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LoRaWAN for Smart Street Lighting Solution in Pangandaran Regency

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***Abstract*— Smart street lighting is a key application in smart cities, enabling the monitoring and control of street lamps through internet connectivity. LoRa/LoRaWAN, an IoT technology, offers advantages such as low power consumption, cost-effectiveness, and a wide area network. With its extensive coverage of up to 15 kilometers and easy deployment, LoRa has become a favored connectivity option for IoT use cases. This study explores the utilization of LoRaWAN in Pangandaran, a regency in the West Java province of Indonesia. Implementing LoRaWAN in this context has resulted in several benefits, including the ability to monitor and control street lighting in specific areas of Pangandaran and real-time recording of energy consumption. The primary objective of this research is to estimate the number of LoRaWAN gateways required to support smart street lighting in Pangandaran. Two methods are employed: coverage calculation using the free space loss approach and capacity calculation. The coverage calculation suggests a requirement of 34 gateways, whereas the capacity calculation indicates that only two gateways are needed. Based on these findings, it can be inferred that, theoretically, a maximum of 34 gateways would be necessary for smart street lighting in the Pangandaran area. However, further research, including driving tests, is recommended to validate these results for future implementation. This study provides insights into the practical application of LoRaWAN technology in smart street lighting, specifically in Pangandaran. The findings contribute to optimizing infrastructure and resource allocation, ultimately enhancing the efficiency and effectiveness of urban lighting systems.**

***Keywords*— LoRaWAN; smart lighting; smart city.**

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I. INTRODUCTION

Smart street lighting is a popular smart city use case where a software application can monitor streetlamps. Its benefits are to increase safety for drivers who travel at night and to prevent criminal acts due to the lack of light at night. It can be achieved because the municipal can monitor all streetlamps and respond quickly if broken lamps are detected. Previously, information about the blackout of public street lighting is still being done by waiting for reports from the citizens or officers who check the lighting manually. This is less effective and inefficient because there is no real-time information when there is a problem with public street lighting, which causes slow handling. In the era of digitalization, more and more devices are already able to access the internet. A monitoring system is required to improve public street lighting management. The system that makes this possible is the Internet of Things (IoT) [1], [2], [3].

Meanwhile, LoRa/LoRaWAN is a connectivity technology that is now becoming popular in IoT use cases. It offers low power, low cost, and a wide area network to connect IoT devices to the internet cloud [4], [5], [6]. LoRa is suitable for massive IoT use cases like smart lighting since the efficiency will be significant due to the high number of smart lightings in an entire city. This research talks about implementing LoRa-based smart lighting in the Pangandaran Regency, West Java province, Indonesia. LoRa coverage and gateway distribution will also be discussed. The remaining paper consists of four sections. Section II discusses the literature review, and section III presents the methodology. Section IV provides the result and analysis, and section V provides the conclusion of this paper.

II. MATERIALS AND METHOD

A. Related Studies

Smart lighting adds intelligence and control to streetlights to help reduce the most considerable energy expense of a typical City. Smart lighting is remotely controlled to better control the amount of lamp time with the lights on. This arrangement can minimize energy costs without compromising public safety. Several previous studies discuss the monitoring system for public street lighting. One of them is controlling streetlights based on sunlight and object detection using Arduino Uno with LDR and infrared sensors to turn on the lamp automatically with DIM status at night and switch to a "high" status on object detection [7]. The system was developed in the lab using serial communication.

The next article relates to Wi-Fi-based smart street lighting. The paper studied designing “on” and “off” status automatically and how it saves electrical energy and human resources [8]. The smart street lighting system can also be monitored regularly, related to maintenance and quality of service via the internet. To ensure whether the lights are turned on or not, a light sensor is needed, in this case, a light-dependent resistor (LDR). However, to meet the needs of the system, enough Wi-Fi access points are needed to cover the area of public street lighting.

In addition to using Wi-Fi, specific research relates to a monitoring and control system for public street lighting based on an SMS gateway [9]. The working principle is to detect voltage and current with the ATMEGA328 microcontroller by using the SIM800L module as an SMS-based data sender module. Based on this paper, the results of testing using an SMS gateway, if the signal is not good, it is difficult to send SMS data to mobile phones. There is a need for additional interfaces or website-based programs.

