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Link Budget Simulation and Analysis for Cambium Radio in Telkomsat Radio IP Service

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Abstract

Telkomsat's shift to a self-managed Radio IP service requires accurate device selection and transmission planning. Although few studies benchmark commercial radio hardware under real deployment conditions, this research fills the gap by analyzing link budget performance using Cambium devices with the Link Planner and validating results through manual calculations. Without direct field testing, this combined approach provides a reliable estimate of real-world performance. Two models—eForce 200 and eForce 300 Connectorized—are compared across various distances and configurations. Key parameters evaluated include Fresnel Zone Clearance (FZC), Free Space Loss (FSL), Effective Isotropic Radiated Power (EIRP), Received Signal Level (RSL), System Operating Margin (SOM), availability, and bandwidth. Simulations were conducted at 31 customer locations. Results show that 100% of EIRP values met standards, 87% of RSL values were good, 13% very good, and 94% of SOM values were acceptable while 6% were poor. Minimal differences between simulation and manual calculations validate the planning tool's accuracy. Findings indicate that the eForce 300 Connectorized performs better over long distances and supports higher bandwidth. This research offers practical guidance for device selection and transmission during Telkomsat's transition, and a validated framework for radio performance evaluation.

Keywords: Link Budget; Link Planner; FZC; FSL; EIRP; RSL; SOM

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1. Introduction

In today's digital era, the demand for remote communication systems continues to increase, in line with the growing mobility of users and the need for secure, high-capacity data transmission. While wired communication systems offer stability, their implementation often incurs high costs and faces challenges in remote or rural areas. Wireless communication technologies, by contrast, offer a more flexible and cost-effective solution for long-distance communication [1].

Telkomsat provides Radio IP services to meet the demand for secure and reliable connectivity. These services are classified into managed and self-managed models, depending on the ownership and control of the equipment. Currently, Telkomsat is planning operational shift-from partner-managed to fully self-managed Radio IP services. To support this transition, accurate link budget analysis and the selection of appropriate radio devices are essential to maintain service quality and network stability [2].

Several studies have previously examined link budget analysis in wireless communication systems. Some have addressed WLAN network design using Mobile Simulator for rural areas, while others evaluated link budget performance in LTE infrastructure through field tests and planning to optimize throughput and signal quality. Additional research has assessed hybrid network efficiency by combining fiber and radio systems, though detailed performance comparisons of commercial radio devices are less common. Many existing studies primarily rely on generic simulation tools without validation against specific commercial hardware. Moreover, variations in performance between different radio device models under operational constraints are often not explored, nor is the use of device-specific planning tools, such as Cambium's

Link Planner, which aim to better represent actual hardware capabilities.

Despite growing interest in link budget analysis, limited research has evaluated Cambium radio devices using both simulation and manual calculations. Moreover, prior studies have not addressed how device-level analysis can support strategic transitions in service management. This gap may hinder operators like Telkomsat from making informed decisions during their shift to self-managed Radio IP services. Therefore, this study aims to fill the gap by comparing two Cambium radio models-eForce 200 and eForce 300 Connectorized-using Link Planner software and validating them with manual link budget calculations. The results are expected to provide practical guidance for device selection and network planning, contributing to Telkomsat's operational autonomy and service reliability.

2. Research Method

2.1 Literature Review

The following are some previous studies used as references in the preparation of this report. With the increasing communication needs today, it has become necessary to design a radio-based communication network in Darul Aman Village and Lhok Asan Village, Geureudong Pase District. A Wireless Local Area Network (WLAN) was proposed due to the poor quality of existing infrastructure. The main approach involved calculating the link budget both theoretically and through simulation using a Radio Simulator [1].

In another study, link budget performance in an LTE network was evaluated through a combination of field testing and network planning tools. Field tests provided accurate measurements of real-world signal conditions and interference, enabling precise adjustments to the network configuration. At the same time, the planning tools enabled simulations to identify potential problems and optimize performance before deployment. This integrated method significantly enhanced spectrum efficiency and connection stability, addressing the rising demand for mobile data services. The results offer valuable insights for optimizing LTE link budgets and future cellular technologies [2].

Over the past few decades, radio frequency networks have remained a popular choice for network development. However, many implementations have increasingly integrated RF systems with fiber optic infrastructure. RF networks offer advantages such as broad coverage area and ease of development. Nonetheless, they face challenges such as frequent radio propagation issues including wave interference. As a result, many organizations have adopted hybrid systems combining both technologies to balance performance and reliability [3].

