IEEE 802.11ah Network Planning for IoT Smart Meter Application: Case Study in Bandung Area

Perancangan Jaringan IEEE 802.11ah untuk Aplikasi Smart Meter IoT: Studi Kasus di Wilayah Bandung

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Abstract – The growth of Wireless Fidelity (WiFi) technology is so rapid and popular. The technology most widely used for WiFi services is the IEEE 802.11 family of standards. To support the Internet of Things (IoT) era, 802.11ah standard technology has developed, and the standard is intended to provide a low-cost mode of operation, with a wider coverage area, and can support thousands of devices per cell. This paper discusses IEEE 802.11ah Standard Network Planning for the Internet of Things Application (Case Study: Smart Meter Using WiFi.id Network in Bandung), with the aim of improving network quality in terms of coverage and capacity to improve the efficiency of the WiFi network and so that it can supports the Internet of Things (IoT) service. Network planning using 802.11ah for the internet of things application with a smart meter case study using the WiFi.id network has been successfully carried out. To cover the entire area of Bandung, 23 sites are required. In the capacity, the Tx slots needed to cover possible smart meters for each site are only 9 tx slots out of a total of 100 tx slots.

Keywords: 802.11ah, internet of things (IoT), smart meter, low power wide area network (LPWA), wireless fidelity (WiFi)

Abstrak *– Pertumbuhan teknologi Wireless Fidelity (WiFi) begitu pesat dan populer. Teknologi yang paling banyak digunakan untuk layanan WiFi adalah keluarga standar IEEE 802.11. Untuk mendukung era Internet of Things (IoT), teknologi standar 802.11ah telah dikembangkan, dan standar ini dimaksudkan untuk menyediakan mode operasi berbiaya rendah, dengan area jangkauan yang lebih luas, dan dapat mendukung ribuan perangkat per cell. Penelitian ini membahas tentang Perencanaan Jaringan Standar IEEE 802.11ah untuk Internet of Things Applicatiom (Studi Kasus: Smart Meter Menggunakan Jaringan WiFi.id di Bandung), dengan tujuan meningkatkan kualitas jaringan dalam hal coverage dan capacity, untuk meningkatkan efisiensi jaringan WiFi, sehingga dapat mendukung layanan Internet of Things (IoT). Untuk mencakup seluruh wilayah Bandung, diperlukan 23 site. Pada capacity, dibutuhkan 9 tx slot untuk mencakup possible smart meter pada setiap site, dari total 100 tx slot.*

Kata Kunci: *802.11ah, internet of things(IoT), smart meter, low power wide area network (LPWA), wireless fidelity (WiFi)*

INTRODUCTION

The development of Wireless Fidelity (WiFi) technology has developed rapidly and is popular. IEEE 802.11 standard technology has been used massively in a variety of environments (such as homes, offices, roads, campuses, etc.), where different devices (for example smartphones, laptops, tablets, wearables devices, etc.) use the standard is the main access method for connecting to the internet (Banos, Afaqui, Lopez, & Garcia, 2017). The technology most widely used for WiFi services is the IEEE 802.11 a / g / n / ac standard. The a / g / n / ac version of IEEE 802.11 technology does not focus on developing the Internet of Things (IoT) specification (Banos et al., 2017). To support the Internet of Things (IoT) era, 802.11ah standard technology has widely developed, and the standard is intended to provide a low-cost mode of operation, with a wider coverage area, and can support thousands of devices per cell (Banos et al., 2017). IEEE 802.11ah has a high data rate and uses a wider bandwidth compared to other technologies that support the Low Power Wide Area (LPWA) (Wang & Fapojuwo, 2017).

Internet of Things (IoT) is a network of devices that communicate among themselves using Internet Protocol (IP) connectivity without human intervention (Singh & Singh, 2016). The Internet of Things (IoT) ecosystem consists of smart objects, intelligent devices, smartphones, tablets, and others (Singh & Singh, 2016). WiFi is a good candidate for ensuring connectivity in IoT applications because of its extraordinary growth over the past few years, even though power consumption is much higher (Mahmoud & Mohamad, 2016). The IEEE 802.11 standard (also known as WiFi) is the wireless standard most commonly used in traditional networks (Toni Adame, Albert Bel, Boris Bellalta, Jaume Barcelo, 2014). Machine to Machine (M2M) communication via the Internet of Things (IoT) network can be done via WiFi because its base widely used, both public and private, as well as its popularity as a technology of access to the internet (Anis, Gadallah, & Elhennawy, 2016). Some wireless protocol options available for Internet of Things (IoT) devices are Bluetooth Low Energy (BLE), Zigbee 802.15.4 based, HaLoW 802.11ah, WiFi, and cellular (Finnegan & Brown, 2018).