Based on the conditions and constraints of the internet network, which is not always available in all places, and the cellular operator network that covers public street lighting, a monitoring and control system is needed as an alternative to internet networks or cellular operators. One of the technologies that can be used is LoRaWAN.

B. LoRa/LoRaWAN Overview

LoRa itself is a wireless communication system for IoT that offers remote and low-power communication. LoRa's efficient use of power is due to the asynchronous communication model, which means that a node will only communicate when the power is sent. LoRa can also be used for various IoT applications, for example, for smart cities where LoRa can support sensors interacting directly. More specifically, LoRaWAN is a network protocol for LoRa devices that is open source and supported by the LoRa Alliance. This technology also has the advantage of saving battery and operating in the 920-923 MHz frequency. In addition, LoRaWAN also fulfills critical IoT requirements, such as two-way communication, end-to-end security, mobility, and locating services.

LoRaWAN devices and protocols enable IoT applications to solve some of the major challenges facing humans, such as energy management, natural resource management (SDA), pollution control, infrastructure efficiency, disaster prevention, and many more. With more than 158 million devices connected to networks in 92 countries that will continue to grow in the future, LoRaWAN is demographically very suitable to be developed in Indonesia to support IoT. LoRaWAN is one of the IoT protocols included in the Low Power Wide Area Network (LPWAN) based on LoRa technology. Long Range Access (LoRa) is a low-power wireless technology that uses a radio spectrum with a sub-gigahertz frequency band.

LoRa can be used with public, private, or hybrid networks to achieve a greater range than cellular networks. LoRa technology can easily integrate with existing networks and enables low-cost, battery-operated Internet of Things. These technologies are ideal for smart cities because of their long signal range and minimal power requirement. LoRa has a unique modulation format acquired by Semtech with chirp spread spectrum (CSS) modulation with the option to add different spreading factors (SF) and bandwidths to optimize the modulation to meet the range and data requirements to cover a wide area [7]. Fig. 1 explains the comparison among LPWAN technologies [10].

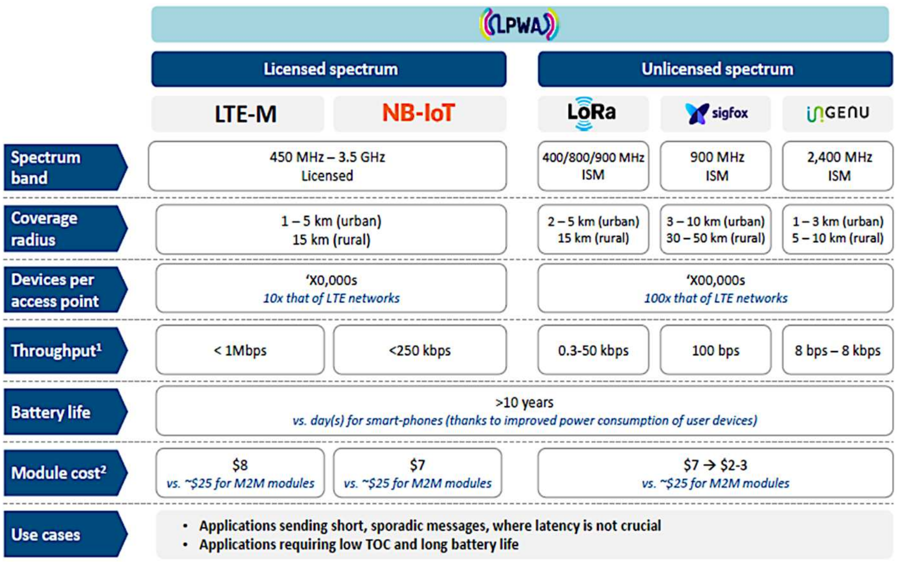

Fig. 1 LPWAN comparison [10]

Based on Figure 1, LoRaWAN has the advantage of using an unlicensed spectrum and efficient power, reducing the cost of the smart street lighting system. Meanwhile, LoRaWAN networks have been deployed nationwide, making implementing the smart lighting use case easier.

