



Planning of Indoor Femtocell Network for LTE 2300 MHz on Railways Carriages Using Radiowave Propagation Simulator 5.4

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Abstract — The indoor communication system is a system to solve the problem of weak signals received by placing a Femtocell Access Point (FAP) indoor area. The design of an indoor cellular communication network system is carried out using the Radiowave Propagation Simulator 5.4. The parameters observed were Received Signal Level (RSL) and Signal to Interface Ratio (SIR). The case study is the passenger carriage of the executive, business, and economy passenger class. The research includes link budget calculations based on coverage and capacity by considering the type of train carriage material and train passenger capacity. The capacity calculation produces 1 FAP for executive and business class cars, while economy class cars obtained 2 FAP. In the best scenario for executive class, namely scenario 1A, the receiver gets an average RSL of approximately -32.26 dBm and SIR of 0 dB. Meanwhile, in the best scenario for business class, namely scenario 2A, the receiver gets an average RSL of approximately -32.57 dBm and SIR of 0 dB. Finally, in the best scenario for economy class, namely scenario 3A, the receiver gets an average RSL of approximately -29.80 dBm and the receiver gets average SIR of approximately 6.97 dB.

Keywords – Femtocell, Long Term Evolution, Radiowave Propagation Simulator, RSL, SIR

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I. INTRODUCTION

The utilization of cellular communication technology services is essential in our society. According to data compiled from the Indonesian Central Statistics Agency, cellular phone users in Indonesia in 2014 amounted to 211 million users. Then in 2018, it increased to 325 million users [1]. Long Term Evolution (LTE) technology is designed for data access speeds, broader coverage and capacity, multiple-antenna support, flexible bandwidth usage, and integrated with existing technologies. LTE technology specifications are targeted to serve at least 100 Mbps downlink and at least 50 Mbps uplink. A broader spectrum of up to 20 MHz to provides compatibility with existing cellular technologies and increase system capacity [2]. In addition, LTE can support all existing applications, including voice, data, video, and Internet Protocol (IP) TV. Users need reliable LTE network access in any place wherever the

user is either inside the building (indoor) or outside the building (outdoor), including when the user is on high-speed transportation such as trains. With a maximum speed of 120 km/hour, the cellular communication network's performance is volatile due to the Doppler Effect and the train carriage material's attenuation, which can weaken radio wave emission from eNodeB [3], [4].

The indoor communication system is applied to overcome the weak signal received from eNodeB to fulfill cellular communication services. Indoor network communication is a system applied in buildings to support outdoor systems (macrocell and outdoor microcell) in fulfilling cellular and wireless services to overcome blank spots within the coverage area of a cell, covering areas that are difficult to eNodeB, expanding cell coverage area, and overcome congested users in the building. Indoor cellular

communication network system can use femtocell technology [5], [6].

Femtocell is a micro transmitter technology or the so-called low power Home Base Station, which functions to expand coverage and increase capacity due to cellular communication networks' limitation. It provides wireless services in the form of voice and data that operates on licensed frequencies such as those used on cellular networks, especially indoors, such as housing or offices that are often not covered by conventional eNodeB. Femtocell is used for areas that are not covered by Base Transceiver Station with very high traffic levels. The coverage of this cell is only 10 meters to 30 meters [7], [8]. In this research, Universal Small Cell (USC) 8718 Femtocell Access Point (FAP) is used [9].

The simulator for designing the indoor femtocell network in railroad cars is the Radiowave Propagation Simulator (RPS) version 5.4, which can be used to analyze radio wave propagation or predict the coverage of the design area. This research is to design an indoor LTE femtocell network with a frequency of 2300 MHz and a bandwidth of 20 MHz in train cars using RPS version 5.4 in terms of coverage planning and capacity planning by considering the type of railroad car material and calculating the link budget. The parameters observed were Received Signal Level (RSL) and Signal to Interference Ratio (SIR).