Optimization efforts show that WiFi can be 10 times more energy-efficient than ZigBee. Also, because of the wide spectrum of data rates needed for the Internet of Things (IoT) applications (Mahmoud & Mohamad, 2016). IEEE802.11ah supports features such as extended range (around 1 km), a large number of devices per Access Point (AP), low power operation, support for bandwidth channels 1, 2, 4, 8 and 16 MHz; 158 kbps with data rates reaching 78 Mbps, scheduled and unscheduled operations and short frame structures (Domazetovic, Kocan, & Mihovska, 2017). IEEE 802.11ah (Domazetovic et al., 2017) operates on unlicensed radio bands (all sub-1GHz) that depend on specific country regulations. For example, the targeted frequency bands are 863-868 MHz in Europe, 902-928 MHz in the US, 916.5-927.5 MHz in Japan and China, South Korea, and Singapore also have special allocations. Channel bandwidths of 1 MHz and 2 MHz have been widely adopted, although, in some countries, wider configurations using 4, 8, and 16 MHz are also allowed.

In designing or evaluating services that depend on WiFi infrastructures, such as the Internet of Things (IoT) services for smart cities, coverage, and signal strength are very important. Based on this, this paper discusses IEEE 802.11ah Standard Network Planning for the Internet of Things Application (Case Study: Smart Meter using WiFi.id Network in Bandung). To improve network quality in terms of coverage and capacity to improve network efficiency WiFi and so that it can support the Internet of Things (IoT) services. WiFi.id was chosen because it has many existing sites in public areas and has a large market penetration. Also, people are more familiar with WiFi.id as a WiFi service in public areas. Because 802.11ah belongs to the 802.11 WiFi family. The Internet of things applications used in this study is a smart electricity meter. The user assumption is PLN's electricity meter.

OVERVIEW

Internet of Things (IoT)

Internet of Things (IoT) (Singh & Singh, 2016) is a computational concept that describes a future in which everyday physical objects will be connected to the Internet and can identify themselves to other devices. Internet of Things (IoT) is a network of devices that communicate among themselves using Internet Protocol (IP) connectivity without human intervention. The Internet of Things (IoT) ecosystem consists of smart objects, intelligent devices, smartphones, tablets, and others. Internet of Things (IoT) networks run using Radio-Frequency Identification (RFID), Quick Response (QR) codes, sensors, or wireless technology to enable communication between devices. The concept of IoT leads to the need for inter-communicability and the inter-operability of sensor nodes that communicate wirelessly (Gunasagaran et al., 2015). In practice, it is not possible to design all Internet of Things (IoT) nodes to use the same communication protocol, because each node requires different data rates, coverage and power requirements based on their respective applications (Gunasagaran et al., 2015). Healthcare smart wares such as smart bands require low power consumption and usually use the Bluetooth Low Energy (BLE) protocol for communication while communications for smartphones with an Internet of Things (IoT) environment use WiFi for better data rates (Gunasagaran et al., 2015). Machine to Machine (M2M) communication via the Internet of Things (IoT) network can be done via WiFi because its base is widely used, both public and private, as well as its popularity as a technology of access to the internet (Anis et al., 2016).

At present, the IEEE 802.11 standard can be considered a ubiquitous technology found in various electronic device users and used in heterogeneous scenarios (Banos et al., 2017). However, the IEEE 802.11 standard has not shown a significant presence in the Internet of Things (IoT) market (Banos et al., 2017). IEEE 802.11 Working Group (WG) aims to bridge the gap by introducing a new amendment called IEEE 802.11ah (Banos et al., 2017). The IEEE 802.11ah standard is the first approach of the IEEE 802.11 Working Group (WG) which aims to support specific features of the Internet of Things (IoT) with thousands of stations operating in the sub 1 GHz frequency band, namely for Industrial, Scientific, and Medical frequency bands (ISM) band (Banos et al., 2017).