C. *LoRaWAN Architecture*

LoRaWAN network is built using a star-to-star topology, which allows the device to work on battery for a long time, which is longer than the mesh network topology [4]. LoRaWAN, a low-power wide-area networking protocol, is designed to connect IoT devices wirelessly. It is built on the lower level LoRa protocol, which can be used on its own, but its previous work (of being used for a smart city environment) suggests that a more robust communication could be achieved by using LoRaWAN on the LoRa physical layer.

A typical LoRaWAN network consists of the following elements: end devices, network servers, application servers, and join servers. A LoRaWAN end device can be a sensor, an actuator, or both. They are often battery-operated. These end devices are wirelessly connected to the LoRaWAN network through gateways using LoRa RF modulation. The gateway is registered (using configuration settings) to a LoRaWAN network server. A gateway receives LoRa messages from end devices and simply forwards them to the LoRaWAN network server. The Network Server manages gateways, end devices, applications, and users in the LoRaWAN network. The Application Server processes application-specific data messages received from end devices. It also generates all the application-layer downlink payloads and sends them to the connected end devices through the Network Server. The Join Server assists in secure device activation, root key storage, and session key generation.

LoRaWAN makes it simple for a user to deploy their gateway. The ability to deploy gateways makes LoRaWAN apt for city-scale IoT deployments. LoRaWAN meets the key IoT requirements, such as bi-directional communication, end-to-end security, mobility, and localization services. It is ideal for covering wide areas where trees and other obstacles might block Wi-Fi signals. Fig. 2 depicts the LoRaWAN architecture in the IoT value chain [11].

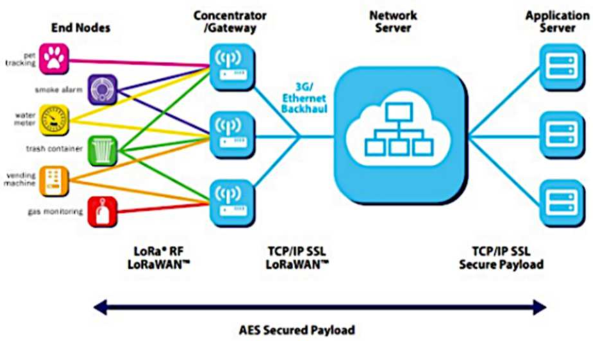

Fig. 2 LoRaWAN Architecture [11]

Based on Figure 2, LoRaWAN architecture consists of a device, gateway, network server, and application server. The device is usually an IoT sensor to capture the measured data. The gateway serves to forward the data from the device to the network server. The network server collects, processes, and sends the data to the application server. Then the last, the application server stores the data and visualizes them into a dashboard or other application.

D. *LoRaWAN Layers*

Two terms need to be distinguished, namely LoRa and LoRaWAN. For the term LoRa, it works at the physical layer (PHY), and wireless modulation is used in long-distance communications. LoRaWAN works on an open network protocol that provides secure two-way communication, mobility, and localization services that are standardized and managed by the LoRa Alliance. Fig. 3 depicts the LoRaWAN layer [12].

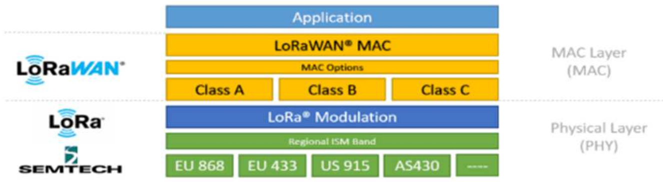

Fig. 3 LoRaWAN Layers [12]

It can be seen in Figure 3 that the physical layer is the layer where LoRa works, such as what frequency and modulation are used. LoRaWAN itself works at the MAC Layer. There are three classes, each with its advantages and disadvantages.

E. *Class on LoRaWAN*

LoRaWAN has different classes of end devices to meet various needs in its application, where the main requirements are battery life and communication latency from the network server to the gateway to the device (downlink) [12]. The classes are defined as Class A, Class B, and Class C. All the LoRa classes-based end devices are bi-directional for communication. The following section mentions the basic features of these LoRa class types.