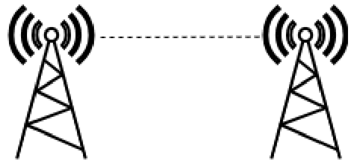

Fig. 1. Line of Sight (LoS)

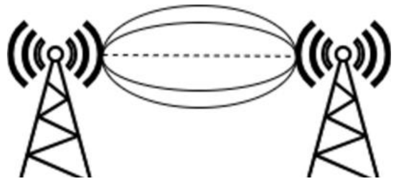

Fig. 2. Fresnel Zone Clearance (FZC)

2.2 Theory

A. Wireless Network

Wireless network is a technology that establishes telecommunication connections without using cables but instead air as a transmission medium to send electromagnetic waves. Wireless network operate at frequencies of 2.4 GHz and 5 GHz up to 5.8 GHz [4].

B. Radio Communication System

Radio communication system is a communication system that uses air and radio wave frequencies to propagate radio waves, which serve as carriers of information signals. This system consists of two main components; the transmitter (Tx) and the receiver (Rx) [5].

C. Radio Devices

Radio device have varying communication capabilities and capacities. Some are designed to deliver high bandwidth, while others support lower bandwidth. In this study, the author used two types of Cambium-brand radio: Cambium eForce 200 and Cambium eForce 300 Connectorized [6].

D. Link Budget

Link budget is the total calculation of gains and losses in a transmission network system. Its purpose is to maintain a balance between gain and loss from the transmitter (Tx) to the receiver (Rx) while also considering the base stasion coverage [7].

E. Line of Sight (LoS)

Line of Sight is the direct line of vision between the transmitter and receiver, with no obstacle between them. Good visibility is essential for long-distance communication that requires high speed [8]. The illustration of LoS can be seen on Fig. 1.

F. Fresnel Zone Clearance (FZC)

Fresnel Zone Clearance is the area within the microwave transmission channel, represented in an elliptical shape, which indicates RF (Radio Frequency) wave interference when obstructed or disrupted. The illustration of FZC can be seen on Fig. 2.

Table 1. RSL Categories Based on TIPHON Standard

Categories	TIPHON Standard (dBm)
Excellent	>-70
Good	-70 s/d -85
Marginal	-85 s/d -100
Poor	< -100

Table 2. SOM Categories Based on TIPHON Standard

Categories	TIPHON Standard (dBm)
Excellent	> 29
Good	20 s/d 29
Marginal	11 s/d 19.9
Poor	< 6.9

$$F1 = 17.3\sqrt{\frac{d}{4(f)}} \quad \ldots.. (1)$$

F1 is the First Fresnel Zone measured in meters. f and d are parameters used for FZC calculation, where f represents the frequency in GHz, and d denotes the Tx-Rx distance in km [9].

G. Free Space Loss (FSL)

Free Space Loss refers to the signal attenuation caused by the air medium through which radio waves travel between the transmitter and receiver.

$$Lfs = 92.44 + 20\log d + 20\log f \quad \ldots.. (2)$$

Lfs is measured in dB, d and f are parameters used for FSL calculation, where d represents the distance in km, and f denotes the frequency in GHz [9].

H. Effective Isotropic Radiated Power (EIRP)

EIRP is a calculation used to determine signal strength and maximum power levels. According to regulation set by the Ministry of Communication and Information, the maximum average value of EIRP for Point-to-Point (PTP) wireless network is 36 dBm.

EIRP = Tx – Lfeeder – Lconnector + Gantenna..(3)

Tx is the transmitter power measured in dBm, Lfeeder is the cable loss in dB, Gantenna is the antenna gain in dBi, and Lconnector is the connector loss, which ranges from 0.01 to 0.05 dB [10].

I. Received Signal Level (RSL)

Received Signal Level is a value used to determine whether the receiver has sufficient signal strength to a good wireless connection.

RSL = PRX = PTX + GTX + GRX – FSL ……(4)

PTX is the transmitter power measured in dBm, PRX is the Received Signal Level (RSL) in dBm, GTX is the transmitting antenna gain in dBi, GRX is the receiving antenna gain in dBi, and FSL is the Free Space Loss (FSL) in dB [11]. RSL Categories Based on TIPHON Standard can be seen on Table 1.