IEEE 802.11ah

Some wireless protocol options available for Internet of Things (IoT) devices are Bluetooth Low Energy (BLE), Zigbee 802.15.4 based, HaLoW 802.11ah, WiFi, and cellular (Finnegan & Brown, 2018). IEEE 802.11ah is the overhead version of the lightweight IEEE 802.11 standard to meet the needs of the Internet of Things (IoT) (Toni Adame, Albert Bel, Boris Bellalta, Jaume Barcelo, 2014). The IEEE 802.11 standard (also known as WiFi) is the wireless standard most commonly used in traditional networks (Toni Adame, Albert Bel, Boris Bellalta, Jaume Barcelo, 2014). IEEE 802.11 Standard Technology has widely adopted for all digital devices, including laptops, smartphones, tablets, and digital television. However, the original WiFi standard is not suitable for IoT applications because of overhead frames and high power consumption (Toni Adame, Albert Bel, Boris Bellalta, Jaume Barcelo, 2014). Therefore, the IEEE 802.11 working group initiated the 802.11ah task group to develop standards that support low overhead, and power-friendly communication suitable for sensors and motes (Singh & Singh, 2016). IEEE802.11ah supports features such as extended range (around 1 km), a large number of devices per Access Point (AP), low power operation, support for bandwidth channels 1, 2, 4, 8 and 16 MHz; 158 kbps with data rates reaching 78 Mbps, scheduled and unscheduled operations and short frame structures (Domazetovic et al., 2017).

IEEE 802.11ah defines two operating modes (Toni Adame, Albert Bel, Boris Bellalta, Jaume Barcelo, 2014): (a) Traffic Indication Map (TIM) mode and (b) non-TIM mode. Stations that operate in one of these two modes are each referred to as TIM- and non-TIM status. TIM stations have periodic access to the medium and are usually used for high bandwidth requirements and receive up and down access. TIM stations wake up periodically to receive beacons that are broadcast by AP (Toni Adame, Albert Bel, Boris Bellalta, Jaume Barcelo, 2014). On the other hand, in non-TIM mode (power saving mode), the station does not need to wake up periodically to receive beacons. Instead, they send at least one PS-Poll or trigger frame transmission to the AP associated with each listen interval. Non-TIM stations are intended to exchange low amounts of data and thus can request buffered DL traffic from the AP or send UL traffic whenever they wake up. IEEE 802.11ah (Domazetovic et al., 2017) operates on unlicensed radio bands (all sub-1GHz) that depend on specific country regulations. For example, the targeted frequency bands are 863-868 MHz in Europe, 902-928 MHz in the US, 916.5-927.5 MHz in Japan and China, South Korea, and Singapore also have special allocations. Channel bandwidths of 1 MHz and 2 MHz have widely adopted, although, in some countries, wider configurations using 4, 8, and 16 MHz are also allowed. Table 1. shows the basic PHY parameters of 802.11ah.

Table 1 Basic PHY Parameter of 802.11ah (Domazetovic et al., 2017)

PHY Parameters	Supported Value
Channel Bandwidth	1Mhz, 2Mhz, 4Mhz, 8Mhz, 16Mhz
Modulation Schemes	BPSK, QPSK, 16QAM, 64QAM, 256QAM
Code Rates	1/2 with 2 times repetition, 1/2, 2/3, 3/4, 5/6 in either convolutional or low-density parity-check (LDPC)
Maximum Number of Spatial Streams	Four spatial streams
Data Rates	150kbps (1Mhz channel bandwidth, 1 spatial stream, BPSK, 1/2 coding rate, repetition coding) to 374Mbps (16 Mhz channel bandwidth, 4 spatial streams, 256QAM, 5/6 coding rate)

PHY transmission (Domazetovic et al., 2017) is an OFDM-based waveform consisting of 32 or 64 tones / sub-carriers (including tones that allocated as pilots, guards, and Current Current) with a distance of 31.25 kHz. Modulations supported include BPSK, QPSK, and ranging from 16 to 256-QAM. Technologies such as single-user beamforming, Multi-Input Multi-Output (MIMO) and multi-user MIMO downlinks, were first introduced in IEEE 802.11ac, and have now been adopted in the IEEE 802.11ah standard.

Smart Meter

Smart meters (Lloret, Tomas, Canovas, & Parra, 2016) are digital electronic devices that collect information about electricity, water, or gas usage and send it safely to utilities. This counter provides end-users with insights into real-time consumption to the utility and, in some cases. Also, this data makes it possible to understand shopping habits, improve network efficiency, and contribute to saving electricity, water, or gas. Thanks to smart meters, consumption data can be managed, and every impact on the network can be monitored in real-time.

