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PROPAGATION BASED ON DEPLOYMENT PLANNING LORAWAN GATEWAYS OF SMART METER IN URBAN AREA

Andrianingsih Andrianingsih[1], Eri Prasetyo Wibowo[1,*]
I Ketut Agung Enriko[2], Setia Wirawan[1] and Robby Kurniawan Harahap[1]

[1]Doctoral Program in Information Technology
Gunadarma University
Jl. Margonda Raya No. 100, Pondok Cina, Depok, Jawa Barat 16424, Indonesia
andrianingsih@civitas.unas.ac.id; { setia; robby_kurniawan }@staff.gunadarma.ac.id
*Corresponding author: eri@staff.gunadarma.ac.id

[2]Unit Research and Innovation Management
Telkom Corporate University
Jl. Gegerkalong Hilir No. 47, Bandung 40152, Indonesia
enrico@telkom.co.id

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Abstract. *A smart meter is a system that can automatically measure real-time electric power usage in residents or offices. With the advancements in Internet of Things (IoT) technology, in these years the implementation of smart meters is progressing. LoRa/LoRaWAN is the preferred connectivity for smart meters since it offers low power, wide area, and low-cost IoT connectivity. In Indonesia, the LoRa network has already been deployed in many cities, especially to serve smart meter systems. This research aims to calculate the optimum number of LoRa gateways needed for smart meter service in Jakarta city with coverage and capacity calculations. From the coverage calculation (geographical approach), only 11 gateways are needed to cover the Jakarta area. Meanwhile, from the capacity calculation, there should be at least 289 gateways to cover Jakarta with 3.6 million smart meter customers as per the market demand.*
Keywords: Internet of Things, LoRaWAN, Smart meter, Smart grid

1. **Introduction.** Based on previous research such as path loss modeling using the Lee propagation model at 900 MHz, with two modes, area by area, and point by point, and in Lagos Nigeria [1], the path model for smart meters in Thailand [2], and path loss model in Malaysia [3], there have differences in various factors, for example, Malaysia has cleaner weather, which will affect radio signal propagation to be different in each country even though using the Okumura-Hata model and LoRa which is part of the Internet of Things can also be implemented into one of the other fields such as smart farming. Indonesia will develop smart meter installation infrastructure. The development of smart meter infrastructure in Indonesia is carried out by a national smart meter supply company ("PT A"), which in 2019-2028, is planned to build an electrification infrastructure of 35,000 MW and a transmission network along 46,000 km. This research was conducted to contribute to the planning of the development of smart meter procurement to use LoRa. In this regard, intelligent technology is needed to measure the consumption and availability of electrical energy through smart grid technology, where the concept aims to increase the efficiency and effectiveness of smart meter use. A smart grid is a power grid that is connected to a data communication network so that it can be monitored parameters that need to be measured [4]. Implementing the smart grid has been an important role in improving the quality of service to the customers. The smart grid system is known

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as a smart meter, which is a system that can collect, monitor, and control in real time, measure and analyze the distribution of electrification energy use, to then implement it into a measuring tool that can meet the needs of the users effectively [5]. In addition, smart meters can automate smart meter data recording and detect interference. A smart meter device needs to connect to the Internet network [6]. Some connectivity technologies can be used such as Wi-Fi, 3G/4G, and low power and wide area network (LPWAN) networks such as LoRa. Today, LPWAN connectivity is increasingly used because it offers several advantages such as energy-saving, wide range, and low cost. In Indonesia, the LoRa network has been deployed by a national telecommunication company ("PT B"). They also held research cooperation with PT A to implement LoRa-based smart meters. PT B will roll out LoRa infrastructure, installing LoRa gateways in areas needed for smart meter implementation [7]. This research points to calculate the distance to the farthest point and the placement of LoRaWAN gateways to be more efficient with the demand [29].

The problem statements and preliminaries of this discussion are

- How to use Okumura-Hata model methods for support coverage and capacity planning on LoRaWAN gateway.