Table 3. Equipment Configuration

Parameters	Value
Band	5.8 GHz
Channel Width	20 MHz
Mode	PTP
DL/UL	50/50

Table 4. Specifications Cambium eForce 200

Parameters	Value
Max Modulation	MCS15 (64QAM, 0.83)
Transmitter Power	22 dBm
Antenna Gain	22 dBi
Antenna Type	Integrated Dish Antenna
Receiver Sensitivity	-92 dBm

Table 5. Specifications Cambium eForce 300 CSM

Parameters	Value
Max Modulation	MCS9 (256QAM, 0.83)
Transmitter Power	27 dBm
Antenna Gain	30 dBi
Antenna Type	External Dish Antenna
Receiver Sensitivity	-89 dBm

J. System Operating Margin (SOM)

System Operating Margin is the power level that must be reserved. A good connection typically result is an SOM of 10-15 dBm.

SOM = Rx *signal level* – Rx *sensitivity* ….. (5)

SOM is the System Operating Margin in dBm, Rx signal level is measured in dBm, and Rx sensitivity is the sensitivity level of the receiving device in dBm [12]. SOM Categories Based On TIPHON Standard can be seen on Table 2.

2.3 Research Flow and Stages

This research follows a structured methodology consisting of several key stages: data input, equipment configuration, simulation, manual calculation, and result validation.

The process begins with identifying and geospatially positioning each transmission point, including the transmitter point and receiver point, using their geographic coordinates. The planned tower height of 25 meters is input into Link Planner, a wireless network simulation tool specifically developed for Cambium Network devices [13]. To visualize the terrain profile and potential obstacles such as buildings or vegetation between the transmitter and receiver, Google Earth Pro is utilized [14]. This visualization aids in assessing LoS conditions and identifying possible signal propagation obstructions.

In the equipment configuration stage, key technical parameters are set. The operating frequency band is 5.8 GHz, with a channel width of 20 MHz. The network is configured to operate in PTP mode, with a 50/50 split between download and upload capacity, to ensure stable and efficient bidirectional communication. The complete equipment configuration, including frequency, channel width, and operation mode settings, is detailed in Table 3.

The simulation uses two types of Cambium radio devices: the integrated eForce 200 and the connectorized eForce 300 Connectorized (CSM). The eForce 200 features a built-in directional antenna with a gain of 22 dBi, a transmitter power of 22 dBm, a receiver sensitivity of -92 dBm, and supports modulation up to MCS15 (64QAM, coding rate 0.83). The eForce 300 CSM requires an external directional antenna; for this purpose, a compatible antenna with a gain of 30 dBi was used. It has a transmitter power of 27 dBm, a receiver sensitivity of -89 dBm, and supports modulation up to MCS9 (256QAM, coding rate 0.83). Detailed specifications are presented in Table 4 and Table 5.

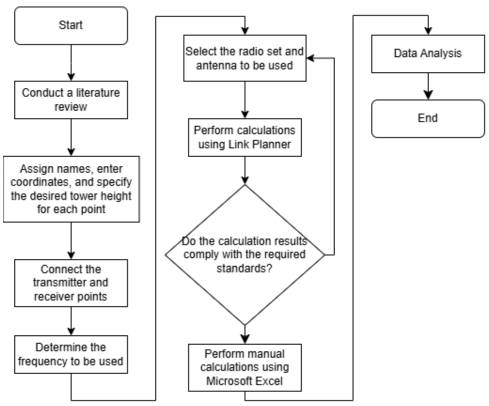

Fig. 3. Research Method Flowchart

Table 6. Transmitter Point

Parameters	Value
Name	Titik STO
Latitude	0.134995N
Longitude	101.5943285E
Maximum Height	50 meters

Table 7. Receiver Point

Parameters	Value
Name	Titik Pelanggan
Latitude	0.1181599N
Longitude	101.5943285E
Maximum Height	50 meters

Table 8. Selecting Parameters and Devices

Parameters	Value
Band	5.8 GHz
Product	Cambium eForce 300 CSM
Regulation	Indonesia
Mode	PTP
Channel Width	20 MHz
DL/UL	50/50
Maximum Modulation	MCS9 (256QAM, 0.83)

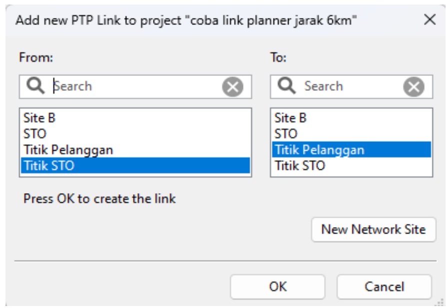

Fig. 4. Connecting Between Points

Simulations are conducted using Link Planner, which generates key performance metrics including FZC, FSL, EIRP, RSL, SOM, availability (%), and bandwidth (Mbps). Evaluation thresholds are set—for example, a minimum RSL of -80 dBm and a SOM of 10 dBm—to ensure acceptable network performance.