For this reason, it is important to emphasize several functional aspects related to this device. On the one hand, the meter's battery life limits the amount and frequency of data transmission. Several power-saving and energy optimization techniques must be applied. On the other hand, high-frequency data reading opens up new spectrums of possibilities for understanding electricity/water/ gas demand networks and service management.

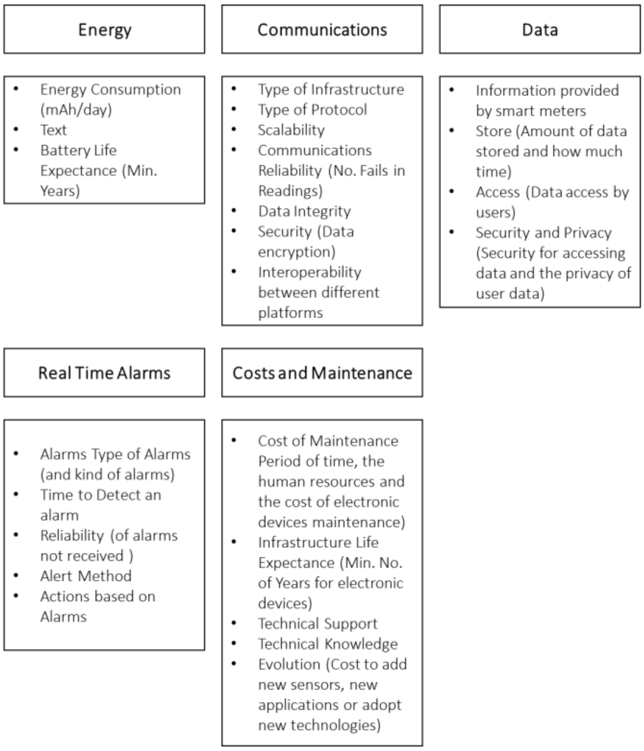

Figure 1 Features of Smart Meter

At present, the measurement system has developed into Smart Metering Systems (SMS) (Martirano, Manganelli, & Sbordone, 2015). Distributed SMS is a measurement system consisting of different meter structures located in the power system at various distribution levels (delivery points, main switchboard, local switchboard, individual users) (Martirano et al., 2015). Directive 2012/27 / EC defines SMS as an electronic system that can measure energy consumption, provides more information than conventional meters, and can send and receive data using a form of electronic communication (Martirano et al., 2015). The most common architecture of a distributed intelligent measurement system is made by (Martirano et al., 2015): (a) Smart meter devices, local electronic meters (b) Data concentrators (DC), process data from several meters; (c) Communication protocols, which allow two-way communication between smart meters and data concentrators on a local or wide area network; (d) The monitoring system, the IT platform on which the program obtains and describes different data. Data collection was done in two steps (Martirano et al., 2015): (1) the smart meter sends data to the data collector, and then (2) the data collector sends the data to the utility provider or smart network.

METHODOLOGY

In this study, an IEEE 802.11ah network planning standard analysis will be conducted. The Internet of things applications used in this study is smart meters. The area used in this study is Bandung City, and the case study in this study is the smart meter connected to the WiFi.id network. The study that will be reviewed from the implementation, namely coverage prediction and capacity prediction. Flowcharts in this study are as follows:

