The Effect of Spreading Factor Value on the Number of Gateways in the LoRaWAN Network at Bandung City

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***Abstract*—Technological developments in the Internet of Things are increasing rapidly so that a protocol is needed to realize a smart city, one of which is by using LoRaWAN network connectivity as a LoRa communication protocol that supports the use of IoT at a frequency of 920-923 MHz. This study compares the spreading factor to the LoRaWAN network design. The area in this study is the city of Bandung with an area of up to 167.31 km2. The design of the LoRaWAN network uses coverage planning using Forsk Atoll 3.4.0 simulation software. The parameters used in this study are Spreading Factor (SF) 7 to 12, Signal to Noise Ratio (SNR), and Effective Signal Analysis. The results of the research parameter values were analyzed using MATLAB software in the form of a comparison chart. This study aims to compare the effect of using the spreading factor on the number of gateways needed to optimize gateway coverage for data transmission processes in the city of Bandung. The simulation results show that SF 7 requires 13 gates to cover the city of Bandung, which is the largest number of gates. Performance Effective Signal Analysis on SF 7 obtained the highest signal strength of –68.32 dBm. SINR performance on SF 12 obtained the highest signal strength of 10.87 dBm. A larger scatter factor will decrease the signal strength while the signal quality will increase because the sensitivity is better but it will increase the data transmission time and vice versa.**

***Keywords*—spreading factor, LoRaWAN, coverage planning, gateway**

I. Introduction

Technological developments are increasing rapidly every year, making technology an important need for society. The use of technology is not only used in the world of telecommunications, but has been widely applied in industry, agriculture, health, security and other fields. The era of globalization, the internet will synergize with electronic devices to help human activities [1]. Internet of Things (IoT) was developed to support human activities to be more effective and efficient so as to minimize human work. The internet of things is needed to create a smart city, applications from IoT can also be used to monitor several aspects such as the energy needed in daily life, smart public street lighting, smart trash, temperature monitoring, smart parking, and others.

Bandung city already has a smart city, Bandung Development Council or commonly known as the Smart City Council. The council consists of various elements in the Bandung City community and the Bandung City government. There are several names involved in the Smart City Council, one of which is Ilham Habibie who is also the Chief Executive of the National ICT Council, Prof. Dr. Ir. Suhono H. Supangkat, who initiated Smart City Initiatives Indonesia, Budi Rahardjo, an ITB lecturer who is also active in the Local Startup community, to representatives from the startup community in Bandung, namely Yohan Totting from the Bandung Children's Web Forum.

To support a smart city in Bandung, it is necessary to design a LoRaWAN network as a LoRa protocol on the coverage side to find out how many gateways are needed as a means of communication between sensors and servers in the process of sending data. LoRaWAN is a communication protocol and system architecture for LoRa physical layer transient networks that enable remote communication coverage [2].

The planning of LoRaWAN network uses a frequency range of 920-923 MHz according to the frequency applied in Indonesia with the parameters used are Spreading Factor (SF), Bandwidth, Signal to Noise ratio (SNR), and Received Signal Strength Indicator (RSSI).

Fig. 1 is the LoRaWAN Architecture network is built using a star topology which allows devices to work using batteries for a long time compared to a mesh network topology. In LoRaWAN the network end-nodes such as asset tracking, gas monitor, water meter, trash contrainer, vending machine, and fire detection are not associated with any particular gateway. Instead, data sent by a node is usually received by many gateways. Each gateway will forward packets received from end-nodes to cloud-based network servers via multiple backhauls such as cellular, Ethernet or WIFI and then will be displayed on the application server [2].