II. RESEARCH METHODS

A. Propagation Model

Propagation is a radio wave transmission of a transmitter antenna to a receiver antenna that runs through the air as a signal conduit. Free space propagation occurs when there is a Line of Sight (LOS) path, i.e., there is no barrier blocking the propagation of radio waves between transmitter and receiver. There are only signal losses in free space propagation as a function of the distance between transmitter and receiver. The simplest model is when the conditions for seeing each other between the transmitter and receiver are met, and only one direct signal is received, so the calculation of attenuation is carried out using the Free Space Loss (FSL) formula [10]:

$$FSL = 32.5 + 20 \log f \text{ (MHz)} + 20 \log d \text{ (km)} \quad (1)$$

In Free Space Attenuation (FSA), the two variables that influence it are the carrier frequency used and the distance between the transmitter and receiver. The propagation model based on environmental conditions of the transmitter and receiver can be divided into two, namely indoor propagation and outdoor propagation models. In the indoor propagation model, several additional parameters that need to be considered, such as the number of walls and floors. Until now, the empirical model of indoor propagation attenuation for 2300 MHz frequency usage is still under further research. This propagation model across the walls in the vertical and horizontal planes between the

transmitter and receiver is taken-into-account. In each barrier wall with its material properties, there is a damping value that is also taken-into-account. Based on the empirical propagation model approach combined with the simulation parameter attenuation, the propagation formula can be written as follows [11]:

$$LT = LFSL + LC + \sum_{i=1}^m nwi \times Lwi + nf \left[\frac{nf+2}{nf+1} \right] \times Lf \quad (2)$$

Several factor of indoor attenuation are determined, including by nw is the penetration wall or the number of walls which becomes the barrier between the transmitter and receiver. Notation nf is penetration floors or a number of floors that become a barrier. The loss between walls and floors is written in the formula with Lw and Lf . For M is the number of wall building materials (number of walls).

B. User Throughput

Capacity-based design is done to determine how many FAPs cover all users in one cell. Several aspects that need to be considered in designing-based: the number of users and the service model used by users will be used to determine the number of FAP based on capacity. In calculating the capacity based on the number of users and the throughput value of the services provided by Femtocell. Session throughput calculation is the number of bits received by each User Equipment (UE) per-session of a service. Service classification is a facility provided by operators to 4G LTE users technology to support user mobility and comfort, such as VoIP, video phone, video conference, real-time gaming, streaming media, IMS signaling, web browsing, file transfer, email, and P2P file sharing. Session Throughput calculation formula can be written as follows [12]:

$$Tp \text{ session} = R \text{ bearer} \times t \text{ session} \times D \text{ session} \times \left[\frac{1}{(1-BLER)} \right] \quad (3)$$

The $Tp \text{ session}$ is the throughput session, the number of bits received by each UE per session of service. Notation of $R \text{ bearer}$ is bearer rate, the data rate at the application bit rate layer. Notation of $t \text{ session}$ is the session time, which is the per-session duration of service, while $D \text{ session}$ is the session duty ratio, which is the data transmission rate per session of service. The $BLER$ is a block error rate, the service error rate due to full capacity or blocking. The single-user throughput calculation is the total throughput required for each service model such as VoIP, video phone, video conference, real-time gaming, streaming media, IMS signaling, web browsing, file transfer, email, and P2P file sharing. Single user throughput calculation formula can be written as follows [13]:

$$TP \text{ SU} = \frac{[\sum \left(\frac{\text{Throughput}}{\text{Session}} \right) \times BHSa \times R \text{ Penetration} \times (1+PAR)]}{3600} \quad (4)$$

The $TPSU$ is single-user throughput, the average number of bits received by each UE per service (Kbps). The $BHSa$ is a busy hour service attempt, which

attempts to get a service by the UE during peak hours. The *R Penetration* is the penetration ratio, which is how well the service can affect the subscriber. The *PAR* is the peak to average ratio, the assumption of the largest percentage of network overload that can occur (35%).

C. System Parameters

The use of simulation parameters aims to facilitate the analysis of results. This parameter is mainly intended to calculate the distribution of power coming from the transmitter antenna. If the power from the transmitter antenna is well distributed, the receiver will also get optimal power. Antenna placement and device selection are also important parts and must be taken-into-account according to environmental conditions. The parameter used for system design indoor network on railways carriages can be seen in Table 1. The simulation process utilizes a frequency of 2300 MHz. The device transmits 20 dBm of power with an omnidirectional antenna, so it is assumed that the antenna gain is 0 dBi. The antenna height of the transmitter device 2.610 meters is adjusted to the height of the train carriage, and for users as high as 0.5 meters, it is assumed that the passenger is sitting in the passenger seat.