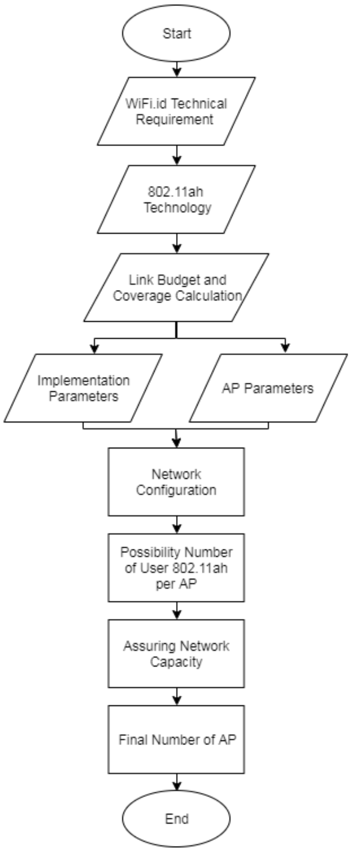

Figure 2 Study Flowchart

Coverage prediction simulations are carried out using radio network planning tools such as Forsk Atoll 3.3.2. IEEE 802.11 technology is a WiFi telecommunications standard commonly used for interworking, such as security, hotspots, quality of service, roaming, and the like. IEEE 802.11ah offers various advantages, such as easy to use in outdoor environments, excellent propagation characteristics from low frequencies, and various levels of installation scenarios (license-exempt, light licensing, professional / interference reduced) (Aust, Prasad, & Niemegeers, 2012). High sensitivity and link margins are further characteristics of IEEE 802.11ah (Aust et al., 2012). Besides, long battery life and energy-saving strategies will be an integral part of the IEEE 802.11ah standard (Aust et al., 2012).

Defined Scenarios

In this study, the scenario divided into two, namely coverage planning and capacity planning. In coverage planning, there are five existing outdoor WiFi.id areas. Table 2 shows the five existing outdoor WiFi.id areas of Bandung City owned by PT Telkom that used for the coverage planning scenario in this study. WiFi.id was chosen because it has many existing sites in public areas and has a large market penetration. Also, people are more familiar with WiFi.id as a WiFi service in public areas. Also, because 802.11ah belongs to the 802.11 WiFi family. The Internet of things applications used in this study is smart meter, the smart meter used is PLN's electricity meter, assuming the user is PLN's electricity meter. The following coverage planning scenarios used in this study:

Table 2 Coverage Planning Scenarios

No.	Site Name	Region
1	Taman Gor Saparua	Bandung
2	Taman Lansia	Bandung
3	Rest Area Km 147	Bandung
4	Taman Jomblo / Taman Pasupati	Bandung
5	Taman The Marakesh	Bandung
6	Outdoor WiFi to cover smart meters throughout the Bandung area.	Bandung

In capacity planning, the scenario based on report types (with a payload of 20 bytes) on smart meter technical requirements with the assumption of concurrent users. Concurrent users are the number of users requesting a system with the same payload simultaneously. The capacity analysis is carried out to find out how many devices can connect and be serviced by IEEE 802.11ah technology standards. Devices or internet of things applications used in this study is the smart electricity meter. In capacity planning, the scenario carried out is based on report types (with a payload of 20 bytes) on smart meter technical requirements with the assumption of concurrent users. Concurrent users are the number of users requesting a system with the same payload simultaneously. The capacity analysis is carried out to find out how many devices can connect and be serviced by IEEE 802.11ah technology standards.

Coverage Planning

The link budget is done to calculate the gain and loss from the transmitter to the receiver. To calculate for the attenuation of the signal sent during transmission, i.e., a random attenuation, such as attenuation caused by reflection. Received power or the link budget between the Transmitter and receiver can be explained using the following equation [21]:

$$P_{rx} = P_{tx} + G_{tx} + G_{rx} - PL \quad (1)$$

Where, P_{rx} is Received power, expressed in dBm, P_{tx} is Transmitted power, expressed in dBm, G_{tx} is Transmitter gain, expressed in dB, G_{rx} is Receiver gain, expressed in dB, and PL is Path Loss. PL depends on the environment, the frequency used, and the distance between the two devices (Bellekens, Tian, Boer, Weyn, & Famaey, 2017). PL can be simulated with the path loss model, which can empirically or deterministically calculate signal loss (Bellekens et al., 2017). Propagation Loss Model (Bellekens et al., 2017) is used to determine signal strength in a wireless medium based on the distance between the transmitter and the receiver.

Propagation Loss Model for IEEE 802.11ah standard technology divided into two, namely indoor and outdoor. The Propagation Loss Model for indoor is the same as for the IEEE 802.11n standard technology (Bellekens et al., 2017). Propagation Loss Models for outdoor can use macro deployment (Bellekens et al., 2017). The following parameters used in this study:

Table 3 Coverage Simulation Parameters

Parameters	Values	References
Band Frequency	920 - 923 Mhz	(Kementrian Komunikasi dan Informatika Republik Indonesia, 2019)
P_{rx}	-98 dBm	(Newracom, 2019)
P_{tx}	24 dBm	Assumption
G_{tx}	3 dB	(Aust, 2014)
GP_{rx}	3 dB	(Toni Adame, Albert Bel, Boris Bellalta, Jaume Barcelo, 2014)
Antenna	Omnidirectional	Assumption
Antenna's height	25 meters	Assumption

The following are the Receiver Sensitivity at 2 Mhz Channel Bandwidth:

