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Long Range (LoRa) Network Planning Analysis at 920-923 MHz Frequency for Region Palabuhanratu

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***Abstract*—LoRa technology in Indonesia is currently in the development stage to accelerate the digitalization of cheap and reliable connectivity-based smart utilities. Palabuhanratu is a potential area for LoRa network infrastructure development due to the density of end devices in Palabuhanratu which causes the process of sending data on a network to be hampered. The parameters used in the LPWA software simulation include Signal Level, Noise to Interference Carrier Level and Link Budget.**

This research method analyzes the simulation results on Signal Level, Noise to Interference Carrier Level and Link Budget as parameters for the construction of LoRa network infrastructure at a frequency of 920-923 MHz in Palabuhanratu. The research is divided into two planning stages. The first planning stage is the calculation of capacity and calculation of coverage. The second planning stage is simulation using Atoll Low Power Wide Area software.

The results of the simulation analysis obtained in this study are that there are 10 gateway capacities using the Atoll application software. The average values generated by the simulation parameters include the Signal Level, which is -64.06 dBm with the ”good” category based on the KPI standard, which is more than - 80 dBm and the Noise to Interference Carrier Level parameter of 27.71 dB which is included in the ”excellent” category, namely greater than 12 dBm in KPI standardization, and the resulting path loss is -107.74 dBm at a cell radius of 1.261 km.

Keywords*— LoRa Network, Capacity Planning, Coverage Planning, Signal Level, Level Carrier Noise to Interference, Link Budget.

I. Introduction

The development of the Internet of Things in Indonesia is increasingly rapid, including new innovations, namely Long Range Technology. In LoRa Technology, the network architecture used is Low Power Area Network (LoRaWAN). This LoRa network works in the 920 to 923 MHz frequency band in accordance with the license from the Ministry of Communication and Information Technology in Indonesia. The modulation used for LoRa is Chirp Spread Spectrum modulation which can allow data exchange on the sending and receiving sides even though it is in a long range [1]. The battery power used in the LoRa Network is durable because the power consumed only ranges from 13 Ma to 15 Ma, so the battery can last up to 20 years of service life[2].

Previous research has been done by Destalia Sallyna, based on the calculation of SF 7 to SF 12, the best bit rate results are at SF 7 of 5.47 kbps and coding rate of 4/5 of 0.8. In the capacity planning scenario, there are 98 gateway units for SF 7 and 2,437 for SF 12. In the coverage planning scenario, there are 12 gateways for SF 7 and 33 gateways for SF 12. Based on the Key Performance Index (KPI), the average simulation result is "Good" with a signal level value of -57.31 dBm and a level value (C/I+N) of -70.41 dBm [3].

This final project aims to develop a LoRa network in the Palabuhanratu area as an implementation of Smart City in order to optimize network performance for the implementation of the Internet of Things in the next five years. Optimization targets that have been simulated are Signal Level analysis which plays a role in measuring the signal indication level captured by the transmitter, Link Budget analysis aims to predict path loss and cell radius on gateway performance and level (C/I+N) which aims to predict noise level undesirable in LoRa network planning.

II. Theorical Background

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A. *Long Range Technology*

LoRa network is a modulation format created by semtech. The transmission modulation used is spread spectrum[2]. LoRaWAN (Long Range Wide Area Network) is a wireless telecommunication network used for Internet of Things devices. In this research, LoRaWAN is used as a data transmission medium with a sub urban area scenario in Palabuhanratu[4]. The following are the specification parameters for the LoRa network shown in table 1.

Table 1. *Specification of LoRa Network*

LoRa Parameters	Explanations
Work Frequency	433-, 868-, 915-, 923-MHz
Data Transmission Speed	0.3 -50 kbps
LoRa Modulation	Chirp Spread Spectrum (CSS)
Bandwidth Channel	125-, 250-, 500-kHz
MAC options	Class A (baseline), Class B (beacon), Class C (Continuous)
Data Rate	290 kbps – 50 kbps
Max Output Power	20 dBm
Power Efficiency	Very High

B. *LoRaWAN Architecture*

LoRaWAN architecture using a topology star for each class. The process of sending LoRaWAN data is as follows in figure 1.