If the simulation results meet these criteria, manual link budget calculations are performed using Microsoft Excel [15], which include calculating FSL using the standard free space propagation formula and manually verifying EIRP and RSL values based on device specifications.

The final stage involves validating the results by comparing simulation outputs with manual calculations to ensure consistency and accuracy. This validation confirms the reliability of Link Planner simulation results and provides a strong basis for practical wireless network recommendations.

While detailed environmental factors are not quantitatively analyzed in this study, Google Earth Pro visualization serves as a qualitative tool to identify potential obstacles and assess Line-of-Sight (LoS) conditions affecting signal propagation.

Fig. 3 illustrates the research workflow in a structured sequence, beginning with the input of preliminary data—such as site coordinates and tower height—through to the final validation stage. The diagram outlines the logical flow of tasks, including linking transmitter and receiver points, defining the operating frequency, selecting appropriate radio and antenna devices, and conducting link budget simula-

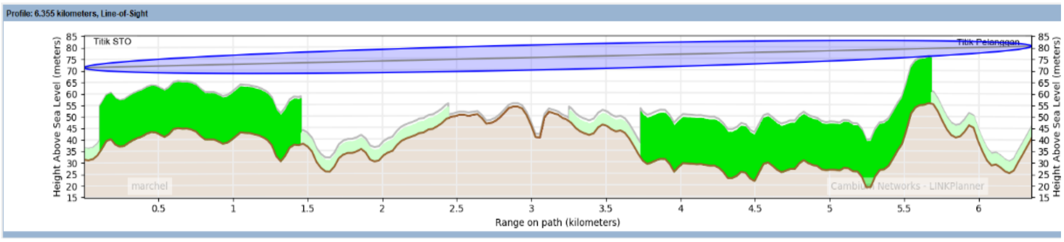

Fig. 5 Link Planner Graph

Table 9. Configuration

Parameters	Value
Antenna Height	40 meters
Cable Loss	1.0 dB
EIRP	35.1 dBm
Maximum Power	7 dBm

Table 10. Performance Results

Parameters	Value
FSL	123.81 dB
RSL	-64 dBm
SOM	22.19 dBm
Bandwidth	65.17 Mbps
Availability	100%

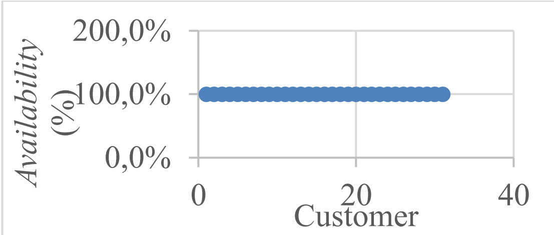

Fig. 6. Availability Results

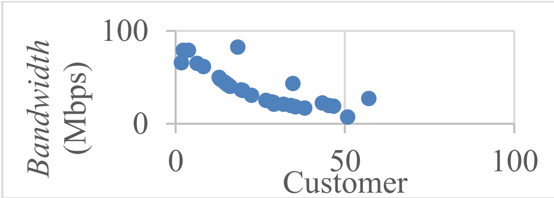

Fig. 7. Bandwidth Results

tions using Link Planner. If the simulation results meet the performance thresholds, the process advances to data analysis; otherwise, manual calculations using Microsoft Excel are conducted for validation. The diagram provides a clear visual summary of the methodology and emphasizes the iterative nature of the process to ensure the accuracy and reliability of the results.

3. Result and Discussion

3.1 Simulation Process

This research simulates and analyzes the link budget of Cambium brand radios for IP Radio services at Telkomsat using Link Planner. The parameters tested and analyzed include FZC, FSL, EIRP, RSL, SOM, Availability and Bandwidth.

The first step is to name the transmitter and receiver points, then enter the coordinates of each point to be connected in a PTP configuration, as well as input the desired maximum antenna height. This first step can be seen in Table 6 and 7.

In the second step, a PTP link is established by selecting the designated transmitter and receiver sites from the list of available locations. As illustrated in Fig. 4, the transmitter site named Titik STO is linked to the receiver site named Titik Pelanggan. This selection defines the primary communication path used for simulation and analysis.