In this paper, Section 1 focuses on the basic problem of LoRaWAN, followed by an overview of theories in Section 2, with Section 3 presenting achievable formula by Okumura-Hata model propagation for measurement with another category. Furthermore, this research provides analysis of the optimal gateway with coverage and capacity planning in Section 4 as the result. Finally, conclusions are given in Section 5.

2. **Related Works.**

2.1. **Smart grid.** Smart grids are devices that utilize digital communication technologies to improve efficiency, sustainability, and reliability in power grids. One of the most prominent advantages is that the entities in the smart grid can communicate with each other in real time [8, 9].

2.2. **Smart meter.** The smart meter relies on the device to identify and detect household smart meter use and provide real-time information to be sent to a cloud-based platform. Some of the advantages that can be obtained with the use of smart meters are identifying the peak and overall demand, identifying transmission and distribution (T&D) losses and operational expenses, structuring tariffs based on data, and increased predictive capabilities for demand and supply balance [10, 11]. Previous research conducted by Cheng et al. in 2018 aimed to explore the implementation of secure and cost-effective smart meter infrastructure with the performance of LoRa technology [12]. Meanwhile, another study conducted by Enriko et al. in 2021 evaluated the implementation of smart meters with LoRaWAN in rural areas discussing the high availability, cost optimization, and large-scale implementation [13]. The smart meter system was applied to 10,000 households with gateways covering a radius of up to 1.58 km and it is found that the cost efficiency is IDR 11.3 million per month. In terms of architecture, Figure 1 shows the overall smart meter architecture, similar to the value chain system of the Internet of Things (IoT) [14]. At the bottom is the side of the device that is in the customer or is often called the device domain. Next is communication technology that sends data from the side of the device to the server or platform. The electric smart meter system platform is known as the meter data management system (MDMS), whose function is to collect smart meter customer meter data [7, 15]. Finally, applications are used as user interfaces with techniques such as system billing, and dashboard.

2.3. **LoRa parameter.** LoRa used bandwidth such as 500/250/125 kHz. It has spreading factors of 7-12 symbols. It uses coding rate capacity 4/4-4/8 and transmission power 4-20 dBm with standardization based on LoRa Alliance [16, 17].