Table 1. System Parameters

Parameter	Value
Frequency (MHz)	2300
Bandwidth (MHz)	20
Transmitter	
Max Transmit power (dBm)	20
Antenna Height (m)	2.610
Antenna Type	Omni
Receiver	
Antenna Polarisation	Vertical
Antenna Height (m)	0.5
Antenna Type	Omni

Determination of the transmit power of the antenna or known as Effective Isotropic Radiated Power (EIRP), obtained from the transmit power plus the antenna gain, in this simulation the gain antenna is 0 dB because it uses an omnidirectional antenna. The EIRP formula is as follows [15]:

$$\text{EIRP} = P_{tx} \text{ (dBm)} + G_{tx} \text{ (dB)} - L_{tx} \text{ (dB)} \quad (5)$$

P_{tx} is transmit power (dBm), G_{tx} is transmitter antenna gain (dB), and L_{tx} is losses in the transmitter (dB). So that the power received on the receiving antenna (Received signal) is obtained from the transmit power of the antenna reduced by the propagation attenuation in this case the indoor propagation as in equation (2), can be formulated as follows [15]:

$$\text{RSL} = \text{EIRP (dBm)} - L_{\text{propagasi (dB)}} + G_{rx} \text{ (dB)} - L_{rx} \text{ (dB)} \quad (6)$$

The RSL is a signal level that can be received at the receiver and the resulting value must be greater than the sensitivity of the receiving device. The sensitivity itself can occur because of the sensitivity of a certain device on the receiving side. Propagation is wave losses that occur while operating, G_{rx} is gain at the receiving antenna, and L_{rx} is losses due to the receiver line.

D. Case Study Characteristics

In this study, locomotive railroad transportation is used as a case study with research focusing on executive class passenger cars (Fig. 1), business class train cars (Fig. 2), and economy class train cars (Fig. 3). Passenger seat capacity for executive class is 50 passenger seat, capacity for business class is 64 passenger seat, and capacity for economy class is 106 passenger seat. The locomotive carriage was chosen as a case study because this means of transportation is the type of transportation that is often chosen by Indonesians, especially those who live on the island of Java, to travel between cities. In addition, a locomotive train is a public place where train passengers need access to a smooth and stable cellular network when traveling.

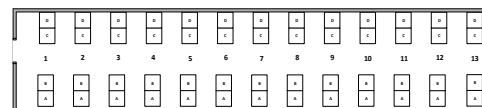


Fig. 1. Executive Passenger Class Seat Plan

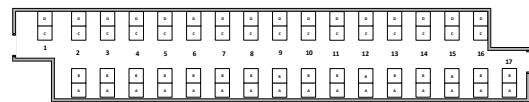


Fig. 2. Business Passenger Class Seat Plan



Fig. 3. Economy Passenger Class Seat Plan

Indoor damping is done to get how much is the result of the loss of material for train passenger cars such as types of walls, doors, windows and passenger seats. With a train passenger car length of 20 meters, width of 2.99 meters, and height of 2.61 meters. The materials for train passenger cars such as carbon fiber as a wall material, acrylic rayben as a window material, the foamed polyester as a passenger seat material, and the combination of carbon fiber and acrylic rayben as a door material. Material damping is done to get how much damping is the result of the different material making up the train carriages such as the types of walls, windows, doors and passenger seats. After getting the total attenuation, then calculating the permissible propagation after passing the loss. The type of material

and the attenuation value of the carriage can be seen in the Table 2.

Table 2. Type of Attenuation Material

Material	Type of Material	Attenuation Value (dB)
Wall	Carbon fiber	18
Door	Carbon fiber + Acrylic rayben	18.8
Window	Acrylic rayben	0.8
Passenger Seat	Foamed polyester	4

E. Simulation Scenario

The total number of FAP placement scenarios is 9 scenarios can be seen in the Table 3. There are 3 types of train passenger car classes with different numbers of passengers in each class. In each car, 3 attempts to place the FAP were carried out until the RSL and SIR values were obtained which were in accordance with the Key Performance Indicator (KPI).