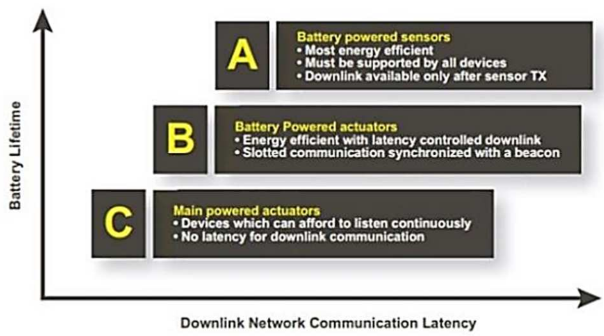

Fig. 4 Class comparison on LoraWAN [12]

Classes in LoRaWAN are divided into three classes, namely class A, class B, and class C. Each class has its advantages and disadvantages. It can be seen in Figure 4 that class A has a type of device that supports two-way communication where each device sending data (Uplink message) will be followed by two short downlinks receiving windows. The transmission slot scheduled by the device itself can be periodic or event. Device class A has the lowest power and is suitable for using device sensors with battery power. The advantage of class A is that the power consumption is low, so it can be used for a long time to save battery usage. The drawback in this class is that the latency is quite large, so the delivery process takes longer.

Class B is also a class with faster latency because the energy efficiency with latency is controlled by downlink and makes more wasteful battery consumption than class A. For the last class, class C (two-way communication device with maximum receive slot): Class C devices almost have a slot receive window that is open continuously and only closed when sending data. This device consumes more power and is designed for actuator devices without latency for downlink communication. This device is not intended to use limited battery resources except for battery sources that have an automatic charging system, such as solar panels or a State Electricity Company. Class C also has a small latency advantage so that data is sent faster than other classes so that data sent in real-time is faster, accurate, but due to the small latency, the power is used more often, so it consumes more power and shortens battery life.

F. LoRaWAN Modulation

LoRa's physical layer uses a spread spectrum modulation technique based on Chirp spread spectrum modulation. Chip Spread Spectrum (CSS) is a spread spectrum dual access technique that can simultaneously accommodate multiple users in one channel. The spread spectrum technique is a technique of exclusive modulation provided by Semtech. Fig. 5 illustrates LoRa modulation using CSS modulation[13].

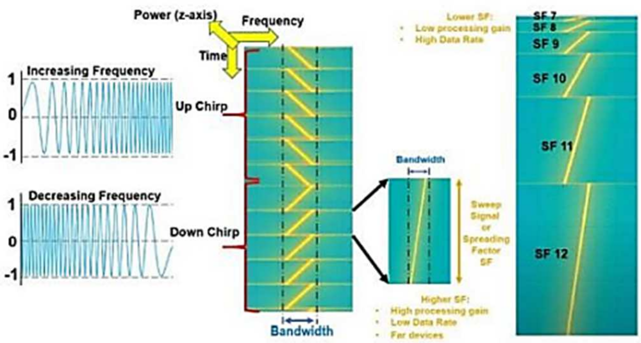

Fig. 5 LoRa Chirp Spread Spectrum Illustration [13]

There are two types of chirp: up-chirp (increased frequency from low to high) and down-chirp (decreased frequency from high to low). The advantage of this method is that the timing and frequency between transmitter and receiver are equivalent, thus greatly reducing the complexity of receiver design. This chip frequency bandwidth is equivalent to the spectral bandwidth signal. The data signal carrying data from the end device to the gateway is chipped off at higher data rates and modulated to the chirp carrier signal. LoRa modulation also includes a variable error correction scheme that increases the robustness of the transmitted signal. The fifth bit of parity information is sent for every four bits of information [13].

G. LoRaWAN Frequency Allocation

LoRaWAN frequency specifications differ from region/country to region/country. This depends on the spectrum allocation and the policies of each country. The following figure shows LoRaWAN frequency allocation globally[12].