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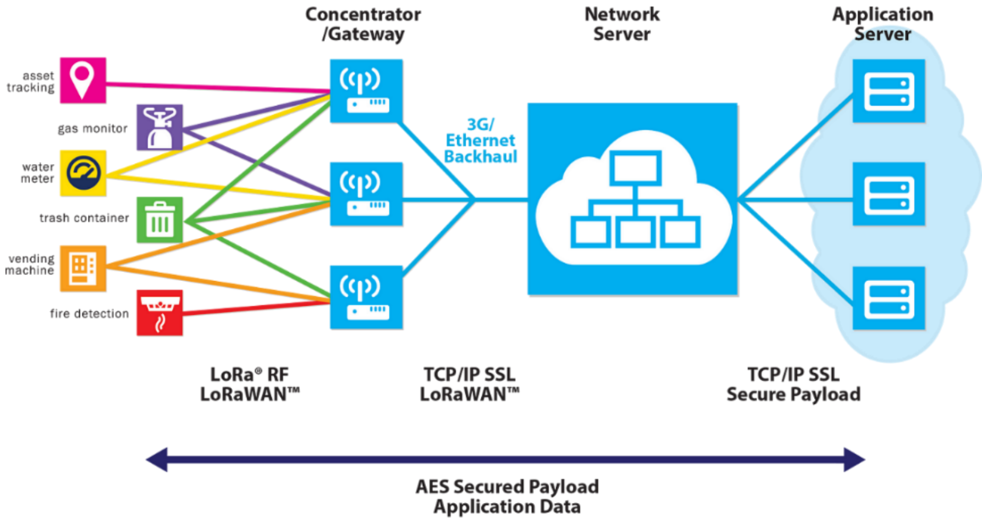

Figure 1. LoRaWAN architecture [3].

Fig. 2 is the modulation used in LoRa. LoRa uses a Spread Spectrum modulation scheme and uses the Chirp Spread Spectrum (CSS) technique where the information signal is propagated in the frequency domain [3].

There are 2 types of chirp, namely up-chirp (increasing frequency from low to high) and down chirp (decreasing frequency from high to low). The advantage of this method is that the timing and frequency settings between the transmitter and receiver are equivalent, thereby greatly reducing the complexity of the receiver design. This chirp frequency bandwidth is equivalent to the signal's spectral bandwidth. The data signal that carries data from the end device to the gateway is chipped at a higher data rate and modulated onto the chirp carrier signal [3].

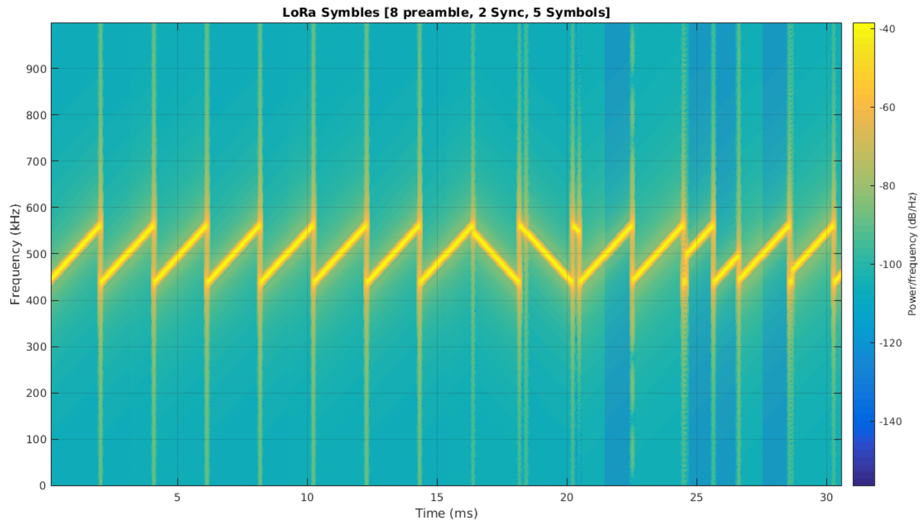

Figure 2. LoRa modulation illustration [3].

LoRaWAN targets deployments where end devices have limited energy, so end devices do not need to transmit more than a few bytes at any given time. While Semtech Corporation provides LoRa chipsets, the LoRa Alliance drives global standardization and harmonization of LoRaWAN standards for a broad ecosystem [4]. The Spreading Factor shows how many chips are used to represent one symbol. The greater the spreading factor, the more it affects the distance and time of data transmission [5]. LoRaWAN has several advantages, namely supporting two-way communication, low power usage, wider coverage of up to 2-5 km (urban) and 15 km (suburban), longer battery life (long life battery), and using frequencies that are not licensed (ISM Band) thereby making LoRaWAN have lower implementation costs than other technologies.