Table 4 Rx Sensitivity at 2 Mhz Channel Bandwidth

Modulation	Rx Sensitivity
256 QAM	-72 dBm
64 QAM	-78.5 dBm
16 QAM	-85 dBm
QPSK	-91 dBm
BPSK	-98 dBm

Macro deployment model assuming the antenna height is 15 meters above the rooftop (Bellekens et al., 2017), and in this study, the antenna height is assumed to be 25 meters, with propagation loss (in dB) as follows:

$$PL(d) = 8 + 37.6log_{10}(d) + 21log_{10}(d) + \left(\frac{f}{900\,Mhz}\right) \quad (2)$$

Where $PL(d)$ is the path loss for the macro deployment model, d is the distance between the access point and the smart meter (in $meter$), and f is the transmission frequency used (in Mhz). To find out the single-site coverage and total sites needed can be calculated using the following formula:

$$single\ site\ coverage = 3.14 \times (d)^2 \quad (3)$$

$$total\ sites = \frac{area\ wide}{single\ site\ coverage} \quad (4)$$

Bandung is a city with an area of 168.4 km^2. PLN electricity customers in Kota Bandung are 844,224 customers (Badan Pusat Statistik Kota Bandung, n.d.). To find out PLN electricity customers in the city of Bandung per km^2 can be calculated using the following formula:

$$PLN\ customers\ /\ km^2 = \frac{number\ of\ PLN\ customers}{area\ wide} \quad (5)$$

Capacity Planning

The capacity analysis is carried out to answer the question of how many end devices be served by an Access Point (AP) or gateway. Calculating the number of Access Points (AP) needed to meet the needs of bandwidth sites is the recommended way to start the density wireless network design. ERC recommendation (Qutab-ud-Din et al., 2016) defines the duty cycle as a percentage of the maximum transmitter "on" time (active duration) at one carrier frequency, relative to one hour. Thus we can formulate the percentage of duty cycle D as follows:

$$D = 100 \times \frac{t\ active}{3600} \quad (6)$$

Duty cycle (Qutab-ud-Din et al., 2016) usually specified per device, i.e., only the marked device activity is related and not the whole network. The duty cycle for the ISM sub GHz band in the US, in Europe, the duty cycle for devices must not exceed 2.8%, being an important coexistence mechanism, as long as it complies with LBT and AFA channel access requirements. There are even more stringent requirements for devices that do not support LBT and AFA, ranging from 0.1% to 1%. That is, with a duty cycle of 1%, the available time slot in 1 hour is 100 tx slots. 802.11ah can support STA or users up to $8{,}191\ (= 2^{13} - 1)$ (Toni Adame, Albert Bel, Boris Bellalta, Jaume Barcelo, 2014). 1 tx slot can hold as many as 8,191 STAs or users. Here are the parameters to determine the capacity user:

Table 5 Capacity Parameters

Parameters	Values	References
Payload	20 bytes	(Hidayati, Reza, & Adriansyah Mufti, 2019)
Payload Overhead	30 %	("Documentation," n.d.)
Duty Cycle	1 %	(Qutab-ud-Din et al., 2016)
User Type	Concurrent User	("Documentation," n.d.)
Channel Bandwidth	2 Mhz	Assumption

IEEE 802.11ah includes Low Power Wide Area (LPWA) technology that supports the internet of things industry. The frequency of work for the internet of things in Indonesia is 920 - 923 MHz (Kementrian Komunikasi dan Informatika Republik Indonesia, 2019). The frequency used for Low Power Wide Area (LPWA) telecommunications equipment. The range of channel bandwidth available for Low Power Wide Area (LPWA) devices in Indonesia is 3 Mhz, whereas the IEEE 802.11ah standard technology supports 1 Mhz, 2 Mhz, 4 Mhz, 8 Mhz, and 16 Mhz channel bandwidths (Domazetovic et al., 2017). IEEE 802.11ah standard technology in Indonesia only supports 1 Mhz or 2 Mhz channel bandwidth. The following are the table for Data Rates based on modulation in 2 Mhz Channel Bandwidth (Domazetovic et al., 2017):

Table 6 Data Rates at 2 Mhz Channel Bandwidth

Modulation	Data Rates
256 QAM	7.8 Mbps
64 QAM	6.5 Mbps
16 QAM	3.9 Mbps
QPSK	1.95 Mbps
BPSK	0.65 Mbps

COVERAGE AND CAPACITY ANALYSIS

Based on calculations, the number of sites needed to cover the entire Bandung area is 23 sites and the number of PLN electricity customers in the Bandung area 5,014 user per km^2.