The third step is to select the equipment or parameters, such as the frequency band, devices, and the country regulation to be used. Next, choose the PTP mode, bandwidth, down link and up link. This third step can be seen in Table 8.

After entering all the required parameters, Link Planner will generate an output in the form of a LoS graph that connects the transmitter and receiver points. This graph can be seem in Fig. 5.

In addition to displaying the output in graphical form, Link Planner will also provide the configuration of each point along with its performance results. Configuration and performance result can be seen in Table 9 and 10.

From the result displayed in the result performance, it can be seen that the availability and bandwidth at the receiving point meet the expected values. The availability show a value of 100%, exceeding the typical industry standard requirement of 99% for reliable IP Radio Services and the bandwidth is 65.17 Mbps meets the expected throughput necessary to support current customer data. This occurs because the PTP communication between the transmitting and receiving points has achieved a LoS condition without any obstacles or interference blocking the two points. The following is a performance graph of availability and bandwidth values can be seen in Fig. 6 and 7.

Based on the obtained data, it can be seen that the availability value for each customer is the same, at 100%. This is attributed to the established LoS path between transmitter and receiver. As for the band-

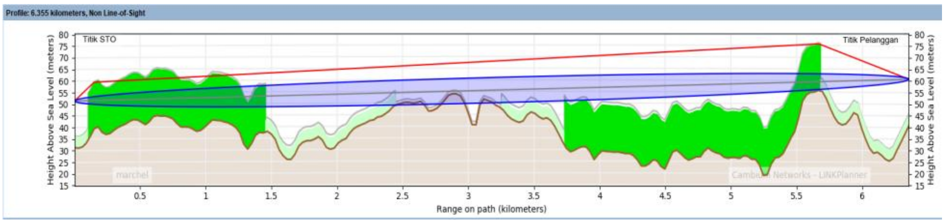

Fig. 8. NLoS Condition

Table 11. Performance Results

Parameters	Value
FSL	171.65 dB
RSL	-112 dBm
SOM	-25.05 dBm
Bandwidth	0 Mbps
Availability	0 %

Table 12. Result Performance

Parameters	Value
FSL	123.81 dB
RSL	-61 dBm
SOM	27.39 dBm
Bandwidth	76.74 Mbps
Availability	100 %

width values, the data shows that the resulting bandwidth varies. This confirms that the selection of radio equipment and transmission distance significantly impact the bandwidth performance.

Further analysis of the simulation data reveals several factors contributing to the differences in bandwidth performance across customer sites. The observed variations in bandwidth across customer locations can be attributed to a combination of environmental and technical factors. While some sites achieved high bandwidth due to clear LoS conditions, others experienced degraded performance as a result of partial or full Non-Line of Sight (NLoS) propagation. In NLoS conditions, obstacles such as buildings, trees, and varying terrain introduce diffraction, reflection, and scattering effects that reduce the RSL. This reduction often leads to a fallback to lower-order modulation schemes, consequently decreasing the available bandwidth.

For instance, in areas where the first Fresnel zone was partially obstructed or where antenna height was insufficient, bandwidth dropped significantly—sometimes to zero. This was evident in simulations where bandwidth fell 0 Mbps and availability dropped to 0% under NLoS conditions. In contrast, when antenna height was increased or the device was upgraded to a higher-performance unit (e.g., Cambium eForce 300 CSM), LoS conditions were restored, resulting in improved RSL and bandwidth recovery.

These findings highlight the critical role of environmental conditions in wireless performance and reinforce the importance of precise planning during network deployment. Therefore, it is evident that environmental conditions and appropriate link planning—such as proper device selection and antenna elevation—are essential to achieving optimal bandwidth and maintaining stable wireless connectivity. Bandwidth differences between customer sites are primarily caused by environmental obstacles that impact LoS conditions, confirming the significance of accurate and proactive link budget planning.

Here is an example of a case where PTP communication between transmitter and receiver does not achieve LoS conditions. In this case study, the radio device used is Cambium eForce 200. This example can be seen in Fig. 8 and Table 11.

As shown in the graph, a NLoS condition is observed at a distance of 6.355 km, indicated by a red line that signifies the system's failure to establish a LoS connection. The performance result report a bandwidth of 0.00 Mbps and an availability of 0.00%, indicating a complete communication failure.

To address this issue, the antenna height was increased to restore a clear LoS and reduce interference. Additionally, the radio device was upgraded to enhance signal reception and overall link performance.

