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LoRaWAN Network Planning at Frequency 920-923 MHz for Electric Smart Meter: Study Case in Indonesia Industrial Estate

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Abstract—This paper plans a LoRaWAN network for smart meters in Karawang Industrial Estate, Indonesia's largest industrial estate. To measure and recognize electricity use in a place immediately, we use a tool called a smart meter, which is part of the Internet of Things (IoT), to provide control and optimization of electricity. Smart meters will operate using LoRaWAN network connectivity as a LoRaWAN communication protocol that supports IoT use at a frequency of 920-923 MHz using coverage planning and capacity planning using Forsk Atoll 3.3.2 simulation software. The parameters used in this study are Spreading Factor (SF) 7, Code Rate (CR) 4/5, Bandwidth 125 kHz, Signal to Noise Ratio (SNR), and Reference Signal Received Power (RSRP). We use them to obtain the number of gateways needed to optimize the scope of gateways for sending electricity monitoring data to Karawang Industrial Estate and knowing the value generated from the parameters above. The simulation of LoRaWAN planning resulted in RSRP with a mean of -77.94 dBm and a standard deviation of 8.27 dBm. The SNR result has a mean of 13.14 dB with a standard deviation of 9.68 dB. The last parameter is that throughput ranges of 4-6 kbps with a mean of 5.47 kbps. The result of this planning produces RSRP, SNR, and Throughput parameter values in good condition to be applied to the application of smart metering in Karawang Industrial Estate.

Index Terms—LoRaWAN, spreading factor, gateway, smart meter, karawang industrial estate, IoT

I. INTRODUCTION

The rapid development of technology has made technology an important need for society. The use of technology is now not limited only to the world of telecommunications. It was used widely in industry, agriculture, health, security, and other fields. In the era of globalization, the internet will synergize with electronic devices to help human activities [1]. The development of the Internet of Things (IoT) used to support human activities to be more effective and efficient to minimize human beings' work. IoT applications are used to monitor aspects such as the energy needed in everyday life, such as electrical energy.

Electrical energy is one of the energy sources often used in daily life in Fig. 1, both for lighting, household

appliances, industrial equipment, hospitals, and other uses in large quantities.

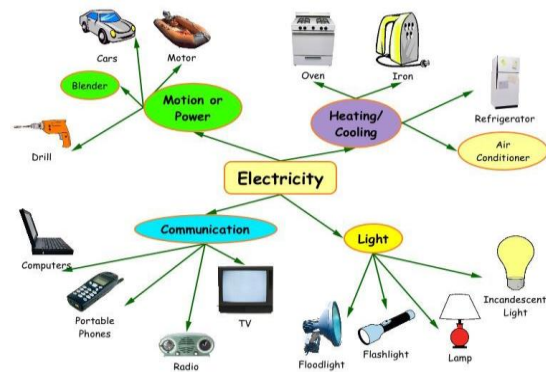


Fig. 1. Electrical energy in daily life [2]

The International Energy Agency has reported that energy demand worldwide grew by 2.3% in 2018, the fastest pace in the past decade. Global electricity demand grew by 4% in 2018 to more than 23,000 TWh [3]. The preservation of electrical energy needs to be done considering Indonesia is one of the most wasteful countries in electricity use. In 2010-2014 the average growth of power generation capacity was around 6.5% per year. It occurs due to a lack of public awareness and austerity efforts, such as turning off lights during the day. The problem of wasteful electricity use also occurs in large industrial fields with many workers and machinery,. According to the data statistics of the State Electricity Company (PLN) 2013, in the industrial sector with only about 0.1% of the total customers, the electricity consumption reached 31.59% of the total consumption [4]. The solution is to apply smart metering to avoid excessive use of electrical energy and affect the production budget. Smart metering is a part of the Internet of Things, which can measure, collect, analyze, allow users to check the usage and bill of electricity, and distribute energy and its consumption.