To support LoRaWAN network planning, network planning on the coverage side is needed to find out how many gateways are needed to cover all planning areas in the city of Bandung. This design uses Atoll software version 3.4.0 and Matlab as well as several calculation stages to predict signal strength and quality in Bandung City based on parameters such as frequency, bandwidth, spreading factor, Effective Signal Analysis and SINR.

This research will analyze the strength and quality of the LoRaWAN signal in the city of Bandung in Sections III and IV. In Section III, it describes how the method used in this research is to plan the LoRaWAN network using Atoll Software version 3.4.0. and in Section IV describes the analysis of planning results using graphics from the Matlab software.

II. Literature Review

Research in 2020 with the title "Analysis of Lora Network Planning (Long Range) in the City of Surabaya" discusses planning for the LoRa network for the next few years in the City of Surabaya which has not been served by the LoRa network. In this research, only 12% was taken for the calculation of required packets for IoT devices on the grounds that it is not possible if the LoRa network at Surabaya city. The parameters in this research consist of spreading factor, Received Signal Strength Indicator (RSSI), Signal to Noise Ratio (SNR) and signal level. LoRa network planning in this research uses a frequency of 921.5 Mhz with a bandwidth of 125 kHz, the coding rate used is 4/5 and data transmission can run smoothly if the spreading factor parameter used is spreading factor (SF) 7 [6].

Research in 2021 with the title "LoRaWAN Network Planning At Frequency 920-923 MHz for Electric Smart Meter: Study Case in Indonesia Industrial Estate" discusses the design of the LoRaWAN network for smart meters in the Karawang Industrial Area to measure and monitor electricity usage. This study aims to obtain the number of gateways needed to optimize gateway coverage for sending electrical monitoring data to the Karawang Estate Industry. The LoRaWAN planning simulation produces an average RSRP of -77.94 dBm. The SNR results have a mean of 13.14 dB. The last parameter is throughput ranging from 4-6 kbps with an average of 5.47 kbps. The results of this planning produce parameter values of RSRP, SNR, and Throughput with good conditions that will be applied to smart metering applications in the Karawang Industrial Area [7].

III. Materials and Methods

The method used in this study is a simulation using Atoll software version 3.4.0 to design coverage and Matlab software to analyze the comparison of the parameters Spreading factor, SINR, Effective Signal, and the number of gateways. Before carrying out the simulation, data such as the size of the research area, link budget, and calculations are needed.

A. Research Area

Determination of the research area is based on data on the area of the city of Bandung. The city of Bandung is a big city with an area of around 167.31 km^2 or 16731 Ha [8]. The population in the city of Bandung is 2,510,103 million in 2020 based on data from the Central Bureau of Statistics for the city of Bandung [9]. Fig. 3 is a map of the city of Bandung.

Figure 3. Bandung city area [10].

Based on the Regional Regulation of the City of Bandung Number 06 of 2008 concerning amendments to the Regional Regulation of the City of Bandung Number 06 of 2006 concerning the Expansion and Formation of the Working Areas of the Districts and Kelurahans in the Bandung City Government Environment Consisting of 30 Districts and 151 Villages [9].

B. Coverage Planning

The design of coverage (coverage planning) on the LoRaWAN network begins with calculating the equations needed to be inputted into the simulation phase later using the Atoll software. The first calculation is Maximum Allowable Path Loss (MAPL) in dB.