Table 3. Simulation Scenario

Passenger Class	Scenario	Number of FAP
Executive	1A	1
	1B	1
	1C	1
Business	2A	1
	2B	1
	2C	1
Economy	3A	2
	3B	2
	3C	2

Scenario 1A, 1 FAP is positioned in the middle of the executive class passenger car (Passenger seat ABCD 7). Scenario 1B, 1 the FAP is positioned at the end of the executive class passenger car (Passenger seat ABCD 1). Scenario 1C, placing 1 FAP in an oblique position in the executive class passenger car (Passenger seat AB 13).

Scenario 2A, 1 FAP is positioned in the center of the business class passenger car (Passenger seat ABCD 9). Scenario 2B, 1 FAP is positioned at the end of the business class train passenger car (Passenger seat ABCD 1). Scenario 2C, 1 FAP is placing the FAP in an oblique position in the business class passenger car (Passenger seat CD 16).

Scenario 3A, 2 FAP is positioned in the middle of the economy class train passenger car (Passenger seats ABCDE 8 and ABCDE 16). Scenario 3B, 2 FAP is

positioned at the end of the economy class train passenger car (Passenger seat ABCDE 1 and Passenger seat ABCDE 24). Scenario 3C, placing 2 FAP in an oblique position in the economy class passenger car (Passenger seat AB 2 and DE 22).

III. RESULTS

The executive class train passenger car for scenario 1A (Fig. 4) obtained the value of RSL is -32.26 dBm with the relative frequency value is 0.02. The relative frequency value means that as many as 2% of users get a power level of -32.26 dBm. Scenario 1B (Fig. 5) obtained the value of RSL is -35.03 dBm with the relative frequency value is 0.03. The relative frequency value means that as many as 3% of users get a power level of -35.03 dBm. Scenario 1C (Fig. 6) obtained the value of RSL is -36.39 dBm with the relative frequency value is 0.02. The relative frequency value means that as many as 2% of users get a power level of -36.39 dBm.

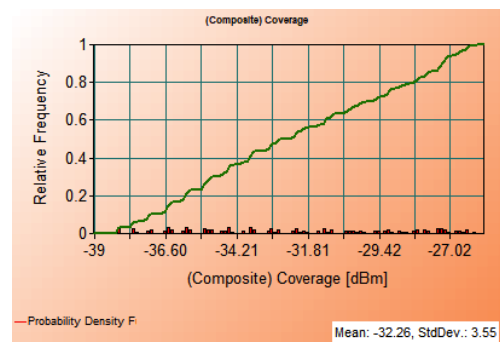
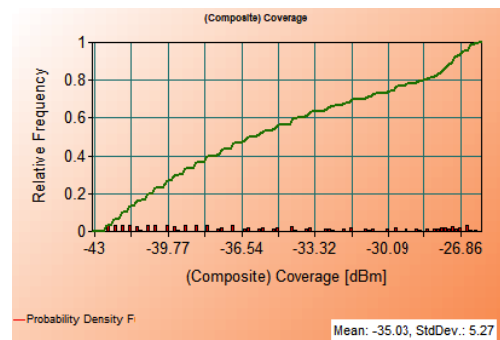
Fig. 4. Composite Coverage Scenario 1^a