Fig. 2 shows that LoRaWAN can be used for IoT connectivity in smart metering, whether it's for electricity, water, or gas. To forward messages or data to the destination, end nodes will be connected to the gateway. Customers must provide accurate data every 15 or 30 minutes to guarantee that electricity energy needs meet

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market needs and the power system is balanced [3]. During peak hours, it seeks to encourage users to use electricity more efficiently. Customers that use energy seek for gaps in their usage in order to adjust the time, the rate of interest, or the overall amount of electricity consumed.

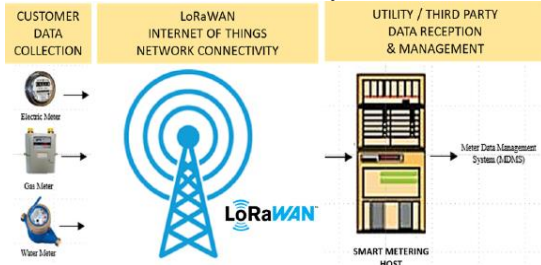


Fig. 2. LoRaWAN for smart meter [5]

"LoRaWAN Internet of Things Network Planning for Smart Metering Services in a Dense Urban Scenario" inspired this study to monitoring the consumption of energy, water, and gas. It is written by Alvin Yusri and M. I. Nashiruddin, and it is located in Jakarta, Indonesia's capital. The number of gateways necessary for Smart meter connectivity is estimated using coverage and capacity planning in this LoRaWAN network design. The LoRaWAN Internet of Things Network Planning for Smart Metering Services in Dense Urban Scenario was established during the writing of this article, and it was then used to the design of the LoRaWAN network in Indonesian industrial regions, notably in the Karawang Industrial Estate.

LoRaWAN is used in this study to provide connectivity for smart power meters to deliver data to the destination. The Karawang industrial estate's LoRaWAN network planning is based on a LoRaWAN simulation with Spreading Factor 7 as the lowest Spreading Factor. Coverage planning and capacity planning scenarios are used in this planning to determine the number of gateways required to cover the Karawang Industrial Estate. The value of the resulting RSRP, SNR, and Throughput parameters is also a purpose of LoRaWAN planning. Simulation of a LoRaWAN network using Atoll planning software version 3.3.2.

This paper is divided into several sections, where Section I is the introduction, and Section II explains smart meters and LoRaWAN. Section III contains the methods used in this study and the results of the calculations. Section IV contains the results of the atoll software's prediction simulations and their analysis, and the last part, part V contains the results of this paper's research.

II. THE TECHNOLOGY OF LORAWAN

A. Smart Meter

Smart metering is a system that can measure, collect, and analyze energy circulation, usage and demand. Users benefit substantially from smart metering services because they can check use and pay bills for electricity, water, and gas from their smartphones and web browsers. Utility offices can also monitor the consumption of electricity,

water, and gas energy in real time to determine whether there is a problem and identify a solution as soon as possible [5].

B. LoRaWAN Overview

LoRaWAN is defined as a communication protocol and network architecture, while the lora physical layer provides network long-distance communication links and is certified by the LoRa Alliance. The protocol and network design have the most impact on a node's battery life, network capacity, quality of service, security, and the number of applications that may be supported by the network [6].

LoRaWAN is an open networking protocol that delivers secure bi-directional communication, mobility, and localization services standardized and maintained by the LoRa Alliance.

TABLE I: LORAWAN SPREADING FACTORS [7]

Spreading Factor (at 125 kHz)	Bitrate	Range	Time on-air (ms) For 10 Bytes app payload
SF 7	5470 bps	2 km	56 ms
SF 8	3125 bps	4 km	100 ms
SF 9	1760 bps	6 km	200 ms
SF 10	980 bps	8 km	370 ms
SF 11	440 bps	11 km	740 ms
SF 12	290 bps	14 km	1400 ms

Table I compares spreading factors with bit rate, range, and time on-air, with different values when using spreading factors from SF 7-SF 12. To communicate over the air, LoRaWAN employs license-free spectrum, usually in the Industrial, Scientific, and Medical (ISM) channels [8]. The European Telecommunications Standards Institute (ETSI) governs ISM band access on the 868 MHz and 433 MHz bands in Europe. Despite the fact that the use of certain bands is restricted, the transmitter's output power Equivalent Isotropic Radiated Power (EIRP) must not exceed 14 dBm or 25 mW. Furthermore, depending on the employed sub-band, the duty cycle required by ETSI in Europe is limited to 1% (for devices) or 10% (for gateways) [7].