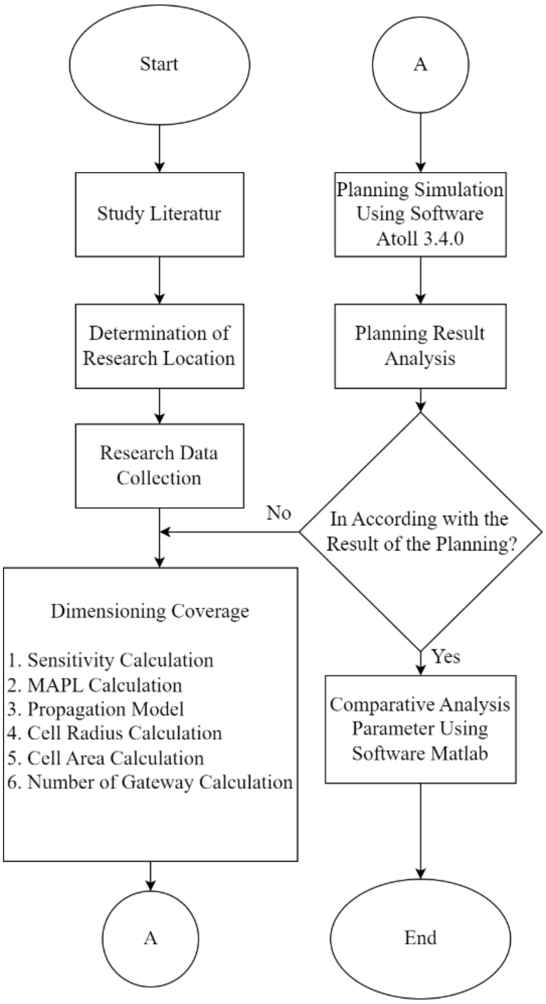

Figure 4. LoRaWAN network planning flowchart.

Fig. 4 is the flowchart used in this research where a literature study was carried out, data collection and research location determination were then carried out to calculate coverage planning and carry out network design using atolls whose results were analyzed using the Matlab software.

1) Link budget calculation

The link budget calculation is needed to calculate the lost signal power between the gateway and the end device to get the maximum coverage area per site [6].

TABLE I. LINK BUDGET LORAWAN [11]

Parameter	UL	DL
Tx Power (dBm)	15	20
Tx Cable loss (dB)	–1	–3
T x Antenna Gain (dBi)	0	9
Tx Antenna Height (m)	30	
RX Antenna gain diversity (dBi)	10	0
Rx Antenna Height (m)	1.5	
Frequency (MHz)	920	
Bandwidth (kHz)	125	

Table I is the lorawan link budget used in this research to obtain the total gateway.

a) LoRa sensitivity calculation

LoRa has high sensitivity and can be identified even if the signal is weak, which makes it possible to increase the communication distance. LoRa sensitivity is used to find the maximum allowable path loss (MAPL) value. LoRa sensitivity can be calculated based on the SF according to the SNR value for each SF used [11].

TABLE II. SNR LORA [11]

SF	SNR Limit
7	–7.5 dB
8	–10 dB
9	–12.5 dB
10	–15 dB
11	–17.5 dB
12	–20 dB

Table II is SNR LoRa. Signal Noise Ratio (SNR) is the signal power received by the user with noise strength. The greater the SNR value, the greater the user's power. The value of LoRa Sensitivity can be found using the Eq. (1).

$$Sensitivity = -174 + 10\log(BW) + NF + (-SNR\ limit) \quad (1)$$

The value of the Noise Figure used in LoRaWAN technology is 6 dB [12].

TABLE III. LORA SENSITIVITY VALUE

Sensitivity (dBm)					
SF 7	SF 8	SF 9	SF 10	SF 11	SF 12
–125	–127	–130	–132	–135	–137

Table III is the result of the calculation of LoRa Sensitivity using equation 1.

b) Maximum Allowable Path Loss (MAPL)

This MAPL calculation is the highest allowable attenuation value between the LoRa gateway and the end device [13]. To calculate the MAPL value, calculations are needed to find the Effective Isotropic Radiated Power (EIRP) value. EIRP is a measurement of the radiated power of an isotropic antenna. The Value of EIRP can be found using the Eq. (2).

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

TABLE IV. EIRP VALUE

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

Table IV is the result of calculations from EIRP using Eq. (2).

After getting the EIRP value, then you can calculate the MAPL value. The formula for the MAPL equation is as follows [13].

$$\text{MAPL} = \text{EIRP} - \text{Sensitivity} \quad (3)$$

The MAPL calculation has a difference in the MAPL value based on the Spreading Factor value used where the greater the Spreading Factor value, the greater the MAPL in LoRa.

TABLE V. MAPL VALUE

SF	MAPL Downlink (dBm)
7	151
8	153
9	156
10	158
11	161
12	163

Table V is the result of calculations from MAPL using Eq. (3).

