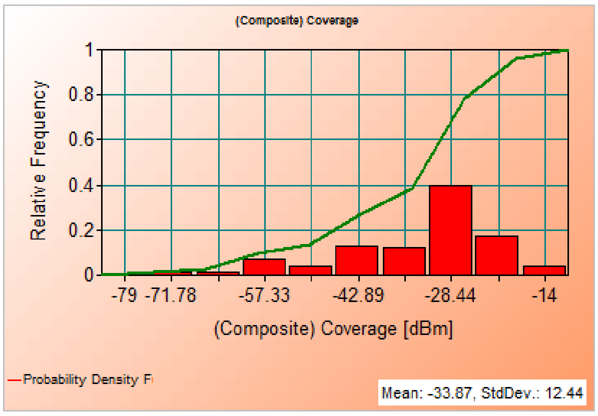

Fig. 17. Simulation histogram 1 FAP composite coverage 1

The following parameter is the Signal to Interference Ratio (SIR), a crucial factor in network design. The Signal to Interference Ratio indicates the signal quality that users can receive. Then, in Fig. 17 and 18, the results show no graph of interference occurrence, as only one Femtocell Access Point (FAP) is placed. Consequently, no interference occurs. To achieve the best coverage and enable the Signal to Interference Ratio, it is necessary to use 2 Femtocell Access Points (FAPs).

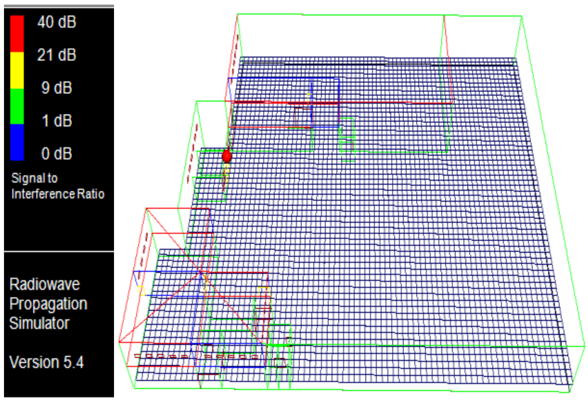

Fig. 17. Simulation results of 1 FAP SIR parameters 3D display

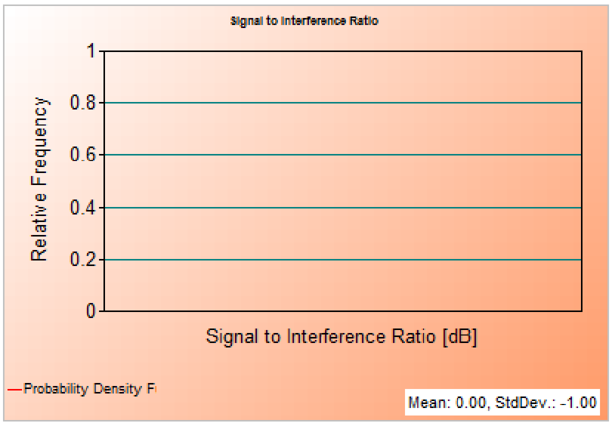

Fig. 18. The SIR histogram uses 1 FAP

C. *Comparison of Simulation Results*

After discussing the simulation results using 1 Femtocell Access Point (FAP) placed in the front position inside the building and comparing it with using 2 FAPs with three scenarios, each scenario is compared to determine the best scenario for achieving good quality. Table following compares coverage and Signal Interference Ratio (SIR) values in Table 1.

The comparison in Table 31 reveals that the simulations using 1 Femtocell Access Point (FAP) and those employing 2 Femtocell Access Points in various scenarios generally result in excellent coverage. However, the analysis here focuses on identifying the position of the Femtocell Access Point (FAP) with the highest coverage value for potential implementation in PT. SAE. The scenario with the highest coverage value is the second scenario, which is -25.60 dBm. Subsequently, when evaluating the overall scenarios for Signal Interference Ratio (SIR), it is observed that almost all scenarios indicate excellent values, providing good SIR coverage across nearly all areas in PT. SAE.

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TABLE 3I
Comparison of simulation results

Simulasi (1 FAP)	
Coverage (dBm)	**SIR (dB)**
m : -33.27	m : 0
Skenario 1 (2 FAP)	
Coverage (dBm)	**SIR (dB)**
m : -29.47	m : 8.23
Skenario 2 (2 FAP)	
Coverage (dBm)	**SIR (dB)**
m : -25.60	m : 14.80
Skenario 3 (2 FAP)	
Coverage (dBm)	**SIR (dB)**
m : -29.98	m : 11.00

Moreover, in terms of the placement of the Femtocell Access Point (FAP), the choice is based on the average SIR values from the scenarios, with the second scenario having the highest average SIR value, precisely 14.80 dB. This scenario is preferred as it demonstrates significantly higher simulation coverage and SIR values than the first and third scenarios. The Cumulative Distribution Frequency (CDF) distribution is also more uniform and favorable in the second scenario compared to the first and second scenarios. Consequently, the authors selects the second scenario with two Femtocell Access Points (FAPs) as it offers a balanced and suitable configuration for implementation.

Regarding the simulation with 1 FAP, it is evident that the coverage value is the lowest compared to simulations using 2 FAPs. The Signal to Interference Ratio (SIR) values indicate the absence of interference, which is attributed to the placement of only 1 Femtocell Access Point (FAP). To achieve optimal coverage and allow for the occurrence of Signal to Interference Ratio, 2 Femtocell Access Points (FAPs) are required.

IV. Conclusion

Based on the link budget calculations considering coverage, employing only 1 Femtocell Access Point (FAP) falls short of comprehensive coverage and fails to yield Signal to Interference Ratio values due to the absence of signal interference. The design of the number of FAPs, based on coverage, involves the use of 2 FAPs as per scenarios 1, 2, and 3. The mean values for composite coverage in these scenarios are -29.47 dBm, -25.60 dBm, and -29.98 dBm, while the Signal to Interference Ratio values are 8.23 dB, 14.80 dB, and 11 dB, respectively.

Simulation results indicate that, on average, users achieve values categorized as very good in composite coverage and Signal to Interference Ratio according to Key Performance Indicators. The study concludes that scenario 2, which employs 2 FAPs, is the most favorable as it exhibits good and substantial coverage and SIR values compared to scenarios 1 and 3. The mean values for scenario 2 are -25.60 dBm and 14.80 dB, respectively.

V. Acknowledgment

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