C. LoRaWAN Architecture

In Fig. 3, the LoRaWAN networks show a "star-of-stars" [9], gateways transfer messages between end devices and a central core network server in this architecture [9]. End-devices communicate with one or more gateways via single-hop LoRa communication, which is connected to the main network server via standard IP connections. Thus, all communication is natively bi-directional, although it was expected that uplink communication from an end-device to the network server as the predominant use case and traffic pattern.

- a. LoRaWAN End Nodes: Sensor is an end device that uses LoRa RF modulation and can connect with LoRaWAN wirelessly.

- b. Gateway: The gateway is connected to the network server by an IP backbone, and it relays messages between end devices and network servers..
- c. Network Server: A network server's job is to route sensor data to the appropriate application server and response to the sensor.
- d. Application servers: Sensor application data must be securely handled, managed, and interpreted by application servers. They also create all of the connected end devices' application-layer downlink payloads [10].

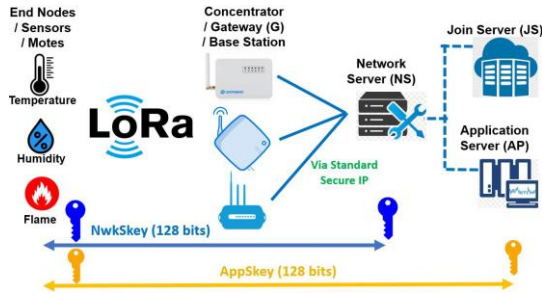


Fig. 3. LoRaWAN architecture [10]

III. RESEARCH METHODOLOGY

A. Research Area

In this study, the area selected is the Karawang Industrial Estate, shown in Fig. 4, with an area plotted as an industrial area of 13,756,358 hectares (137.56358 km²) or 7.85% of a total area of about 1,753.27 km² or 175,327 hectares based on data from the Karawang Manpower and Transmigration Office in 2018. The population of Karawang was 2,370,488 in 2020 based on data from the Central Statistics Agency of Karawang Regency [11]. In addition, 1762 factories were divided into 787 private factories, 269 PMDN, 638 PMA, and 58 joint venture factories [12]. Table II shows the area of the Karawang Industrial Area.

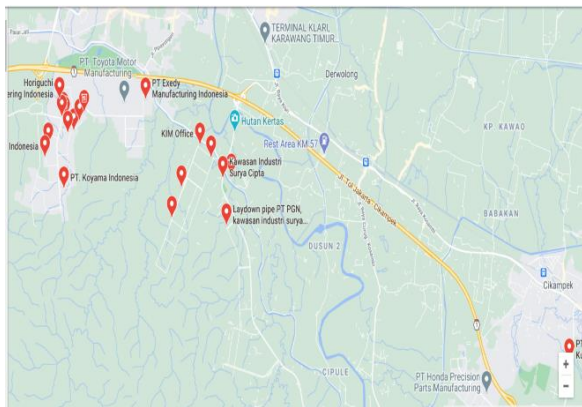


Fig. 4. Karawang industrial estate

TABLE II: KARAWANG INDUSTRIAL AREA [11]

Industrial Area Estate	Area (Ha)
Indotaisei Industrial Estate	694,20 Ha
Kujang Cikampek Industrial Estate	110,00 Ha
Mitrakarawang Industrial Estate	500,00 Ha