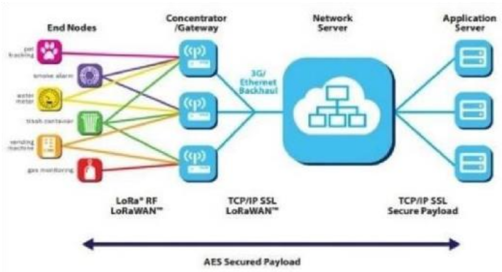


Figure 1. *LoRaWAN Architecture[7].*

The first step, from the device is received by several gateways with the range of LoRaWAN. Each gateway continues to send packets that have been received by the device to a network server available in the cloud via backhaul. Examples are Ethernet, WiFi, Satellite and Cellular. Next, the network server manages the network and filters packets received from the gateway and then does ACK scheduling (acknowledgments) and adjustments to the adaptive data rate[7].

C. LoRaWAN Modulation Parameters

parameters on LoRaWAN modulation include Bandwidth, Spreading Factor, Coding Rate and Bit Rate[3]. This modulation parameter plays a role in the specification and calculation of the LoRaWAN network.

D. Bandwidth

Bandwidth is the width of the frequency used to modulate the signal information. Bandwidth also plays a role in representing the chip rate of the lora signal modulation [16]. Bandwidth for LoRa is in the range of 125 kHz to 500 kHz. In this study, a bandwidth of 125 KHz was used to be applied to the Palabuhanratu area..

E. Spreading Factor

Spreading Factor is the number of chips contained in a symbol[3]. The Spreading Factor value in LoRa consists of a Spreading Factor of 7 to a Spreading Factor of 12. Each number in the Spreading Factor represents the chips that are modulated per symbol. Spreading Factor uses the Code Division Multiple Access (CDMA) technique as a solution to avoid data collisions [10]. The table on the spreading factor for a bandwidth of 125 KHz is shown as follows.

Table 2. *Spreadung Factor for Bandwidth 125 KHz*10].

SF (125KHz)	Range (km)
SF7	2
SF8	4
SF9	6
SF10	8
SF11	11
SF12	14

Based on table 2.1 above shows the comparison of the distance in (km) with the spreading factor at a bandwidth of 125 KHz. The change in distance is directly proportional to the resulting spreading factor, the greater the value of the spreading factor, the further the distance generated, but if the greater the distance setting on the spreading factor is used, it will increase the sensitivity of the receiver and can slow down data transmission [10].

In this research, using a spreading factor of 7 with a coding rate of 4/5 based on a LoRa network simulation scenario, because LoRa requires a high bit rate to handle PER (Packet Error Rate) in order to facilitate the data transmission process. PER is determined by the bit rate in SF, the largest bit rate value is obtained at SF 7 and CR 4/5 with a value of 5,46875 kbps.

F. Coding Rate

Coding Rate is a parameter that works to increase Forward Error Correction (FEC). The redundancy in the coding rate makes the LoRa signal more resistant to short-term interference. The value of the coding rate needs to be adjusted to the condition of the channel used, if there is too much interference, there will be an increase in the coding rate at the existing transmission time [16]. The formula for coding rate is shown as follows.

$$cr = \frac{4}{4+n}$$

Description: n is the value of 1,2,3 and 4.

G. Bit Rate

The formula for coding rate is shown as follows Bit rate is the rate of change of bits per unit time [9]. The bit rate in LoRa is binary, namely 0 or 1[3]. The formula for the bit rate is shown as follows:

$$Rb = SF \left(\frac{1}{\frac{2^{SF}}{BW}} \right) (CR)$$

Description :
Rb : Bit Rate (bits/second)
SF : Spreading Factor
BW : Bandwidth (kHz)
CR : Coding Rate

H. LoRa Network Dimensioning Stage

Dimensioning is part of the detailed planning and optimization process, which provides detailed planning for network estimates. LoRa dimensioning is divided into two parts, namely capacity and coverage[11].