2) Coverage prediction

This coverage prediction is intended to find the number of gateways needed to cover all the Lorawan network planning areas in the city of Bandung.

a) Calculating cell radius using the propagation model

The calculation of the cell radius is used to calculate the coverage area or coverage in one site. In the propagation model used in planning the LoRaWAN network with a frequency band of 920 MHz is the Okkumura Hatta model. Using the MAPL value, you can find the LoRaWAN network radius cell value [14]. The value of Cell Radius can be found using the Eq. (4).

$$PL = 69.55 + 26.16 \log(f) - 13.82 \log hb - a(hm)\ (44.7 - 6.55 \log hb) \log 10\ d \quad (4)$$

$$a\ (hm) = (1.1 \log 10(f) - 0.7) hm\ (1.56 \log 10(f) - 0.8) \quad (5)$$

where:
hb is height of gateway's antenna (m)
hm is height of the device's antenna (m)
f is frequency of transmission (MHz)
d is the distance between the gateway and the devices (km)

TABLE VI. CELL RADIUS VALUE

SF	a(hr)	log (d)	d (km)
7		0.6912	4.911
8		0.7480	5.597
9	0.0167	0.8332	6.810
10		0.8899	7.760
11		0.9751	9.442
12		1.032	10.764

Table VI is the result of calculating the Cell Radius using Eqs. (4–5).

b) Cell area calculation

After the cell radius calculation is obtained, the next step is to calculate the cell area that can be covered by one LoRa gateway site. Calculating the Number of Gateway [15]. The value of Cell Area can be found using the Eq. (6).

$$LCell = \frac{3\sqrt{3d^2}}{2} \quad (6)$$

In calculating the cell area, it is necessary to know the value of d where d means the distance between the transmitter and the receiver in kilometers. Cell is defined as a coverage area with a small size.

TABLE VII. CELL AREA VALUE

SF	Cell Area (km^2)
7	12.760
8	14.541
9	17.692
10	20.161
11	24.531
12	27.965

Table VII is the result of calculating the Cell Radius using Eq. (6).

c) Calculating the number of gateways

In the last calculation in this coverage planning is to calculate the number of gateways needed to cover all areas in the research location. The value of Cell Area can be found using the Eq. (7) [15].

$$\text{Number of Gateways} = \frac{\text{Area}}{\text{Cell Area}} \quad (7)$$

TABLE VIII. NUMBER OF GATEWAYS

SF	Gateway
7	13
8	12
9	9
10	8
11	7
12	6

Table VIII is the result of calculating the total gateway using Eq. (7).

IV. RESULT AND DISCUSSION

The research simulations using Atoll software version 3.4.0, the frequency used is 920 MHz with a bandwidth of 125 kHz. The research also uses Matlab software to analyze the results of parameters such as the number of gateways needed, signal strength (Effective Signal Analysis), and signal quality (SINR).

A. Effective Signal Analysis

Effective Signal Analysis is something that is used to see the received signal power within a specified coverage area. The power received by the end device is within a certain frequency, the farther the distance between the gateway and the end device, the smaller.

Fig. 5 explains Based on the results of calculations and design simulations to cover a planning area of 167.3 km^2, in Fig. 5(a) SF 7 requires 13 gateways, the average value of the Effective Signal Analysis parameter is -68.32 dBm. In Fig. 5(b), SF 8 requires 12 gateways, the average value of the Effective Signal Analysis parameter is -68.94 dBm. In Fig. 5(c), SF 9 requires 9 gateways, the average value of the Effective Signal Analysis parameter is -69.22 dBm. In Fig. 5(d), SF 10 requires 8 gateways, the average value of the Effective Signal Analysis parameter is -72.19 dBm. In Fig. 5(e), SF 11 requires 7 gateways, the average value of the Effective Signal Analysis parameter is -73.18 dBm. In Fig. 5(f), SF 12 requires 6 gateways, the average value of the Effective Signal Analysis parameter is -75.03 dBm where all the spreading factor values show the parameter results in a good category.