Karawang International Industrial City	1.347,00 Ha
Suryacipta City of Industry	1.400,00 Ha
Mandalapratama Permai Industrial Estate	237,50 Ha
Podomoro Industrial Park	542,00 Ha
Artha Industrial Hill Industrial Estate	390,00 Ha
GT Tech Park Industrial Estate	400,00 Ha
Karawang New Industry City	205,00 Ha
Pertiwi Lestari Industrial Estate	791,28 Ha
Karawang Jabar Industrial Estate	400,00 Ha
Other Industrial Estates	6.739,98 Ha
Total Area	13.756,358 Ha

B. Coverage Planning

Coverage planning is the goal of network design: to figure out where the best sites are and what coverage parameters are required. Transmission power and coverage estimate are two important gateway parameters to keep in mind. Link budget calculation and coverage prediction are two aspects of network planning The LoRaWAN design flowchart coverage [13] is represented in Fig. 5

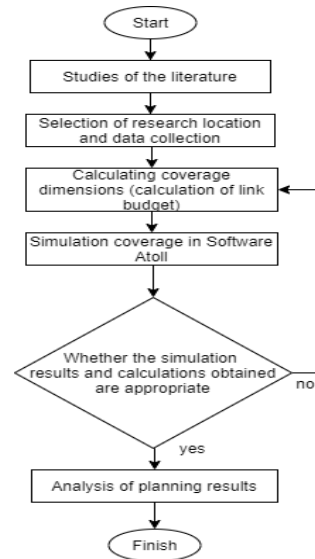


Fig. 5. LoRaWAN design flowchart coverage

1. Link Budget Calculation

Link budget calculation is required to calculate the signal power loss between the gateway and the end device to obtain the maximum coverage area per site. Table III shows the link budget used in this study.

- a. Calculating the LoRa Sensitivity Value

TABLE III: LINK BUDGET FOR LORAWAN [12]

Spreading Factor (at 125 kHz)	UL	DL
Tx Power (dBm)	15	20
Tx Cable loss (dB)	-1	-3
Tx Antenna Gain (dBi)	0	9
Tx Antenna Height (m)		30
RX Antenna gain diversity (dBi)	10	0

4	Antenna Height (m)	1.5
	Frequency (MHz)	920
	Bandwidth (kHz)	125

LoRa sensitivity calculation was based on Spreading Factor and SNR, where the sensitivity calculation is as follows [14]. The sensitivity value used for lora can be found in the following Table IV.

TABLE IV: SENSITIVITY LORAWAN

Sensitivity (dBm)					
SF 7	SF 8	SF 9	SF 10	SF 11	SF 12
-124,53	-127,03	-129,53	-132,03	-134,53	-137,03

$$Sensitivity SF = -174 + 10 \log_s(BW) + 6 + (-SNR \text{ limit}) \quad (1)$$

b. Maximum Allowable Path Loss (MAPL)

MAPL is required to know the highest value of attenuation allowed between the LoRa gateway and the end device. The EIRP and MAPL calculation formulas are as follows [14]. Tables V and VI show the EIRP and MAPL values that were calculated.

$$EIRP (UL/DL) = Tx \text{ Power} + Gain \text{ Antenna Tx} - Loss \text{ Cable} \quad (2)$$

$$MAPL = EIRP - Sensitivity \quad (3)$$

TABLE V: EIRP VALUE

Value (dBm)	Device	Value (dBm)
EIRP Downlink	Gateway	26
EIRP Uplink	End Device	14

TABLE VI: MAPL VALUE

Spreading Factor	MAPL Downlink (dBm)	MAPL Uplink (dBm)
7	151,00	139,00
8	153,00	141,00
9	156,00	144,00
10	158,00	146,00
11	161,00	149,00
12	163,00	151,00

2. Coverage Prediction

Coverage prediction, the number of gateways needed to cover a region can be determined. The propagation used in this coverage planning is the propagation of Okumura Hatta. The selection of propagation is based on their performance in accuracy and simplicity. To calculate cell radius, we can use the following formula [15]. Table VII shows the results of the cell radius calculation.