- ***Capacity Planning***

Capacity planning functions to calculate gateway capacity, cell coverage and cell radius based on cellular network subscribers available in the Palabuhanratu area for electricity, water and gas services as shown in table 2 below.

Table 3. *Calculation of Capacity Parameters*

Description	Electric	Water	Gas	Unit
Total Network User Throughput	264,856	428,723	295,313	Kbps
Total Site Calculation (DL)	8,021	13,892	8,943	Site
Total Site Calculation (UL)	6,683	11,575	7,451	Site
Number of User (DL)	78,816	45,506	70,687	User
Number of User (UL)	94,593	54,616	84,838	User
Cell Coverage (DL)	5,286	3,052	4,740	km
Cell Coverage (UL)	6,344	3,663	5,689	km
Cell Radius Omni (DL)	1,425	1,083	1,350	km
Cell Radius Omni (UL)	1,562	1,186	1,479	km

- ***Coverage Planning***

The link budget calculation in coverage planning determines the final value of MAPL (Maximum Allowable Path Loss). Some of the parameters for the calculation of the link budget are shown in table 3.

Table 4. *Calculation of Coverage Parameters*

Spreading Factor	RSSI (dB)	EIRP Gateway (dBm)	EIRP End Device (dBm)	SNR (dB)	MAPL DOWNLINK (dB)	MAPL UPLINK (dB)
7	-121,531	18	9,67	-7,5	139,031	131,201
8	-124,031	18	9,67	-10	142,031	133,701
9	-126,531	18	9,67	-12,5	144,531	136,201
10	-129,031	18	9,67	-15	147,031	138,701
11	-131,531	18	9,67	-17,5	149,531	141,201
12	-134,031	18	9,67	-20	152,031	143,701

I. *Key Performance Indicator (KPI)*

Key Performance Indicator (KPI) is an indicator from an operator to measure the quality of the network performance. Some of the parameters are:

- *Reference Signal Received Power (RSRP)* RSRP is The average power value received by the user. The following are the signal level criteria for KPI standardization, which are shown in table 4.

Table 5. *KPI of RSRP*

Category	Range RSRP Value (dBm)
Good	-60 to -80
Normal	-81 to -110
Bad	-110 to -130

- *Carrier to Interference Noise Ratio (CINR)*

CINR is the ratio of the signal power which has been modulated with the sum of noise and interference. CINR is often used as a parameter to measure the Quality of Service of a signal and is expressed in dB units. KPI of CINR parameter values can be seen in the table 5.

Table 6. *KPI of CINR*

No.	Categories	Values (dBm)
1	Good	≥16 *to* 30
2	Normal	≥1 *to* < 16
3	Poor	≥-10 *to* < 1

J. *Geographical Conditions of Palabuhanratu*

Palabuhanratu is an area with a geographical location of 726' latitude and 10739' east longitude. Palabuhanratu has an area of about 42.4 km. Topographically, Palabuhanratu sub-district is located at an altitude of 0 to 800 m above sea level, for the agricultural area is 6793.00 Ha and non-agricultural area is 147.00 Ha. The boundaries of Palabuhanratu, Sukabumi Regency, in the north are directly bordered by the Cikakak sub-district, in the south by the Simpenan sub-district, in the east by the Bantargadung sub-district and in the west by the Indonesian Ocean[14].

Figure 2. *Geographical Conditions of Palabuhanratu* [7].

K. *LoRa Network Model and Design*

LoRa network design model is carried out on Atoll software with a Low Power Wide Area template at a frequency of 920-923 MHz. The design of the LoRa network implementation in the context of the formation of a smart city in Palabuhanratu is shown in Figure 2:

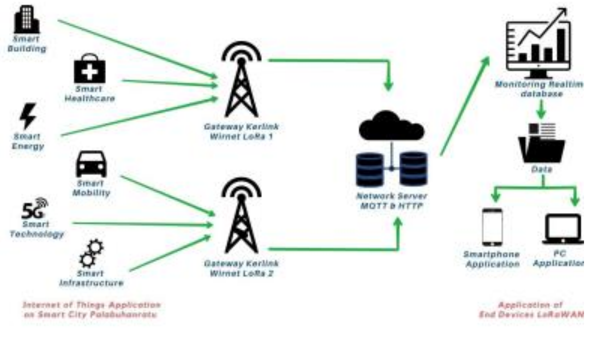


Figure 3. *LoRa Network Model and Design*

The LoRa planning stage begins with data from smart city devices such as smart buildings, smart healthcare, smart energy, smart mobility, smart technology and smart infrastructure that are received by two types of gateways, namely gateway kerlink wirenet stations within LoRaWAN coverage, each gateway continues sending packets received. by a network server with the cloud via backhaul using a cellular data plan or a WiFi network.