	Europe	North America	China	Korea	Japan	India
Frequency band	867-869MHz	902-928MHz	470-510MHz	920-925MHz	920-925MHz	865-867MHz
Channels	10	64 + 8 +8	In definition by Technical Committee	In definition by Technical Committee	In definition by Technical Committee	In definition by Technical Committee
Channel BW Up	125/250kHz	125/500kHz				
Channel BW Dn	125kHz	500kHz				
TX Power Up	+14dBm	+20dBm typ (+30dBm allowed)				
TX Power Dn	+14dBm	+27dBm				
SF Up	7-12	7-10				
Data rate	250bps- 50kbps	980bps-21.9kpbs				
Link Budget Up	155dB	154dB				
Link Budget Dn	155dB	157dB				

Fig. 6 LoRaWAN Frequency Allocation [14]

The frequency allocation for the Indonesia country region is set in the 923 MHz range with the AS923-2 allocation code. In AS923-2, eight channels are available, with seven channels for uplink traffic and 1 for downlink. The spectrum allocated is in the range of 920–923 MHz [15].

H. LoRaWAN Parameters

LoRa technology has some technical parameters to follow so the system will run smoothly and comply with regulations. The parameters are bandwidth, spreading factor, coding rate, transmission power, and duty cycle. The capacities and brief descriptions of these parameters are resumed in Table I.

TABLE I
LORAWAN PARAMETERS

Parameter	Capacity	Impact
Bandwidth	125-500 kHz	If the bandwidth range is high, then the data rate will reach 1 kHz.
Spreading Factor	7-12 symbol	The spreading factor can increase silence in the delivery of data packets.
Payload	50-100 bytes	Data size to be sent
Transmission Power	4-20 dBm	Transmission power increases the ratio of signal to noise.
Duty Cycle	1%	Allowed duration for a LoRa device to connect to the network. For example, a device can only connect to the network with a maximum of 36 seconds per hour (3600 seconds)

Meanwhile, Table II explains the LoRa spreading factor related to how much bit rates, data rates, and maximum payload can be used. In practice, SF=10 is the preferred setting.

TABLE II
LORA MODULATION CHARACTERISTICS

Data Rates	Configuration	Bit Rate (bit/s)	Max Payload
0	SF12/125 KHz	250	51
1	SF11/125 KHz	440	51
2	SF10/125 KHz	980	115
3	SF9/125 KHz	1760	115
4	SF8/125 KHz	3125	242
5	SF7/125 KHz	5470	242
6	SF7/125 KHz	11000	242

Then, Table III shows the LoRa received signal strength index (RSSI) standard, where practically the range of -90 to -110 dBm is acceptable.

TABLE III
RSSI SIGNAL LEVEL [12]

RSSI (dBm)	Information
-30 s/d -60	Very strong. The transmitter and receiver distance is very close
-60 s/d -90.	Very good. Close coverage
-90 s/d -105	Good. Some data are not accepted.
-105 s/d -115	Bad. Can accept but often drop-out
-115 s/d -120	Very bad. Weak signal data is often lost

I. Streetlight

Giving Street Light is perhaps a city lighting company's most significant and costly duty. Lighting can represent 10-38% of the absolute energy bill in a regular urban area worldwide. Road lighting is an especially basic worry for public experts in agricultural nations as a result of its essential significance for monetary and social solidness. Wasteful lighting squanders critical monetary assets yearly, and helpless lighting creates hazardous conditions. Energy productive advances and configuration can cut the road significantly. These investment funds can wipe out or diminish the requirement for new producing plants and give the cash flow to elective energy answers for populaces in far-off territories.

These cost reserve funds can likewise empower regions to extend road lighting to extra regions, expanding admittance to lighting in low-pay and other underserved territories. Also, enhancements in lighting quality and extension in administrations can improve security conditions for both vehicle traffic and walkers. An all-around planned, energy-productive road lighting framework should allow clients to go around evening time with great permeability, well-being, and solace while lessening energy use and costs and improving the presence of the area.