Following these improvements, the PTP communication successfully achieved LoS, eliminating prior obstructions. In this case, the radio device was replaced with a Cambium eForce 300 CSM unit. The corresponding performance metrics and visual output are presented in Fig. 9 and Table 12.

Based on the graph, a LoS condition is observed at a distance of 6.355 km, and the absence of a red line confirms that the communication system has successfully established LoS. Furthermore, the performance table indicates a recorded bandwidth of 76.74 Mbps and an availability of 100%. Table 13 presents a comparison of simulation results using different radio devices.

Based on the table above, it can be concluded that radio equipment selection is a key factor significantly affecting the bandwidth performance of a radio communication system.

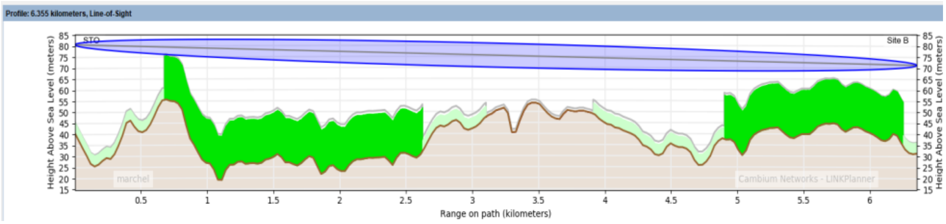

Fig. 9. Condition After Increasing Antenna Height

Table 13. Comparison of Simulating Results

Device Name	Availability (%)	Bandwidth (Mbps)
Cambium eForce 200	100	-64
Cambium eForce 300 Connectorized	100	-61

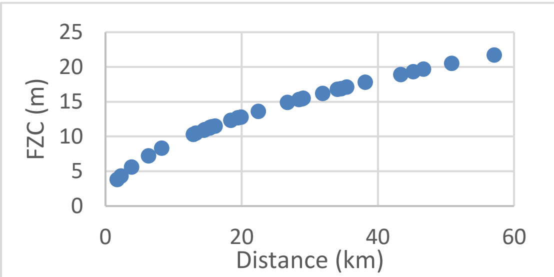

Fig. 10. FZC Calculation Results

3.2 Fresnel Zone Clearance Parameter Analysis

Based on the obtained data, it can be observed that the greater the distance between the transmitter and receiver points, the larger the FZC value. This is because FZC calculation incorporates distance as a key parameter. Although not analyzed in detail, the FZC value serves as a reference for ensuring optimal radio device placement to maintain clear LoS conditions.

3.3 Free Space Loss Parameters Analysis

This calculation aims to determine the loss between the transmitting and receiving points. This analysis is essential because radio wave propagation in free space can attenuate power along its path, potentially reducing the power received at the receiver. This FSL analysis is illustrated in Fig. 11.

Based on the obtained data, the greater the distance between the transmitter and receiver points, the higher the FSL value. This is because FSL, similar to FZC, incorporates distance as a key parameter in its calculation. The FSL value can serve as a reference for radio device installation, as it indicates the magnitude of signal loss between the two points.

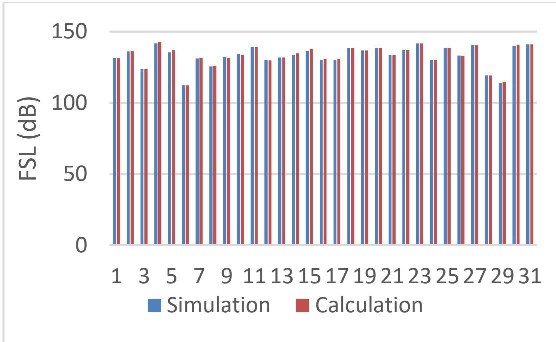

Fig. 11. FSL Analysis Results

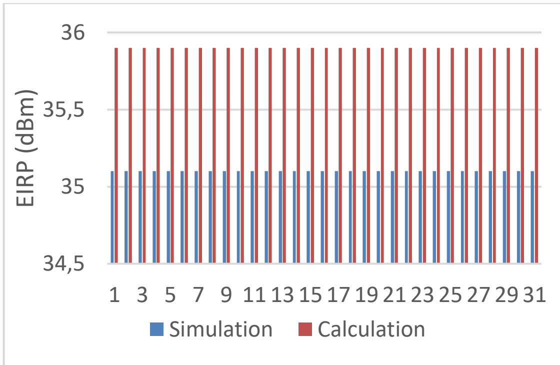

Fig. 12. EIRP Analysis Results

3.4 Effective Isotropic Radiated Power Parameters Analysis

This calculation aims to determine the signal strength transmitted from the transmitter side. The EIRP represents the signal strength obtained by summing the transmitter power, antenna gain, and losses incurred during signal transmission. This EIRP analysis is illustrated in Fig. 12.