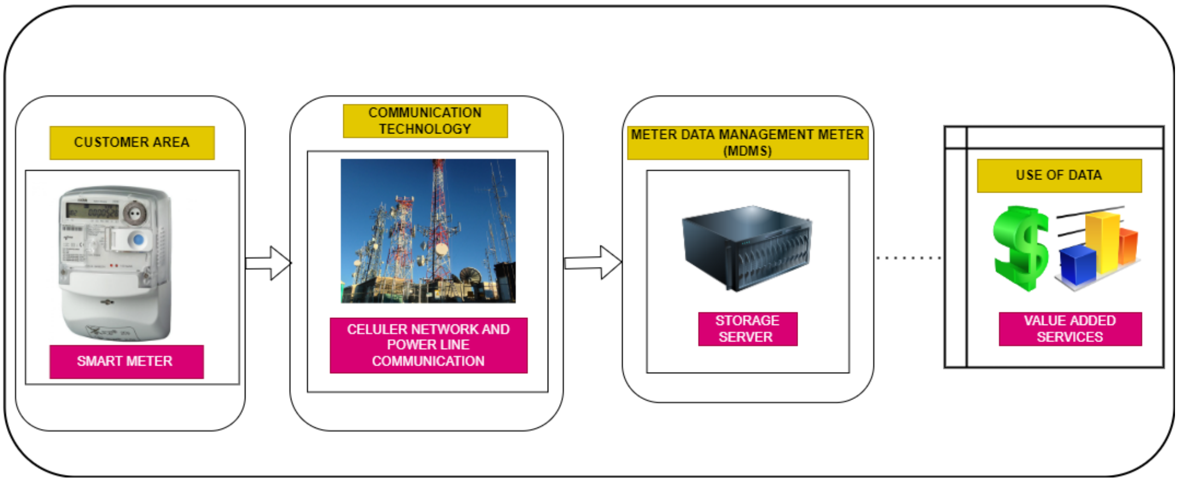

FIGURE 1. Smart meter architecture

2.4. **LoRaWAN architecture.** Important components that make up LoRaWAN are end devices, gateways, and network servers. End devices receive downlink traffic from the network server or device that generates uplink traffic. Meanwhile, gateways are devices that allow LoRa devices to transmit data to the network server [18]. The network server is LoRaWAN's central back end that collects traffic from all gateways and forwards traffic to the application server. Data from the device are received by multiple gateways within the LoRa network based on the star topology. The network server processes and filters the packets before forwarding them to the application server [19].

3. **Methodology.** According to the path loss calculation and using coverage of the site, the number of gateways needed to cover an area can be determined using one of the Forsk Atoll 3.3.2 tools which provide a module for LoRaWAN, in this case, is an urban area, which has the characteristics of buildings located close together, and has tall buildings and a high population density compared to the surrounding cities, therefore using the Okumura-Hata method to calculate the distance between gateways [20, 21].

3.1. **Okumura-Hata.** The Okumura-Hata is an ideal method for urban areas in calculating wireless radio communication propagation, where Okumura is built into three modes, namely for urban, suburban, and rural, which function to predict the behavior of cellular transmission in built-up areas by combining graphical information from the Okumura predictive model. This model also has two other variants for transmission in suburban and open areas. The Hata model predicts total path loss along links from terrestrial wave propagation or other types of cellular communications. This particular version of the Hata model is applicable to radio propagation in urban areas. This model is suitable for both point-to-point and broadcast transmissions and is based on extensive empirical measurements [22, 23].

3.2. **LoRaWAN existing coverage and the demand in Jakarta city.** In this research, the objective is to calculate the number of gateways needed to cover the demand for PT A smart meter in Jakarta city [24]. At the time this paper is written, the existing LoRaWAN coverage in Jakarta is already deployed by PT B. The total number of gateways installed is 44 consisting of 8 in Central Jakarta (Jakarta Pusat), 8 in West Jakarta (Jakarta Barat), 10 in East Jakarta (Jakarta Timur), 6 in North Jakarta (Jakarta Utara), 10 in South Jakarta (Jakarta Selatan) and 2 in the Thousand Island (Kepulauan Seribu). Figure 2 depicts the deployments and coverage of LoRaWAN gateways in Jakarta. The red color represents a strong signal since it is near the gateway, yellow means normal signal coverage, and green means no signal or uncovered.

FIGURE 2. (color online) LoRaWAN gateways deployment in Jakarta

Jakarta city as the object of this research represents urban areas in Indonesia, and is an area with population demographics of 8,540,121 million people spread across six districts and 44 sub-districts. The geographical location is at latitude $-6°12'52.63''$ S, and longitude $106°50'42.47''$ E. Based on the demographic location and geographical location of Jakarta, it is assumed that smart meter users in Jakarta are quite scattered. The demand for smart meters in Jakarta compared to the existing LoRaWAN gateway in PT B is shown in Table 1 below.

TABLE 1. Categories by coverage status

District	**Status**	**Existing**	**Demand**
Jakarta Pusat	High Covered	0	386,633
	Covered	202575	
	Uncovered	187658	
Jakarta Utara	High Covered	280407	667,838
	Covered	212789	
	Uncovered	112953	
Jakarta Barat	High Covered	167249	826,368
	Covered	533045	
	Uncovered	127987	
Jakarta Timur	High Covered	426842	1,039,954
	Covered	471337	
	Uncovered	224033	
Jakarta Selatan	High Covered	106018	706,233
	Covered	555008	
	Uncovered	0	
Kepulauan Seribu Selatan	Uncovered	3476	4,653
Kepulauan Seribu Utara	Uncovered	4919	3,043
Total			3,634,722

Table 1 explains that there are three categories of coverage status of Jakarta's population by checking the gateway deployments. "High Covered" means that an area (a sub-district) is covered by a strong signal with more than one LoRaWAN gateway deployed there. "Covered" means an area is covered by only one gateway. Meanwhile, "Uncovered" is defined as an area that is not yet covered by LoRaWAN.