Street lighting or streetlamps have raised a light source that is often mounted on a lamp column or pole either on the side of the road or within the median or suspended over a wire above the road to provide illumination; lightning should always provide signalized intersections and roundabouts. Street lighting or highway lighting is required along the road to ensure safer, more comfortable, more convenient, and more efficient movement of vehicles and pedestrians at night. Lighting should be planned appropriately, allowing night traffic operations with maximum possible safety, comfort and convenience.

J. Efficient Street Lighting

Street lighting is an essential public service typically provided by public authorities at the sub-national and municipal levels. Cities are increasingly investing in energy-efficient street lighting systems to replace or enhance their outdated systems. While reliable and bright public lighting reduces accidents and crime and allows for economic activity after sunset, modern energy-efficient street-lighting technology can also significantly lower energy consumption as well as operation and maintenance costs.

In the most recent couple of years, innovation head shave prompted the improvement of energy-effective lighting frameworks that comprise at least one part like low misfortune weights, steady wattage extreme focus electronic counterbalances, energy-productive Illumina, tors, and better checking and control systems.

K. Smart Street Lighting

A smart streetlight is a public lighting fixture that incorporates technology, such as cameras, light-sensing photocells, and other sensors, to introduce real-time monitoring functionalities. Also referred to as adaptive lighting or intelligent street lighting, this type of lighting system is recognized as a significant step in developing smart cities. In addition to enabling cities to provide the proper amount of streetlight for local conditions, installing intelligent lighting will help improve citizen satisfaction regarding security and safety.

Smart street lighting aims to monitor and control streetlamps using a software application. Smart street lighting has functionality beyond adaptability enabled by standalone control solutions. It encompasses several concepts. At its most basic, a smart streetlight is connected and intelligent. It can come with different levels of context awareness, network connectivity, and processing capability that allow the automation of lighting based on various prediction algorithms or provide active or passive responses to users.

An IoT sensor is attached to individual streetlamps and usually consists of voltage and current sensors, a switch relay, and an LDR sensor. The sensor sends the data through the LoRa gateway to the platform on the internet cloud, where the application is created as the user interface. Smart LED streetlights operate on a set of sensors, which include motion sensors for controlling lights in areas with irregular usage patterns, dusk-to-dawn photocontrol (photocells) for daylight harvesting, and on-board sensors that provide measurable parameters on the condition of the LED luminaire and its power consumption. Building intelligence into LED luminaires provides embedded programmability that enables control and automation based on sensors' variables or user-defined software rules.

The flow can be vice versa when users want to turn on/off the lamp. Fig. 7 depicts how a smart street lighting system works.

Fig. 7 Smart street lighting system design

This research begins by conducting a literacy study on LoRaWAN technology, such as how the LoRaWAN architecture and how LoRaWAN works, as well as conducting technological literacy on smart streetlights. After that, a survey was conducted in Pangandaran regarding how many streetlamps were installed and the condition, behavior, and shape of the surrounding environment where the street lamps were installed.

The smart street lighting system's main logic is embedded in its IoT sensor, in the microcontroller's firmware. The firmware is designed and coded in an ESP32-based microcontroller and consists of approximately 50 bytes of binary data. Then, the data needs to be sent through the LoRa network to reach the IoT platform. The data transmission reliability depends on LoRa coverage and capacity, which means that the number of LoRa gateways should be adequate to cover all street lighting in the Pangandaran regency.