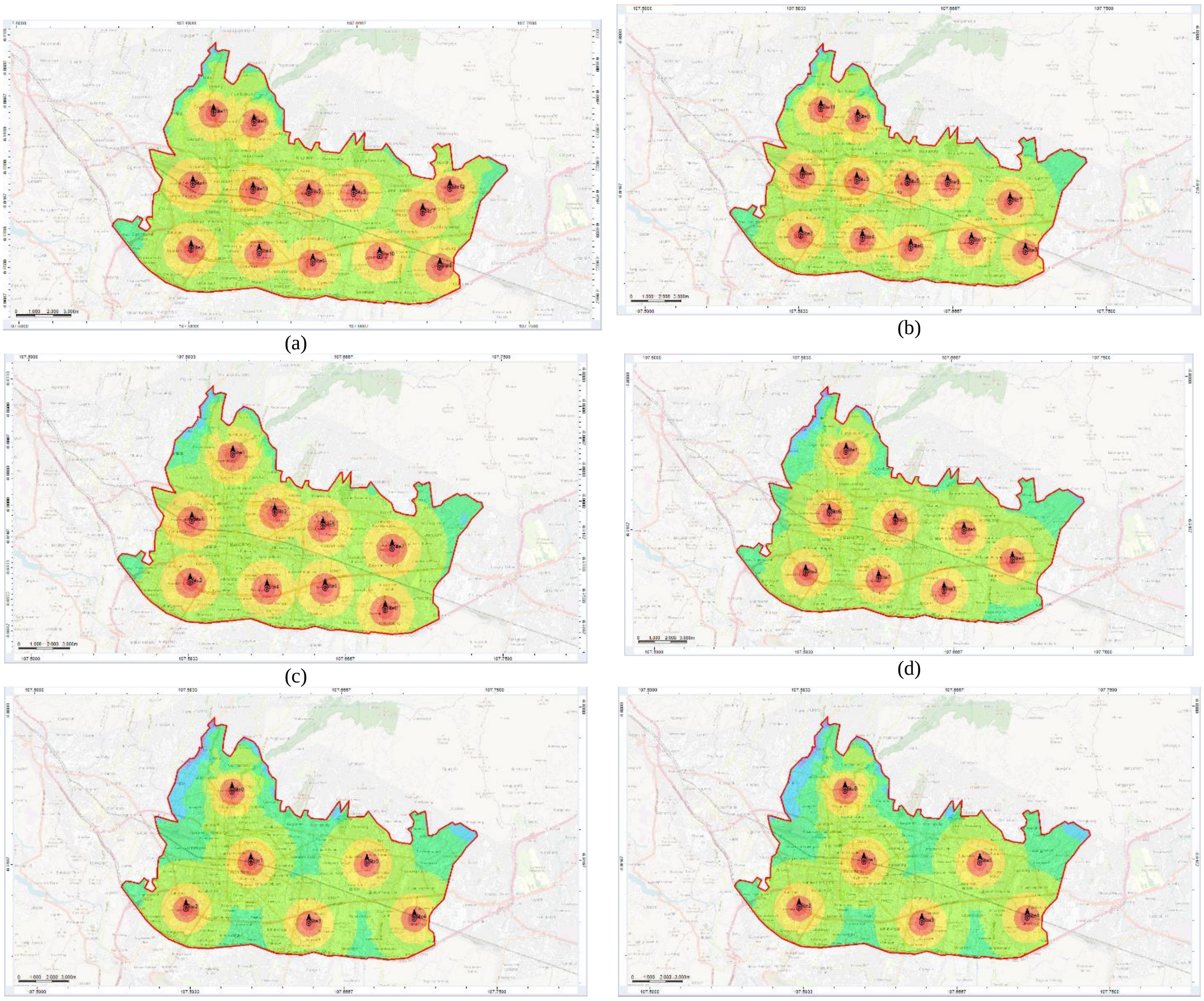

Figure 5. Effective signal analysis prediction (a) SF 7 (b) SF 8 (c) SF 9 (d) SF 10 (e) SF 11 (d) SF 12.