The network server has HTTP and MQTT protocols that regulate network traffic in CDMA so that data collisions do not occur. Network Server also plays a role in filtering packets received from the Kerlink gateway so that data can be monitored. After the data monitoring process is complete, data is sent from the server to the client via a smartphone or personal computer connected to the internet network.

III. Lora System

This research focuses on improving the LoRa network at a frequency 923 MHz in Palabuhanratu Region. In the LoRa Network design system, a flow diagram is required that aims to form a systematic network arrangement. The flow diagram for LoRaWAN network design is shown in figure 4.

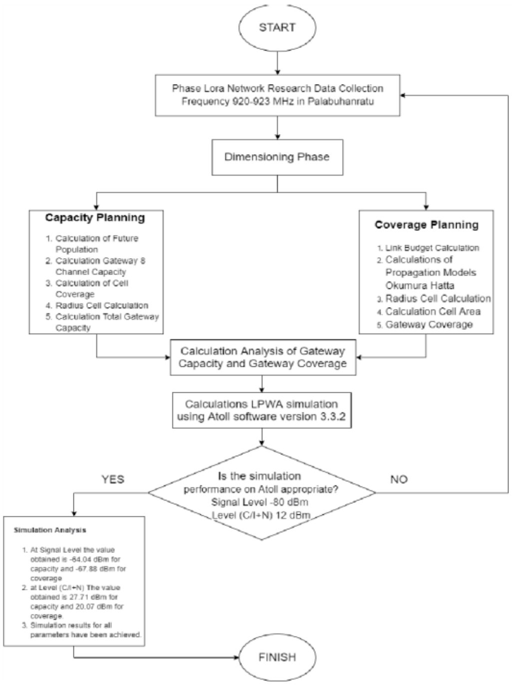


Figure 4. *Flowchart of The Research*

1. Data searches or literature studies play a role in finding some information related to the parameters and specifications of the LoRa Network, population data, geographic conditions of the Palabuhanratu area and the dominant market sell operator used in Palabuhanratu District in the number of data packages used per day. LoRa network analysis is divided into calculation and simulation parameters. The calculation parameters include bandwidth, spreading factor and coding rate. Meanwhile, the simulation parameters include coverage and capacity planning which will later be simulated on the Atoll LPWA software, using each gateway which will be calculated at the LoRa parameter calculation stage.
2. The next stage is dimensioning. The first dimensioning stage is capacity which aims to determine the final value of LoRa on the downlink and uplink. The parameters generated by capacity planning include the total user of dimensioning and the number of gateway capacity. The second dimensioning stage is coverage planning which aims to determine values based on cell size. In dimensioning coverage, uplink and downlink values are influenced by eNodeB height, user equipment and link budget to get the gateway coverage value.
3. The calculation phase consists of capacity planning and coverage planning. Capacity planning is a method that consists of calculating cellular network subscribers, calculating 8 channel gateways, calculating cell coverage and calculating cell radius. Coverage planning is a method that consists of link budget calculations such as SNR, EIRP, MAPL to obtain cell radius values using the Okumura Hatta propagation model, cell area calculations and gateway coverage calculations.
4. After calculating each coverage and capacity parameter, the number of gateways is obtained based on a spreading factor of 7 to a spreading of 27 factor 12. In the capacity of the largest number of gateways, namely spreading factor 12, there are 258 gateways for a coding rate of 4/5. The smallest number of gateways is a spreading factor of 7 as many as 10 gateways at a coding rate of 4/5. In coverage, the largest number of gateways is spreading factor 7 as many as 3 gateways for all coding rates. The smallest number of gateways is spreading factor 11 and 12 as much as 1 gateway for the entire coding rate.
5. Atoll software simulation. The data that is simulated in the software is obtained from the largest number of gateways between coverage planning and capacity planning. Simulation on the Atoll software is carried out to obtain the value of the analysis parameters, namely signal level, level (C/I+N) and link budget.
6. The simulation results on the LPWA software include Signal Level of -64.04 dBm, Carrier Noise to Interference Level of 27.71 dBm and parameters on the link budget such as path loss of 107.74 dB, reception gain 0 dB, EIRP power 20 dBm and level indication of the power received as far as -87.78 dBm for capacity planning. At coverage planning Signal Level is -67.45 dBm, Carrier Noise to Interference Level is 18.27 dBm and parameters on the link budget such as pathloss is 117.58 dB, reception gain is 0 dB, EIRP power is 20 dBm and the level of power indication received as far as -97.58 dBm.