Fig. 5. Composite Coverage Scenario 1B

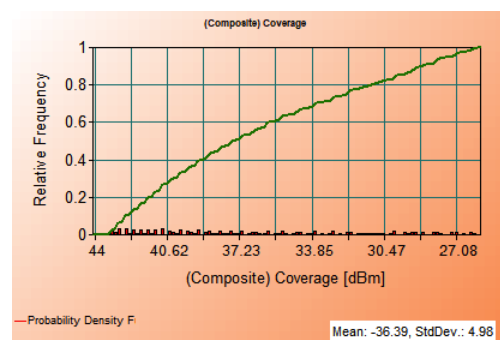


Fig. 6. Composite Coverage Scenario 1C

For business class train passenger cars for scenario 2A (Fig.7), the value of RSL obtained is -32.57 dBm with the relative frequency value is 0.025. The relative frequency value means that as many as 2.5% of users get a power level of -32.57 dBm. In scenario 2B (Fig.8), the value of RSL is -37.29 dBm with the relative frequency value is 0.025. The relative frequency value means that as many as 2.5% of users get a power level of -37.29 dBm. In scenario 2C (Fig.9), the value of RSL is -36.55 dBm with the relative frequency value is 0.025. The relative frequency value means that as many as 2.5% of users get a power level of -36.55 dBm.

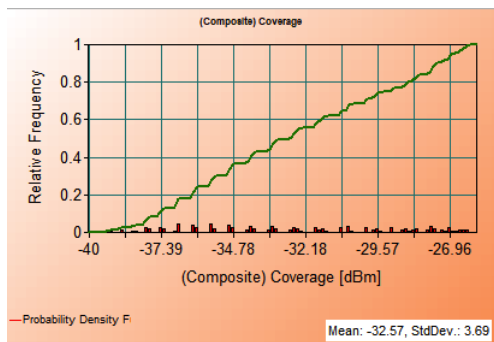


Fig. 7. Composite Coverage Scenario 2A

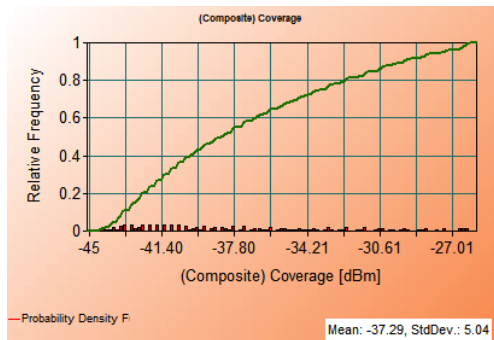


Fig. 8. Composite Coverage Scenario 2B

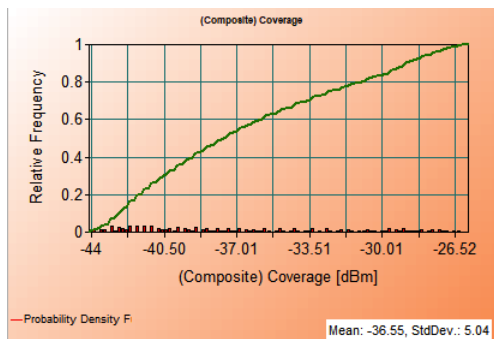


Fig. 9. Composite Coverage Scenario 2C

For the economy class train passenger car for scenario 3A (Fig.10), the obtained RSL value is -29.80 dBm with the relative frequency value is 0.020. The relative frequency value means that as many as 2% of users get power level of -29.80 dBm. Scenario 3B the RSL value is -34.68 dBm with the relative

frequency value is 0.020. The relative frequency value means that as many as 2% of users get power level of -34.68 dBm. Scenario 3C the RSL value is -33.24 dBm with the relative frequency value is 0.020. The relative frequency value means that as many as 2% of users get power level of -33.24 dBm.