3.3. **Implementation of the Okumura-Hata in LoRaWAN coverage and the demand through Jakarta city.** Same as other wireless signals, LoRaWAN signal will decay as it propagates through the air. Coverage planning is needed to estimate the area which will be covered by a gateway, regarding the transmit power and losses [25]. From Okumura-Hata model as a reference of path loss, the typical power received at the intercept point is -85 dBm in the free space [16]. In this paper, the figure will be used to calculate the maximum distance from the LoRaWAN gateway to the farthest point a device still can receive the signal. The equation to find the coverage distance is written in Equation (1) below:

$$L_{FS} = 32.45 + 20\log(d) + 20\log(f) \tag{1}$$

where L_{FS} = Free space loss (in dB); d = Coverage distance (in kilometer); f = Frequency of LoRa (in MHz).

Then the LFS can be obtained by Equation (2) [17]:

$$L_{FS} = P_{TX} + G_{TX} - L_{TX} - L_M + G_{RX} - L_{RX} - P_{RX} \tag{2}$$

where P_{RX} = Power receives, in dBm; P_{TX} = Power transmits, in dBm; G_{TX} = Gain transmits, in dB; L_{FS} = Free space loss, in dB; L_M = Losses media propagation, in dB; G_{RX} = Gain receives, in dB; L_{RX} = Losses receive, in dB; L_{TX} = Losses transmission, in dB.

3.4. **LoRaWAN capacity planning.** In this section, we will discuss about LoRaWAN capacity planning. Besides coverage planning, capacity planning should be calculated to refine the coverage planning, since capacity planning will deal with demand and traffic [20]. In LoRaWAN, some parameters are [26, 27]

1) Channel Bandwith
   Bandwidth will impact the capacity. Typically, higher bandwidth used per device will decrease the overall capacity. 125 kHz bandwidth is used as recommended by LoRa Alliance.
2) Data Size
   Data size impacts the gateway capacity as well. The higher the data size, the longer a device should be connected to the gateway.
3) Spreading Factor (SF)
   In this research, we use SF = 10 since the smart meter data size is about 100 kB. Table 2 explains the relations of SF, channel frequency (bandwidth), and payload size.

Table 2. Categories by coverage status

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

4) Duty Cycle
   The duty cycle is the percentage of time a LoRa device occupies the network. According to the Indonesian government's rule, the maximum duty cycle is 1%.
5) Time on Air (ToA)
   ToA refers to the time spent sending data from the transmitter to the receiver. Table 3 calculates ToA for known SF, using standard data size.

Table 3. Time on air table for LoRaWAN

Spreading factor	Theoretical ToA [ms]	Mean ToA [ms]	Min ToA [ms]	Max ToA [ms]	Number of messages
SF12	1482.80	1483.81	1482.00	1646.00	2544
SF11	823.30	823.00	823.00	823.00	1121
SF10	370.70	372.76	370.00	411.00	1054
SF9	205.80	205.12	205.00	226.00	506
SF8	113.20	113.06	113.00	123.00	362
SF7	61.70	61.01	61.00	66.00	3452

4. Result and Discussion.

4.1. **Coverage planning.** In this section, using Equations (1) and (2), the L_{FS} and the distance can be calculated. From Equation (2), we can check the L_{FS} value. Referring to Indonesian regulation, P_{TX} is 20 dBm, and practical P_{RX} or received signal strength index (RSSI) is −85 dBm. If we omit other gains and losses (since they are quite small), the L_{FS} value can be yielded:

$$\begin{aligned} L_{FS} &= 32.45 + 20\log(d) + 20\log(f) \\ 110.6 &= 32.45 + 20\log(d) + 59.3 \\ 20\log(d) &= 18.85 \\ \log(d) &= 0.9425 \\ d &= 8.76 \text{ km} \end{aligned}$$