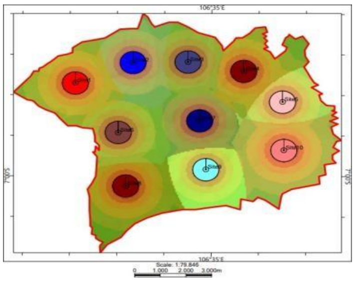
IV. Result and Analysisi

A. *Improvement Simulation Using Atoll*

LoRa In this research conducted a simulation software Atoll dimensioning includes two parameters, namely the capacity and coverage. The optimization carried out is signal level, CINR and link budget.

B. *Signal Level Capacity*

In Figure 5, the sites obtained at gateway capacity are 10 sites to be placed in Palabuhanratu. Sites on the LPWA are installed randomly at an estimated cell radius 1.261 km for each gateway.



Description :

		Min	Max	Legend
1		-70		Best Signal Level (dBm) >=-70
2		-75		Best Signal Level (dBm) >=-75
3		-80		Best Signal Level (dBm) >=-80
4		-85		Best Signal Level (dBm) >=-85
5		-90		Best Signal Level (dBm) >=-90
6		-95		Best Signal Level (dBm) >=-95
7		-100		Best Signal Level (dBm) >=-100
8		-105		Best Signal Level (dBm) >=-105
9		-110		Best Signal Level (dBm) >=-110
10		-115		Best Signal Level (dBm) >=-115
11		-120		Best Signal Level (dBm) >=-120

Figure 5. *Signal Level Capacity*

Indicators at the signal level simulation are divided into 3 colors, the red color is a good condition with a value of -60 dBm to -75 dBm, the yellow color goes into normal conditions with a value of -80 dBm to -90 dBm and the green color goes into a bad condition with a value of -100 dBm to 90 dBm

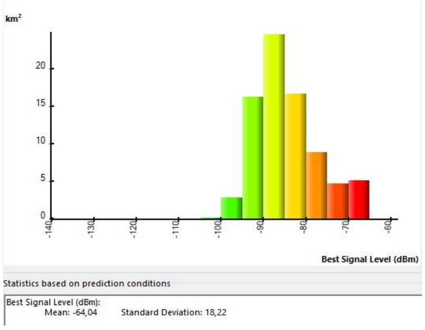
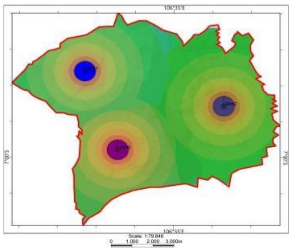


Figure 6. *Histogram RSRP Capacity*

In Figure 6, the vertical line shows the area served in km while the horizontal line shows the value of the signal level in units (dBm). Good capacity signal level is -70 dBm at a distance of 5.09 km. The signal is not good at the value of 100 dBm with a distance of 2.76 km. The closer the LoRa Transmitter is 5.09 km to the gateway, the stronger the signal received is -64.04 dBm by the user. However, if the distance is 2.76 km from LoRa, the site get worse, the stronger the dBm signal received is -100 dBm by the user.