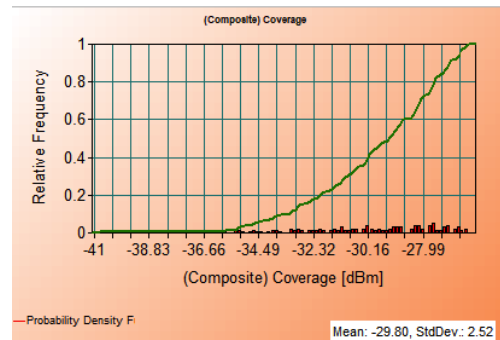


Fig. 10. Composite Coverage Scenario 3A

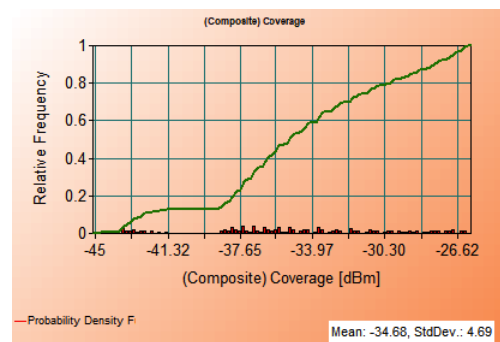


Fig. 11. Composite Coverage Scenario 3B

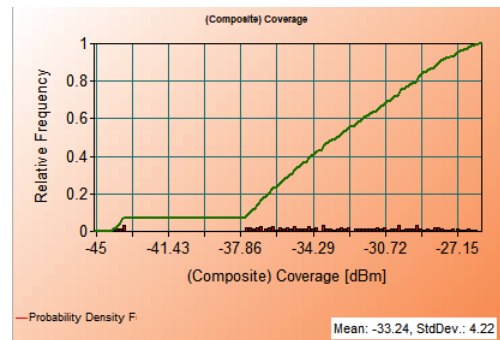


Fig. 12. Composite Coverage Scenario 3C

The average SIR for the overall executive and business class train passenger carriages scenario is 0 dB. It is caused by placing only 1 FAP on train, so that there is no interference from other FAP. Whereas for economy class train passenger cars with the placement of 2 FAP, the average SIR for scenario 3A (Fig.13) is 6.97 dB with the relative frequency value is 0.02. The relative frequency value means that as many as 2% of users get an SIR of 6.97 dB. The average SIR value for scenario 3B (Fig.14) is 7.88 dB, with the relative frequency value is 0.017. The relative frequency value means that as many as 1.7% of users get SIR of 7.88 dB. The average SIR value for scenario 3C (Fig.15) is 8.27 dB with the relative frequency value is 0.02. The

relative frequency value means that as many as 2% of users get an SIR of 8.27 dB.

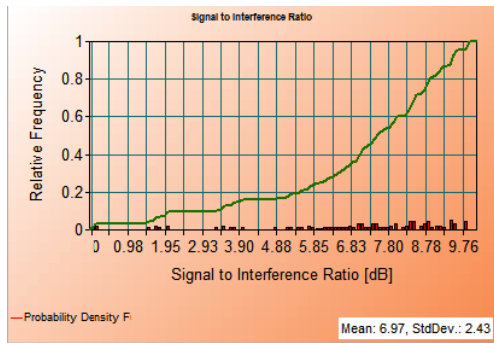


Fig. 13. SIR Scenario 3A

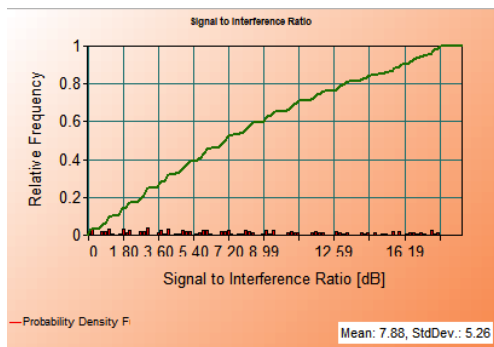


Fig. 14. SIR Scenario 3B

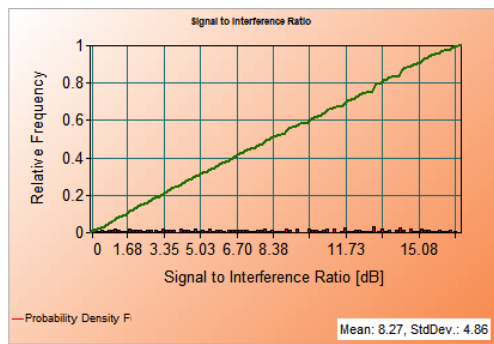


Fig. 15. SIR Scenario 3C

IV. DISCUSSION

The calculation of capacity is based on the number of passengers that passenger seat is assumed to be fully charged; 50 passengers of Executive Class, 64 passengers of Business Class, and 106 passengers of Economy Class. The height of the FAP is set as high as 2.6 meters, while the receiver is set at 0.5 meters, assuming all passengers are seated in the passenger seat.