Based on obtained data, the simulation result show a value of 35.1 dBm, while the calculated result is 35.95 dBm. In this EIRP calculation, it is assumed that the cable loss is 1 dB and the connector loss 0.05 dBm. These values are referenced from previous studies cited in bibliography numbers 6 and 7. Furthermore, the transmission power for the two types of device varies according to their respective specifications and performance. The EIRP calculation results comply with the regulatory limit set by the Ministry of Communication and Information, which specifies a maximum value of 36 dBm.

Table 14. Comparison Table Results

No	Distance (km)	Device (Cambium eForce)	FZC (m)	FSL (dB)		EIRP (dBm)		RSL (dBm)		SOM (dBm)		Availability (%)	Bandwidth (Mbps)
			Cal	Cal	Sim	Cal	Sim	Cal	Sim	Cal	Sim	Sim	Sim
1.	15.2	200	11.2	131.4	131.4	35.1	35.9	71	70.4	14.5	21.6	99.9	42.57
2.	26.7	200	14.9	136.1	136.2	35.1	35.9	76	75.3	7.1	16.7	99.9	25.39
3.	6.3	200	7.2	123.7	123.7	35.1	35.9	64	62.7	27.4	29.3	99.9	65.16
4.	57.1	300 CSM	21.7	141.7	142.8	35.1	35.9	78	76.8	9.1	12.2	99.9	27.14
5.	29	200	15.5	135.4	137.0	35.1	35.9	78	76.0	10.6	16.0	99.9	20.96
6.	1.7	200	3.8	112.2	112.3	35.1	35.9	52	51.3	35.5	40.7	99.9	65.92
7.	15.6	200	11.4	131.1	131.6	35.1	35.9	72	70.6	17.3	21.4	99.9	41.67
8.	8.2	200	8.3	125.5	126.0	35.1	35.9	66	65.0	21.8	27.0	99.9	61.55
9.	15.3	200	11.3	132.2	131.4	35.1	35.9	72	70.4	16.1	21.6	99.9	42.27
10.	19.8	200	12.8	134.3	133.7	35.1	35.9	74	72.7	15.8	19.3	99.9	35.71
11.	38.1	200	17.8	139.2	139.3	35.1	35.9	79	78.3	6.6	13.7	99.9	17.01
12.	12.9	200	10.3	130.1	129.9	35.1	35.9	70	68.9	17.8	23.1	99.9	50.1
13.	16.1	200	11.5	131.9	131.9	35.1	35.9	72	70.9	11.5	21.1	99.9	40.38
14.	22.4	200	13.6	133.6	134.7	35.1	35.9	75	73.7	13.1	18.3	99.9	30.58
15.	31.8	200	16.2	136.3	137.8	35.1	35.9	78	76.8	9.6	15.2	99.9	21.09
16.	14.5	200	11	130.1	131.0	35.1	35.9	71	70.0	16.7	22.0	99.9	44.46
17.	14.4	200	10.9	130.2	130.9	35.1	35.9	71	69.9	16.3	22.1	99.9	44.75
18.	34.0	200	16.8	138.4	138.3	35.1	35.9	79	77.4	8.2	14.6	99.9	19.66
19.	28.4	200	15.3	136.8	136.8	35.1	35.9	77	75.8	10.5	16.2	99.9	23.4
20.	35.4	200	17.1	138.7	138.7	35.1	35.9	79	77.7	8.4	14.3	99.9	18.37
21.	19.4	200	12.7	133.5	133.5	35.1	35.9	74	72.5	14.8	19.5	99.9	36.51
22.	28.8	200	15.4	137.1	136.9	35.1	35.9	77	75.9	9.6	16.1	99.9	23.02
23.	50.8	200	20.5	141.8	141.8	35.1	35.9	80	80.8	6.7	11.2	99.9	7.45
24.	13.2	200	10.5	130.1	130.2	35.1	35.9	70	69.2	17.1	22.8	99.9	48.05
25.	34.6	300 CSM	16.9	138.4	138.5	35.1	35.9	76	72.5	14.5	16.5	99.9	43.55
26.	18.3	300 CSM	12.3	133.2	133.0	35.1	35.9	70	67.0	19.6	22.0	99.9	82.62
27.	43.3	300 CSM	18.9	140.5	140.5	35.1	35.9	78	74.5	12.9	14.5	99.9	22.3
28.	3.8	300 CSM	5.6	119.2	119.3	35.1	35.9	56	53.3	33.2	35.7	99.9	79.06
29.	2.2	300 CSM	4.3	113.8	114.9	35.1	35.9	52	48.9	38.3	40.1	99.9	79.06
30.	45.1	300 CSM	19.3	139.9	140.8	35.1	35.9	78	74.8	11.4	14.2	99.9	19.87
31.	46.6	300 CSM	19.7	141.1	141.1	35.1	35.9	78	75.1	10.7	13.9	99.9	19.16