C. *Signal Level Caverage*

In Figure 7, the sites obtained at gateway capacity are 3 sites to be placed in Palabuhanratu. Sites on the LPWA are installed randomly at an estimated cell radius 2.376 km for each gateway.



Description :

		Min	Max	Legend
1		-70		Best Signal Level (dBm) >=-70
2		-75		Best Signal Level (dBm) >=-75
3		-80		Best Signal Level (dBm) >=-80
4		-85		Best Signal Level (dBm) >=-85
5		-90		Best Signal Level (dBm) >=-90
6		-95		Best Signal Level (dBm) >=-95
7		-100		Best Signal Level (dBm) >=-100
8		-105		Best Signal Level (dBm) >=-105
9		-110		Best Signal Level (dBm) >=-110
10		-115		Best Signal Level (dBm) >=-115
11		-120		Best Signal Level (dBm) >=-120

Figure 7. *Signal Level Coverage*

The signal level indicator in the simulation is divided into 3 colors. The red color is a good condition with a value of 80 dBm to -60 dBm, the yellow color goes into normal conditions with a value of -90 dBm to -81 dBm and the green color goes into a bad condition with a value of -115 dBm to 91 dBm.

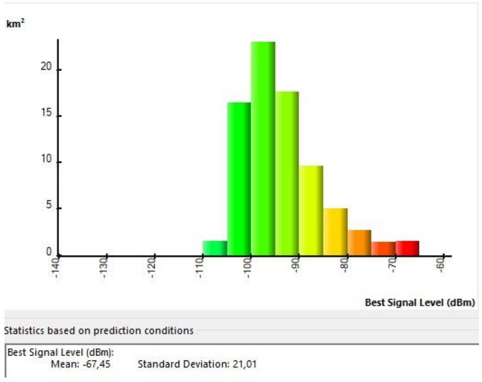


Figure 8. *Histogram RSRP Coverage*

The vertical line shows the area served in km while the horizontal line shows the value of the signal level in units (dBm). A good coverage signal level is -70 dBm at a distance of 1.53 km, while a poor signal is at -100 dBm at a distance of 22.9 km. Based on the signal level capacity simulation using the Atoll LPWA software, the average value of the signal level histogram distribution is -67.45 dBm and the standard deviation is 21.01. The result of the signal level has met the KPI (Key Performance Index) standard because it exceeds -80 dBm with a "good" signal level description.

D. *Level CINR Capacity*

Figure 9 explains the number of gateway capacities with a value of 10 units gateway on the carrier noise to interference level or the signal ratio carrier with interference at gateway.

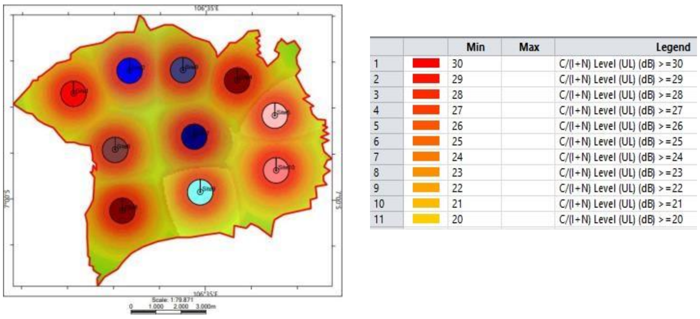


Figure 9. *CINR of Capacity.*

If the signal level is higher, the C/I+N Level obtained also be higher.

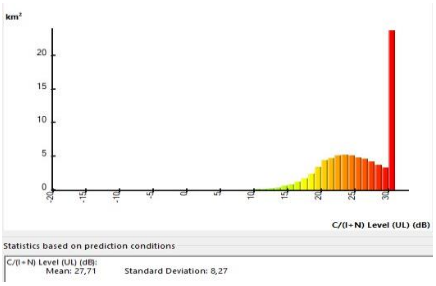
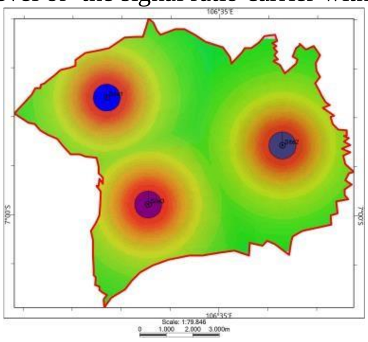


Figure 10. *Histogram CINR Capacity*

In this simulation, the average value obtained is 27.71 dB, which means that the signal quality in the planning area is good or normal. Capacity prediction is done to see the number of users served by eNodeB, downlink and uplink.