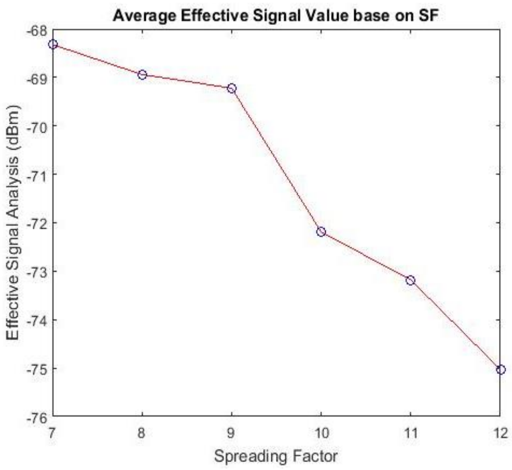

Figure 6. Average effective signal analysis value on SF.

Fig. 6 is the results of the Effective Signal Analysis parameter show varying values for each spreading factor used based on the simulation results that have been carried out. SF 7 shows a value of -68.32 dBm, SF 8 shows a value of -68.94 dBm which is the best parameter value resulting from the various spreading factors used, and SF 12 shows a value of -75.03 dBm. It can be concluded that the simulation results on SF 7 get the best Effective Signal Analysis parameter values from the various spreading factors used.

B. Signal Interference to Noise Ratio

Signal Interference To Noise Ratio is something that is used to see the quality of the received signal within a specified coverage area. the quality of the signal received by the end device within a certain frequency, the farther the distance between the gateway and the end device, the lower the quality of the signal received by the end device.

Fig. 7 explains Based on the results of calculations and design simulations to cover a planning area of 167.3 km^2, in Fig. 7(a) SF 7 requires 13 gateways, the average value of the SINR parameter is 9.29 dBm. In Fig. 7(b) SF 8 requires 12 gateways, the average value of the SINR parameter is 9.31 dBm. In Fig. 7(c) SF 9 requires 9 gateways, the average value of the SINR parameter is

9.61 dBm. In Fig. 7(d) SF 10 requires 8 gateways, the average value of the SINR parameter is 10.04 dBm. In Fig. 7(e) SF 11 requires 7 gateways, the average value of the SINR parameter is 10.42 dBm. In Fig. 7(f) SF 12 requires 6 gateways, the average value of the SINR parameter is 10.87 dBm where all the spreading factor values show the parameter results in a good category.