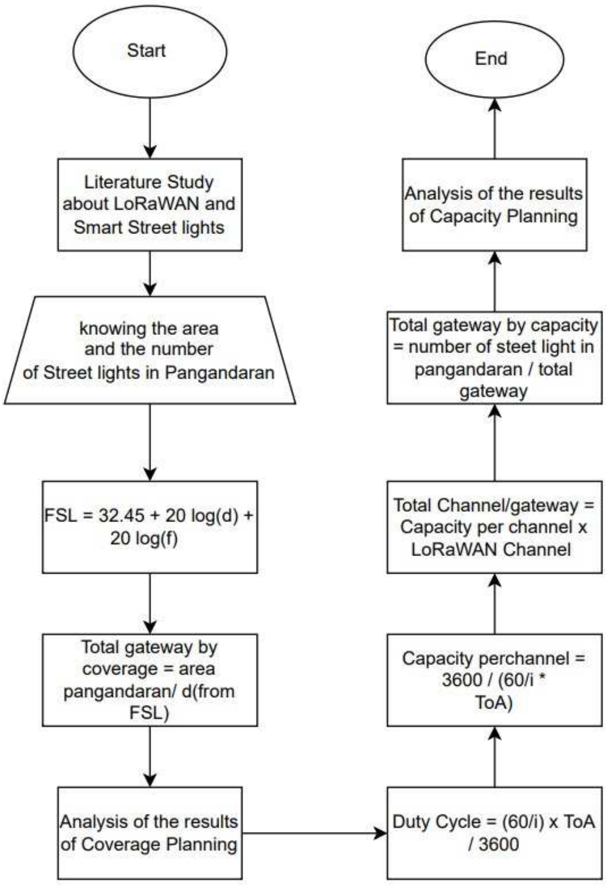

Fig. 8 Research Flow Chart

L. LoRaWAN Coverage

To determine the coverage of the LoRa gateway, a formula of free space loss can be used [16]:

$$LFS = 32.45 + 20\log(d) + 20\log(f) \quad (1)$$

Where:

L_{FS} = Free space loss (dB)
d = Coverage distance (km)
f = Frequency of LoRa (MHz)

L_{FS} can be obtained by Equation 2 [16]:

$$L_{FS} = P_{TX} + G_{TX} - L_{TX} - L_M + G_{RX} - L_{RX} - P_{RX} \quad (2)$$

Where:

P_{RX} = Received power (dBm)
P_{TX} = Transmit power (dBm)
G_{TX} = Transmit gain (dB)
L_{FS} = Free space loss (dB)
L_M = Media propagation loss (dB)
G_{RX} = Received gain (dB)
L_{RX} = Received loss, (dB)

Some variable settings/assumptions are mentioned in the next discussions.

M. LoRaWAN Capacity

To calculate the capacity of each gateway, some technical parameters should be determined first according to standards and recommendations. Table IV informs all the parameter settings in this study.

TABLE IV
LORAWAN PARAMETERS SETTING

Parameter	Capacity
Bandwidth	125 kHz
Spreading Factor	10
Payload	50 bytes
Transmission Power	20 dBm
Duty Cycle	1%

Another important parameter that is included in the capacity calculation is the time on air (ToA). ToA is the time needed to send data from the LoRa gateway [17]. Table V explains ToA values related to the spreading factor and standard data size.

TABLE V
TIME ON AIR TABLE FOR LORAWAN

Spreading Factor	Theoretical ToA [ms]	Mean ToA [ms}	Min ToA [ms]	Max ToA [ms]	Number of Messages
SF 12	1482.80	1483.81	1482.00	1646.00	2544
SF 11	823.30	823.00	823.00	823.00	1121
SF 10	370.70	372.76	370.00	411.00	1054
SF 9	205.80	205.12	205.00	226.00	506
SF 8	113.20	113.06	113.00	123.00	362
SF 7	61.70	61.01	61.00	66.00	3452

III. RESULTS AND DISCUSSION

Pangandaran regency lies on the south side of West Java province, Indonesia, and has an area of 168,509 hectares. The number of public streetlights in the area is approximately 5,000.

A. LoRaWAN Coverage to Cover Pangandaran Smart Street Lightings

First, the number of LoRa gateways to serve smart street lighting in Pangandaran can be calculated using the L_{FS} formula in Equation 1. Assumed that the P_{TX} is 20 dBm [18], practical P_{RX} is -90 dBm, frequency is 920 MHz, and all losses are omitted, the L_{FS} value can be computed:

$$L_{FS} = 32.45 + 20\log(d) + 20\log(f)$$
$$110 = 32.45 +. 20\log(d) + 59.3$$
$$20\log(d) = 18.25$$
$$\log(d) = 0.9125$$
$$d = 8.18 \text{ km}$$

With this number, a map of the Pangandaran regency can be drawn with LoRa gateways placed across the area, as pictured in Fig. 8 below. From the picture, which is mapped with a correct scale, the number of LoRa gateways needed is estimated at 34 gateways.