E. Level CINR Coverage

Figure 11 explains the number of gateway capacities with a value of 10 units gateway on the carrier noise to interference level or the signal ratio carrier with interference at gateway.



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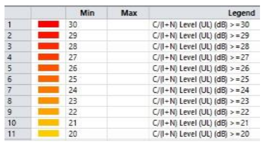

Figure 11. *CINR of Coverage*

The signal level quality simulation performed is Level CINR. The vertical line shows the area served in (km) while the horizontal like shows the value of the signal level units (dBm).

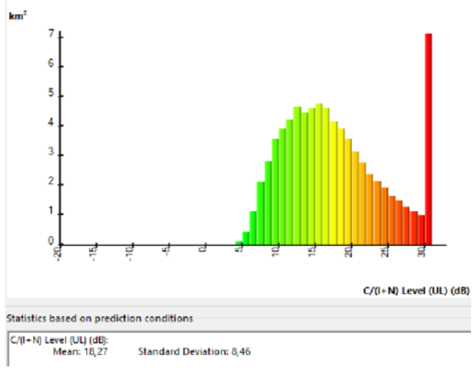

Figure 12. *Histogram CINR Coverage*

A good carrier to interference noise ratio level is 34 dBm at a distance of 6.78 km, while the CINR value is not good at 5 dBm at a distance of 0.37 km. In this simulation, the average value obtained is 18.27 dB, which means that the signal quality in the planning area is good or normal.

V. Conclusions

Recapitulation Result Analysis

The following is a recapitulation table of simulation results and calculation analysis on the LoRa network which is shown in table 6.

Table 6. *Recapitulation for Result and Simulation*

Parameter	Capacity Planning	Coverage Planning
Gateway	10 unit	3 unit
Signal Level	-64,04 dBm	-67,45 dBm
Level (C/I+N)	27,71 dBm	18,27 dBm
Radius sel	1,261 km	2,285 km
Pathloss	107,74 dB	117,58 dB

The results of the simulation recapitulation based on table 4 are 10 gateway units on LoRa which cover the entire area of Palabuhanratu. The average values obtained include signal level, which is -64.04 dBm, signal level coverage to noise interference of 27.71 dBm and link budget such as path loss of 107.74 dB, cell radius of 1.261 km, reception gain of 0 dB, EIRP power is 20 dBm and the signal level indication for receiving power is -87.78 dBm.

While the recapitulation of the simulation results on coverage planning gets 3 gateway units, signal level is -67.45 dBm, signal level coverage to noise interference is 18.27 dBm with link budget parameters such as path loss of 117.58 dB, cell radius of 2,376 km, reception gain is 0 dB, EIRP power is 20 dBm and the signal level indication for receiving power is -96.97 dBm. The results of the simulation analysis and overall calculations that have been carried out on capacity planning meet the requirements for the Palabuhanratu area until 2025.

ACKNOLEDGMENTI

LoRa network planning in this Research uses several parameters such as bandwidth 125kHz, frequency 923 Mhz, spreading factor 7, coding rate 4/5, RSSI -121.531 dBm, and SNR -7.5 dB is using calculations on capacity planning which produces a gateway of 10 units that can cover the entire Palabuhanratu area by 2025.

This LoRa network planning only takes 12% of the total electricity, water, and gas customers in Palabuhanratu based on data from the Central Statistics Agency of Sukabumi Regency. The number of users of an end device that is predicted in 2025 is 623,193 users. The results of this network planning analysis are the farthest transmit power distance of 2.376 km, RSSI value of -121.531 dBm, SNR value of -7.5 dB, Path Loss value of -117.58 dB, using Tx power of 20 dBm and EIRP of 20 dBm. It is estimated that it can produce good signal quality if it is implemented in Palabuhanratu in 2025.