We can depict the LoRaWAN gateways across Jakarta city in Figure 3. From the picture, the estimated number of gateways in Jakarta will be 11 gateways. This value refers to the coverage planning without calculating the gateway capacity yet. The capacity calculation will be discussed in the next section.

This gateway deployment model is a model with a data scale of 1 : 25,000, where the overlap ratio is 40% of $d = 8.76$ km, so that 11 gateways in Jakarta and Kepulauan Seribu islands are located, based on the centroid of the grid of regional boundaries research.

4.2. **Capacity planning.** After calculating the value of d, the next calculation is to find out how many gateways are needed for sending data packets from LoRa to smart meters in intervals of 15 minutes, 30 minutes, and 60 minutes, with the following conditions:

- SF = 10
- Bandwidth = 125 kHz
- Duty Cycle = 1%
- Number of Channels = 8 Channel
- ToA = 411 ms

Referring to Table 4, since payload data for the smart meter is about 100 kB, the maximum SF that can be used is 10. Then the ToA of each message is 411 ms (Table 4). Based on the maximum allowed 1% duty cycle, Table 4 describes the duty cycle of each data-sending interval, where the duty cycle (DC) can be calculated as

$$DC = (60/i) \times \text{ToA}/3600 \tag{3}$$

where 60 is the number of minutes in an hour; i is the delivery interval of data sending (in minutes); ToA is 0.411 seconds; 3600 is the number of seconds in an hour.

If DC is less than or equal to 1%, then that interval is possible to perform (comply with the regulation).

So, if the data will be sent every 5 minutes, it still complies with the Indonesian regulation. In this research, we will use 15 minutes for data sending intervals, according