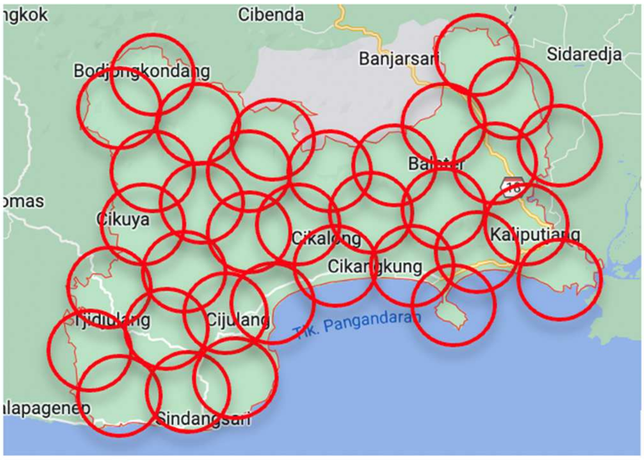

Fig. 9 LoRa gateways to cover Pangandaran regency

B. *LoRaWAN Capacity to Cover Pangandaran Smart Street Lightings*

From the capacity aspect, it is necessary to calculate each LoRa gateway's capacity to handle smart street lighting traffic. The parameters taken are:

- SF = 10 (practical preferable setting)
- Bandwidth = 125 kHz (following Indonesia LPWAN regulation)
- Maximum duty cycle = 1 % (Indonesia regulation)
- Number of channels = 8 channel
- ToA = 411 ms (from Table V)
- Data sending interval = every 5 minutes

First, to comply with Indonesian regulations, we must check whether a data-sending interval of 5 minutes is still under the 1% duty cycle. Here, the duty cycle (DC) can be calculated as:

$$DC = (60/i) \times ToA / 3600$$

Where:

- 60 is the number of minutes in an hour
- i is the delivery interval of data sending (5 minutes).
- ToA is 0.411 seconds (can be rounded to 0.5)
- 3600 is the number of seconds in an hour.

From the calculation, the DC for intervals of 5 minutes is 0.17% or still complies with government regulations.

Then, we calculate the capacity per channel (C_C):

$$CC = 3600 / (60/i * ToA)$$

Where:

- 3600 is the number of seconds in an hour.
- 60 is the number of minutes in an hour.
- i is the interval of data sending (5 minutes).
- ToA is 0.411 seconds or can be rounded up to 0.5 seconds.

Thus, the C_C value or gateway capacity per channel is 600. Meanwhile, LoRaWAN has seven communication channels for uplink (and one channel for downlink), and the overall capacity (C_{TOT}) is:

$$CTOT = c \times CC$$

Where:

- c is the number of uplink channels in LoRaWAN.
- C_C is the capacity per channel.

Since c = 7 and C_C is 600, so the total capacity is 4200 devices per gateway.

So, from the capacity side, each LoRaWAN gateway can handle 4200 smart lighting, or as we know, in Pangandaran there are around 5000 street lighting. At least two gateways are needed. Overall, we should refer to the coverage calculation, which is that 34 gateways should be deployed to cover smart street lighting in Pangandaran.

IV. Conclusion

A smart street lighting system is a good solution to help municipalities monitor and control public street lighting with IoT technology. Meanwhile, LoRa/LoRaWAN is a decent technology to be used in IoT use cases since it offers low power, low cost, and wide coverage. To implement smart street lighting in the Pangandaran regency, many LoRa gateways need to be deployed. Two different methods to calculate the gateways needed are used, namely coverage calculation and capacity calculation. Using coverage calculation with the free space loss approach, the result is an 8.18 km coverage diameter per gateway. Or, to cover Pangandaran, at least 34 gateways need to be deployed. Meanwhile, using capacity calculation with certain parameters taken, only two gateways are needed to handle 5000 street lighting in the Pangandaran regency. Having known the results, the coverage calculation result is more relevant, which is 34 gateways needed to deploy for Pangandaran smart street lighting. For future research, a driving test should prove this theoretical result.

Acknowledgment

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