REFERENCESI

[1] Alston Lloyed Emmanuel, Receive Power Calculation and LoRa Receiver Sensitivity "Optimization of Spreading Factor Distribution in High Density LoRa Networks," pp. 2-4, 2020.

[2] Makadia, "What are differentiations between Bluetooth Beacon, LPWAN, NB-IoT and Zigbee?". Quora Company, 23 September 2019.[Online]. Available:https://www.quora.com/WhatarethedifferentiationsbetweenBluetoothBeacon-LPWAN-NB-IoT-and-Zigbee. [Accessed 16 Oktober 2020].

[3] Sallyna. Destalia, "Parameter Spreading Factor sangat berpengaruh terhadap kinerja dari LoRa" *Perancangan Jaringan Long Range (LoRa)Pada Frekuensi 920-923 di Kota Bandung,* pp 934-935.

[4] Semtech "What are LoRa and LoRaWAN Module?" [Online].Available:https://loradevelopers.semtech.com /library/tech-papers-and-guides/loraand-lorawan/. [Accessed 2020 Oktober 11].

[5] Indonesia,Telkom. "LoRaWAN Downlink Tutorial". Antares, [Online]. Available: https://antares.id/lora-downlink-tutorial.html. [Accessed 11 Oktober 2020].

[6] Haganta. Yeska, "Sejarah Internet of Things," Internet of Things (IoT), pp. 4-5.

[7] Yunus. Muhammad, "LoRaWAN dan LoRa MAC Layers". Medium, 17 Juni 2018 [Online] Available: https:yunusmuhammad007 medium.com/3-lorawan-lora-mac-layer-bb2778244ba7. [Accessed 7 Oktober 2020].

[8] E. M. Shop, "Ori SNI RAK831 LoRa/LoRaWAN Gateway Module 433/470/868/923MHZ". Tokopedia, 25 Agustus 2020. [Online]. Available:https://www.tokopedia.com/elektromurah.shop/origatewaymodule-433470- 868-915mhz. [Accessed 10 Oktober 2020].

[9] N. B. A. Pinky Devi Dama Istianti, Sistem LoRa Antares "Analisis Performansi Jaringan Akses LPWAN LoRa Antares," p. 22023, 2020.

[10] Setiawan. Perdana Irfan, "Parameter dalam modulasi LoRa" Analisis Parameter LoRa dalam Lingkungan Indoor , pp. 7.

[11] M. D. R. M. I. M. Ir.Uke Kurniawan Usman, "Coverage Planning dan Capacity Planning" Perancangan Coverage dan Capacity Jaringan Long Term Evolution (LTE) Frekuensi 700MHz Pada Tol Cipularang (CikampekPurwakartaPadalarang) Menggunakan Metode Physical Sell Identity (PCI).pp 1-2, 2015.

[12] M. E.S. Bengawan Alfaresi and F. Ardianto,"Model Propagasi Okumura Hatta" nalisa Model Propagasi Okumura-Hatta dan CostHatta pada Komunikasi Jaringan Wireless 4G LTE, vol. 1, pp. 3334.

[13] Forsk, "Atoll Modular Architecture". Forsk Company, [Online]. Available:https://www.forsk.com/atoll-modular-architecture. [Accessed 11 Oktober 2020].

[14] D. M. Bambang Saeturahman and R. Rosmayanti, Kecamatan Pelabuhanratu Dalam Angka 2020. Sukabumi, Badan Pusat Statistik Kabupaten Sukabumi, 2020, pp. 1-17.

[15] A. D. Irawan, "Effective Isotropic Radiated Power," Analisis Kualitas Daya Pancar Antena Tongyu TDQ-182020DE-65F Pada BTS Flexi Multiradio (FMR) Nokia Siemens Network (NSN), pp. 5-7, 2013.

[16] F. P. W. Dwi Giovanni and I. M. Ghani, Perancangan Jaringan LTE Radio Link Budget, Institut Teknologi Telkom Purwokerto.