In this paper, the calculation results based on capacity are used because the maximum number of FAP is selected. The calculation results based on capacity obtained one FAP for executive and business class train passenger cars, for economy class train passenger cars obtained two FAPs by using Cisco USC 8718 FAP specification. The cell radius can be covered

by the FAP for executive class passenger cars as far as 78.16 m², business class passenger cars as far as 75.05 m², and economy class train passenger cars as far as 60.04 m².

The average RSL value for each scenario in each class of train passenger cars results in different signal power levels received by users can be seen in Fig. 16. The placement of the FAP in each class of train passenger cars is well fulfilled because the placement of the FAP from the entire scenario already has a power level indicator above -70 dBm. The scenario that already has a power level indicator above -70 dBm, namely the executive class wagon is scenario 1A, the business class wagon is scenario 2A, and the economy class wagon is scenario 3A.

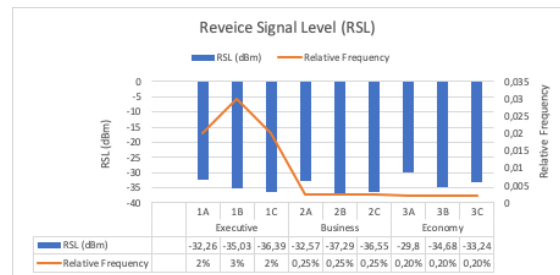


Fig. 16. Average RSL

The average SIR value for each scenario in each train passenger car class results in different SIR values received by different users can be seen in the Fig. 17. The difference in the value of the SIR between executive class and business class passenger cars and economy class passenger cars because the executive and business class passenger cars are only placed 1 FAP so that there's no interference from other Access Points. As for economy class passenger cars, 2 FAP are placed so that there is interference from one Access Point to another Access Point.

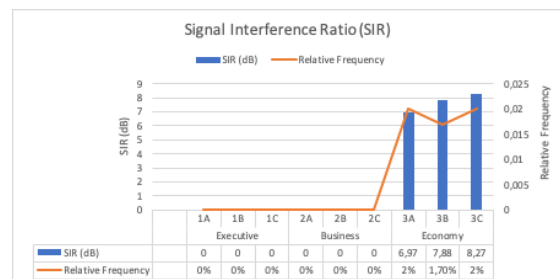


Fig. 17. Average SIR

The results in this paper show that capacity of passenger in each train class, number of FAP, and the FAP placement have an impact on the simulation result can be seen in Table 4. The best placement for the executive class, business class, and economy class is positioned in the middle of the train passenger car. The average of SIR for overall the executive class and business class train passenger carriages scenario is 0

dB. It is caused by placing only 1 FAP on train, so that there is no interference from other FAP.

Table 4. Average RSL and SIR

Passenger Class	Scenario	RSL (dBm)	SIR (dB)
Executive	1A	-32.26	0
	1B	-35.03	0
	1C	-36.39	0
Business	2A	-32.57	0
	2B	-37.29	0
	2C	-36.55	0
Economy	3A	-29.8	6.97
	3B	-34.68	7.88
	3C	-33.24	8.27

V. CONCLUSION

The overall simulation results using 9 scenarios, the best simulation results for the executive class train passenger car, namely the 1A scenario that placed 1 FAP is positioned in the middle of the executive class passenger car (Passenger seat ABCD 7), the Composite Coverage value is -32.26 dBm and the SIR value is 0 dB. The best simulation results for business class train passenger cars, namely scenario 2A that placed 1 FAP is positioned in the center of the business class passenger car (Passenger seat ABCD 9), show that the Composite Coverage value obtained is -32.57 dBm and the SIR value is 0 dB. The best simulation results for economy class train passenger cars, namely scenario 3A that placed 2 FAP is positioned in the middle of the economy class train passenger car (Passenger seats ABCDE 8 and ABCDE 16), get the Composite Coverage value obtained is -29.80 dBm and the SIR value is 6.97 dB. Based on these results, it can be proven that the placement of the FAP in indoor network planning is best implemented, namely when the FAP is placed in the middle of executive class passenger cars, business class cars, and economy class cars, can be implemented.

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