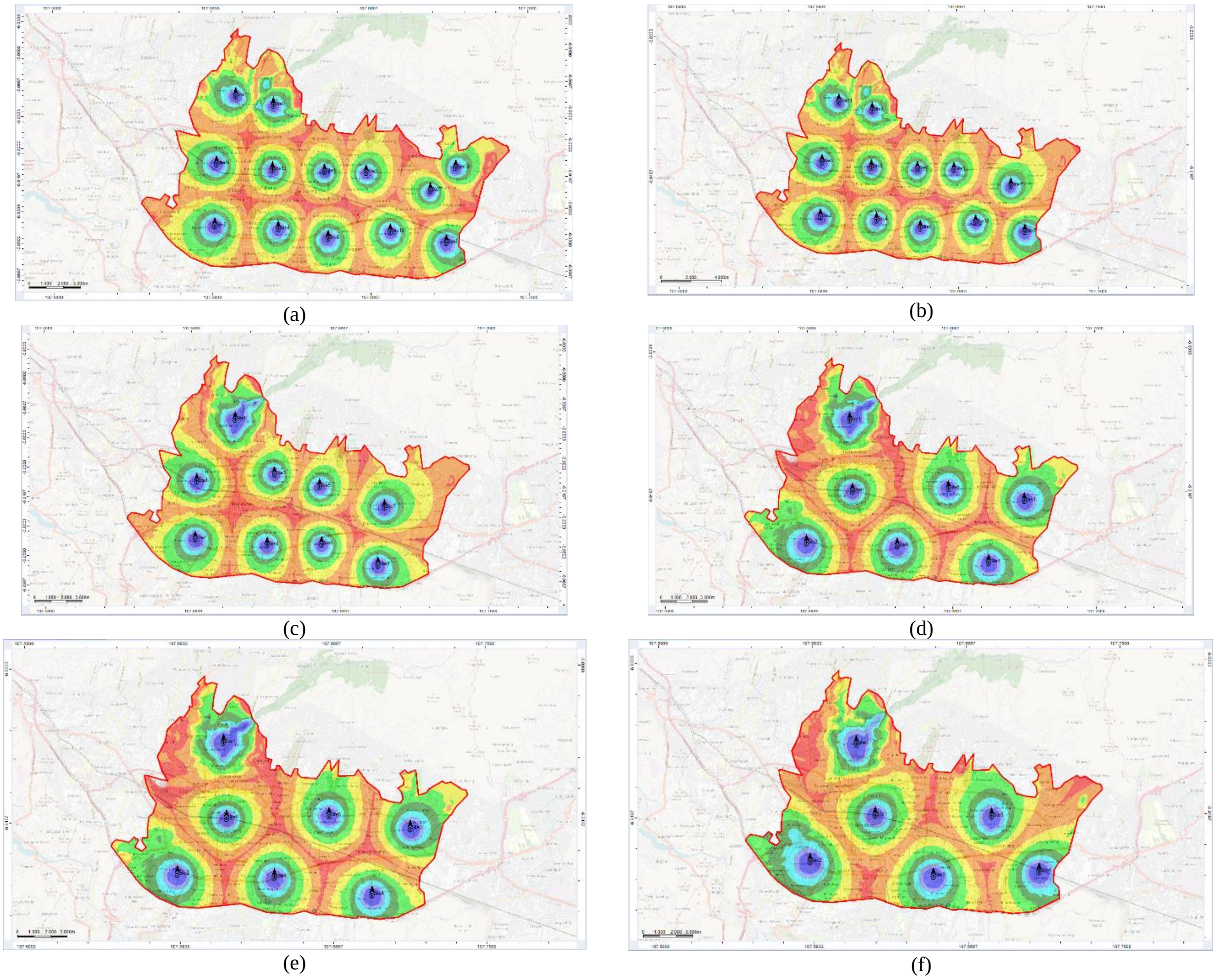

Figure 7. SINR Prediction (a) SF 7 (b) SF 8 (c) SF 9 (d) SF 10 (e) SF 11 (d) SF 12.

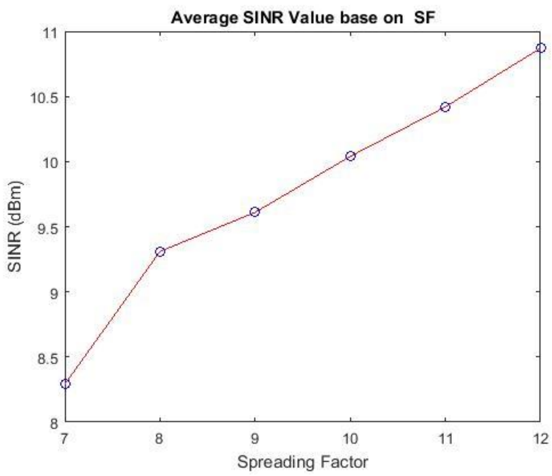

Figure 8. Average SINR value on SF.

Fig. 8 is the results of the SINR parameters show varying values for each distribution factor used based on the simulation results that have been carried out. SF 7 shows a value of 9.29 dBm, SF 8 shows a value of 9.31 dBm which is the best parameter value resulting from the various distribution factors used, and SF 12 shows a value of 10.87 dBm. It can be concluded that the simulation results on SF 12 get the best SINR parameter values from the various distribution factors used.

V. Conclusion

This research analisys effect of spreading factor at Bandung city. The value of SF 7 shown the highest effective signal parameter with an average of -68.32 dBm and requires 13 gateways. Whereas the SF 12 shown the highest SINR parameter with an average value of 10.87 dBm and requires 6 gateways to cover an entire area of 167.3 km^2 at Bandung city.

Variations value of the spreading factor, affected by the cell radius, number of gateways, effective signal, and SINR. The larger value spreading factor will reduce the signal strength while the signal quality will increase because the sensitivity is better but it will increase the data transmission time and otherwise.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest in the process of writing this research.

AUTHOR CONTRIBUTIONS

Gilang Hijrian Fahreja is in charge of calculating coverage planning and developing the LoRaWAN network using Atoll software and Matlab software for this paper. Gilang Hijrian Fahreja also wrote this paper following the design results. Khoirun Ni'amah and Reni Dyah Wahyuningrum contributed by guiding, giving directions, and giving suggestions when compiling papers and correcting mistakes; all authors had approved the final version.

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