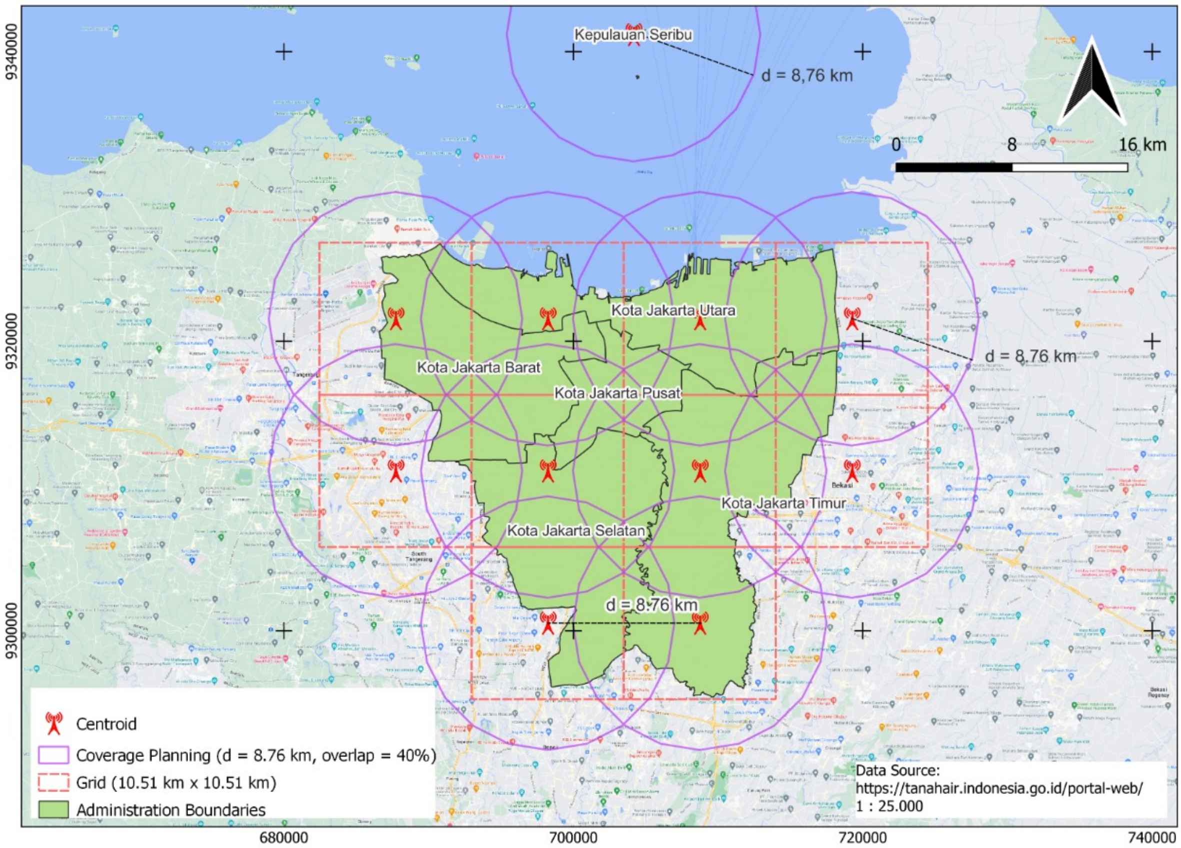

FIGURE 3. Gateway deployment in Jakarta based on coverage planning x_j

TABLE 4. Duty cycle for some sending intervals

Delivery interval (minutes)	Duty cycle
5	0.14%
15	0.05%
30	0.02%
60	0.01%

to the information from PT A expert. With 15 minutes intervals, the gateway capacity can be calculated by determining the occupation of a gateway channel by all devices.

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

$$C_C = 3600/(60/i * \text{ToA}) \tag{4}$$

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 in minutes, here we choose 15 minutes; ToA is 0.411 seconds or can be rounded up to 0.5 seconds.

The C_C value is 1800 which is the capacity of a gateway per channel if we take 15 minutes data-sending interval and ToA of 0.5 seconds. Since LoRaWAN has 7 channels for uplink (and 1 channel for downlink which should be excluded), the overall capacity (C_T) is

$$C_T = c \times C_C \tag{5}$$

where c is the number of channels in LoRaWAN; C_C is the capacity per channel.

Since we have $c = 7$ and C_C is 1800, the overall capacity is 12,600 devices per gateway. From this capacity planning calculation, since in Jakarta city, we have 3,634,722 market demand and each gateway can only serve 12,600 customers per smart meter, so the total number of gateways needed to be installed in Jakarta is 289. This number is far bigger than the coverage calculation which only requires 11 gateways in Jakarta city.

5. **Conclusions.** The implementation of smart meters or smart grids requires efficient connectivity which is found in LoRa/LoRaWAN system. LoRa is the preferred connectivity mode since it offers a long-range, low-power, and low-cost network. In LoRa there are some important parameters like power transmission, RSSI, duty cycle, bandwidth, spreading factor, and data size. With these parameters, LoRa deployment can be planned by calculating coverage and capacity aspects. In this research, the LoRa network deployment plan is used for smart meters in Jakarta city, Indonesia. The parameters' values used are power transmission 20 dBm, RSSI −85 dBm, maximum duty cycle 1% (preferred data sending interval is 15 minutes), bandwidth 125 kHz, spreading factor 10, and data size about 100 kB. Using those parameters, from the coverage calculation, the coverage result is an 8.76 km radius per gateway, or 11 gateways needed to deploy in Jakarta city. Meanwhile, from the capacity calculation, the capacity per gateway is 12,600 devices per smart meter. Having known the market demand is 3,634,722, there should be 289 gateways needed to deploy across Jakarta city.

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