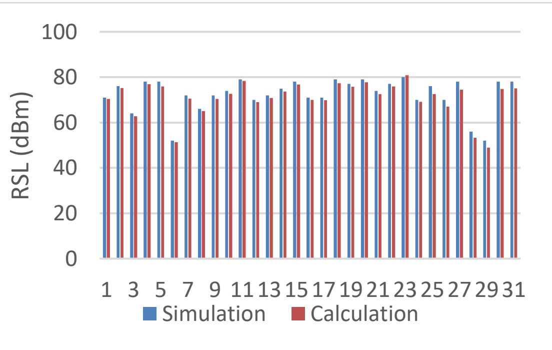

Fig. 13. RSL Analysis Results

3.6 System Operating Margin Parameters Analysis

This calulation aims to determine the power level that must be reserved at the receiving point based on the obtained RSL. In the calculation, the receiver sensitivity value for the Cambium eForce 200 radio device is -92 dBm, while for the Cambium eForce 300 CSM, it is -89 dBm. These values are based on the specifications of each device. This SOM analysis is illustrated in Fig. 14.

Based on the obtained data, the SOM values fall into the categories of marginal, good, and excellent, with two data points classified as poor. These classifications refer to the TIPHON standard as outlined in the theory section. A poor SOM value can result in an unstable signal. Such poor SOM values may arise due to an RSL value that is close to the fair or suboptimal category. Since the RSL value directly affects the resulting SOM value, fluctuations in RSL can impact overall system stability. However, for some companies, this is not a major concern because the radio communication system is not the sole communication method—it is often integrated with other systems, such as fiber optic communication.

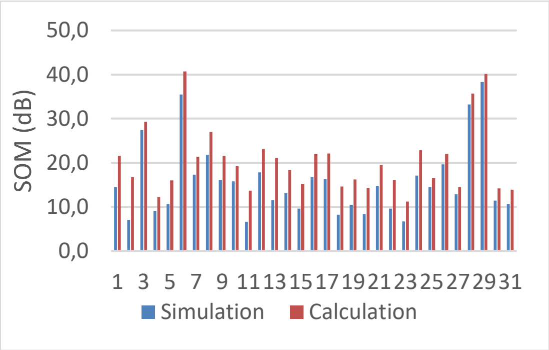

Fig. 14. SOM Analysis Results

The result obtained from this simulation do not necessarily determine whether the radio communication system will function properly. A direct field survey is required to assess real-world interference or obstacles. Nevertheless, the simulation results can serve as a reference or recommendation for development of a radio communication system.

3.7 Comparison Analysis of Simulation Value and Calculation Values

A comparative analysis was conducted between the simulation values obtained using Link Planner and the theoretical calculation values derived from formulas and equations for each parameter. Comparison results between Link Planner simulation and manual calculations are presented in Table 14.

Based on the comparative analysis between the simulation results from Link Planner and the manual calculation results, the percentage difference is relatively small. This indicates that the obtain values are consistent, as the difference between the simulation and manual calculation result is not significant.

4. Conclusions

Link budget calculation is essential prior to installing a wireless communication system, as it ensures the appropriate selection of radio devices and antenna height. For distances below 30 km, Cambium eForce 200 is suitable, while Cambium eForce 300 Connectorized is recommended for longer distances. Key parameters such as FZC and FSL depend on the transmitter-receiver distance. Among 31 tested customers, all met the EIRP standard, with 87% having good RSL values, and 13% categorized as very good. Additionally, 94% met the SOM standard, while 6% were classified as poor. A comparison between Link Planner and manual calculations showed consistent result with minimal differences. The research approach is validated and shows promise for practical implementation; however, to enhance validity, a field survey, use of alternative simulation software, and testing of various radio devices are recommended for a more comprehensive analysis.

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Additional Information