$$PL = 69.55 + 26.16 \log(f) - 13.82 \log(h_b) - a(h_m) + (44.9 - 6.55 \log(h_b)) \log(10) \quad (4)$$

$$a(h_m) = (1.1 \log_{10}(f) - 0.7) h_m - (1.56 \log_{10}(f) - 0.8) \quad (1)$$

Note:

- h_b : height of gateway's antenna (m)
- h_m : height of the device's antenna (m)
- f : frequency of transmission (MHz)
- ch : antenna height correction factor
- d : the distance between the gateway and the devices (km)

TABLE VII: CELL RADIUS

Spreading Factor	$a(h_e)$	Cell Radius (km)	
		Uplink	Downlink
7		0,74344727	1,39816
8		0,82524961	1,5534
9		0,96641149	1,8191
10	0.0167	1,07463900	2,0194
11		1,25735141	2,3646
12		1,39692957	2,6271

The formula for calculating the number of gateways is as follows [13]. Table VIII contains the results of the calculation of the number of gateways.

$$\text{Number of Gateways} = \frac{\text{Area}}{\text{Cell Area}} \quad (6)$$

TABLE VIII: NUMBER OF GATEWAY

Spreading Factor	Number of Gateway (DL)	Number of Gateway (UL)
7	38	71
8	34	64
9	29	55
10	26	49
11	22	42
12	20	38

C. Capacity Planning

To know about the total capacity required for traffic with data communication needs, we used Capacity Planning. For example, inputs from Time on Air (ToA) packages for various data rates and their distribution can produce network capacity. The calculation formula is shown below [16].

$$Time \text{ on Air (ToA)} = T_{\text{Preamble}} + T_{\text{Payload}} \quad (7)$$

$$T_{\text{Preamble}} = (n_{\text{preamble}} + 4.25) \cdot T_{\text{sym}} \quad (8)$$

$$T_{\text{Payload}} = \text{payloadSymbNb} \cdot T_{\text{Sym}} \quad (9)$$

$$N_{\text{payload}} = 8 + \max \text{ cell} \left(\frac{8PL - 4SF + 28 + 16 - 20H}{4(SF - 2DE)} \right) \quad (10)$$

Note:

n_{preamble} : 8

4.25 is the number of symbols added by radio in equation (8).

$T_{sym} = 2SF / \text{Bandwidth (BW)}$

PL : the number of payload bytes

SF : the spreading Factor

H : 0 header enabled and $H = 1$ no header

DE : optimization of low data rate

$DE = 1$ for enabled, $DE = 0$ for disabled

CR : the coding rate from 1 to 4 (1 corresponds to CR 4/5 and 4 corresponds to CR 4/8)

Following the formula, the result of the calculations is obtained in Table IX-XII.

TABLE IX: TIME PREAMBLE

Spreading Factor	T Preamble (ms)
7	12,544
8	25,088
9	50,176
10	100,352
11	200,704
12	401,408

TABLE X: TIME PAYLOAD

Time Payload (ms)						
Coding Rate	Spreading Factor					
	7	8	9	10	11	12
4/5	36	63	114	207	381	708
4/6	35	62	111	203	374	695
4/7	34	61	110	200	369	687
4/8	34	60	109	198	366	680

TABLE XI: N. PAYLOAD

N Payload (ms)						
Coding Rate	Spreading Factor					
	7	8	9	10	11	12
4/5	35	31	28	25	23	22
4/6	34	30	27	25	23	21
4/7	33	30	27	24	23	21
4/8	33	29	27	24	22	21

TABLE XII: TIME ON AIR

Time on-air (ms)						
Coding Rate	Spreading Factor					
	7	8	9	10	11	12
4/5	48	88	164	307	582	1109
4/6	47	87	162	304	575	1097
4/7	47	86	160	301	570	1088
4/8	46	85	159	299	566	1081

IV. RESULT

This research planning uses Atoll software with SF7 and a code rate of 4/5. The LoRaWAN range is not far when using SF7, but the speed of the resultant data is

significantly faster than when using SF12. According to the table VIII calculation result, the number of data transmission gateways generated in the Karawang industrial estate using SF 7 is 38.

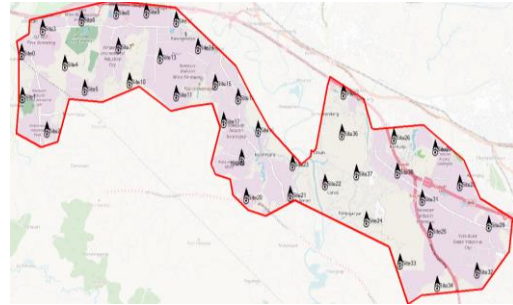


Fig. 6. Gateway placement in atoll

Fig. 6 presents the placement of gateways in the Karawang Industrial Estate, where a total of 38 gateways are required, according to the calculations. There will be two predictions based on LoRaWAN planning using Atoll software. Signal level prediction and throughput distribution were the results of the first network coverage prediction. The second prediction is the Signal to Noise Ratio (SNR).

A. Reference Signal Received Power (RSRP)

RSRP is an RSSI type of measurement. Here are some definitions as well as some details about it. To detect RSRP/RSRQ, a minimum of -20 dB SINR (of the S-Synch channel) is required.

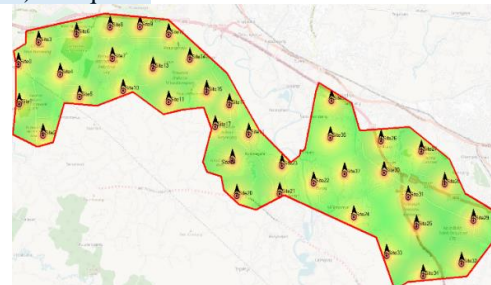


Fig. 7. RSRP prediction result

Fig. 7 shows the placement of the gateway as well as simulations conducted on RSRP parameters. From the prediction signal level, the number of gateways used is still the same, 38. With this prediction, we can know the value of the histogram of RSRP.

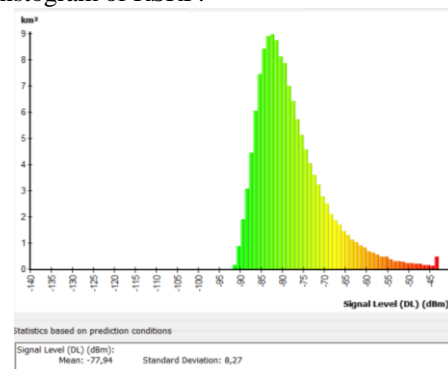


Fig. 8. Histogram of RSRP

Fig. 8 shows the RSRP on the histogram, the resulting value, on the x-axis to indicate the magnitude of the signal produced and on the y-axis to indicate the distance in kilometers squared. The resulting RSRP is -77.94 dBm with a standard deviation of 8.27 dBm, which means it belongs to the good category

B. Throughput

The quantity of bandwidth capacity consumed is referred to as throughput.

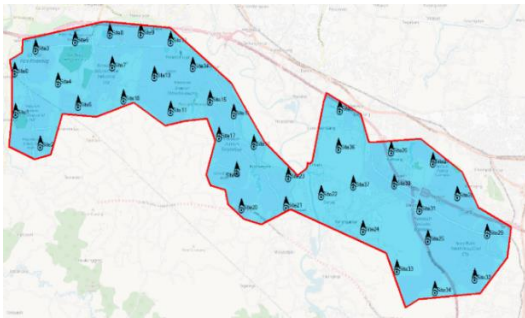


Fig. 9. Throughput Prediction Result

Fig. 9 illustrates throughput predictions with the same number of gateways (38 gateways) as before. The terrain contour of the place, in this case the Karawang Industrial Estate, has an impact on LoRaWAN throughput.

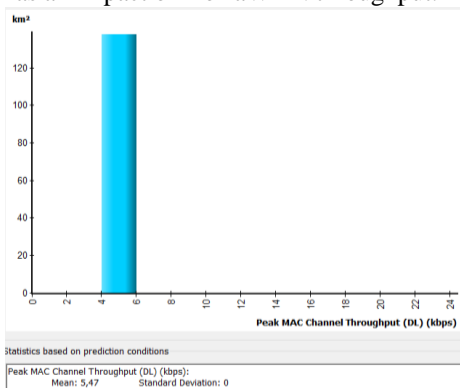


Fig. 10. Histogram of SINR

Fig. 10 shows the obtained throughput results, where the histogram produces a mean of 5.47 kbps in a range of 4-6 kbps. On the vertical axis, there is a distance in kilometers squared where throughput can be measured, ranging from 0 to over 120 kilometers squared. The following is the link between distance and throughput: The lower the signal received and the speed, the lower the throughput. The longer the radiance distance between Tx and Rx, the lower the signal received and the speed..

C. Signal to Noise Ratio (SNR)

The ratio of signal power to noise power is known as the Signal to Noise Ratio.

Fig. 11 represents an SNR prediction simulation result in which the area of Karawang Industrial Estate is predominantly green, with the color corresponding to the obtained SNR results. The Signal-to-Noise ratio is

calculated by reducing the unwanted noise signal to the wanted signal level.

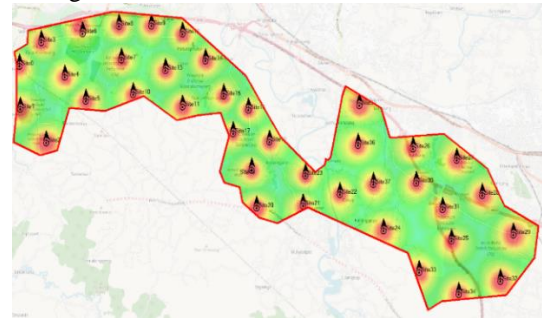


Fig. 11. SINR prediction result

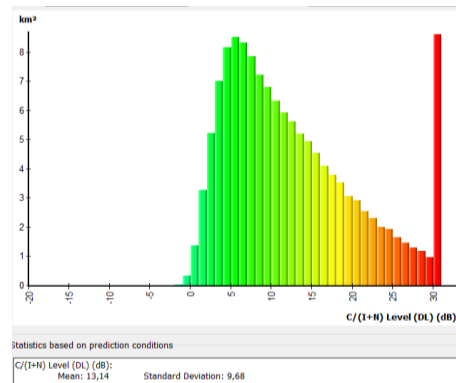


Fig. 12. Histogram of SINR

The SINR obtained at 13,14 dB with a standard deviation of 9,68 dB is shown in Fig. 12. As a result, SINR in this simulation falls into the good category.

V. CONCLUSION

Based on the simulation of the LoRaWAN network design at a frequency of 920-923 MHz for smart meters in Karawang Industrial Estate; it concluded that the LoRaWAN planning needs to use 38 gateways, as calculated by the number of gateways for the Downlink scheme using spread factor 7 and code rate 4/5. With a mean of -77.94 and a standard deviation of 8.27 for the study parameters used, the LoRaWAN simulation findings at Karawang Industrial Estate received an RSRP value in the good category. Furthermore, simulation-based throughput predictions range between 4-6 kbps, with a mean of 5.47 kbps. The last parameter is SNR, with SNR predictions on LoRaWAN simulation averaging 13.14 dB.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Puspa Rahmawati was tasked with calculating coverage, capacity planning, and developing the LoRaWAN network on Atoll software for this paper. Puspa Rahmawati also wrote this paper following the design results. Alfin Hikmaturokhman and Khoirun Ni'amah contributed by guiding, giving directions, and making suggestions while drafting papers and correcting errors.

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