Coverage Analysis

1.) The following are the coverage prediction in Taman Lansia:

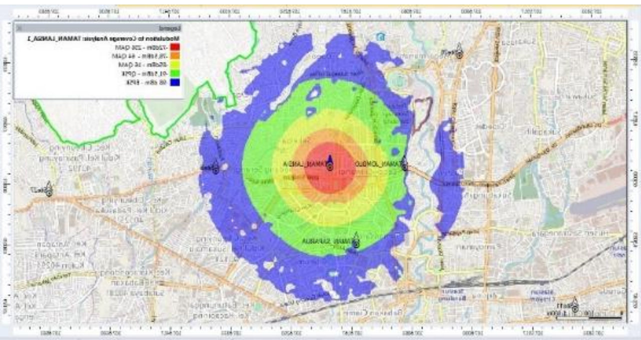

Figure 3 Coverage Prediction of Taman Lansia

The implementation of IEEE 802.11ah standard technology has been successfully simulated at the Taman Lansia site, with longitude x = 107.621666and latitude y = -6.902965. Poor coverage occurs because of the uneven contours of the earth.

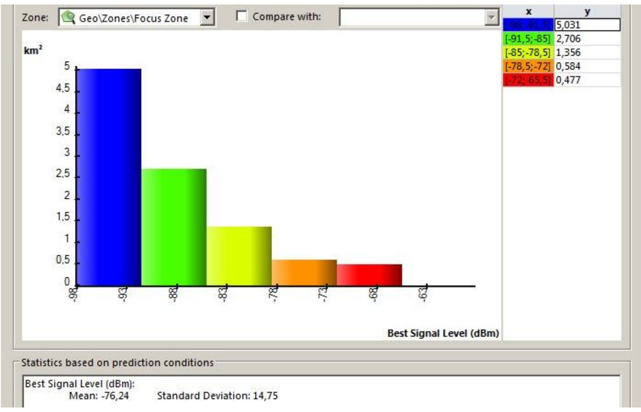

Figure 4 Signal Level Histogram (dBm) Histogram Area (km^2) Taman Lansia

Zone	Prediction	Legend	Zone surface (km^2)	Surface (km^2)	% of Covered Area	% Focus Zone
Focus Zone	Modulation to Coverage Analysis: TAMAN_LANSIA_1		168,4	10,15337	100	6
		-72dBm - 256 QAM	168,4	0,47702	4,69814	0,3
		-78,5dBm - 64 QAM	168,4	1,0609	10,44875	0,6
		-85dBm - 16 QAM	168,4	2,41677	23,80264	1,4
		-91,5dBm - QPSK	168,4	5,1226	50,45222	3
		-98 dBm - BPSK	168,4	10,15337	100	6

Figure 5 Area Coverage Based on Signal Strength in Taman Pasupati / Taman Lansia

The area that successfully covered after implementing the IEEE 802.11ah standard technology is 12.37037 $\boldsymbol{km^2}$. The average power or signal level successfully received by end-users is -76.24 dBm, with a standard deviation of 14.75 dBm. That means that by installing an IEEE 802.11ah access point (AP) standard in the Taman Lansia area, the Bandung area that was successfully covered was 6% of the total area of Bandung. Predicted users based on coverage around Taman Lansia are 50,909 smart electricity meter users.

2.) The following are prediction coverage in Taman The Marakesh:

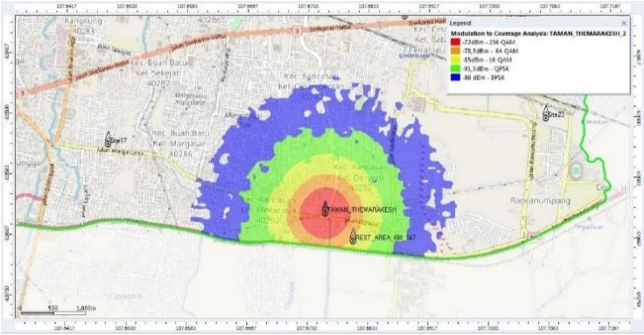

Figure 6 Coverage Prediction of Taman The Marakesh

The implementation of IEEE 802.11ah standard technology has been successfully simulated at The Taman Marakesh site with longitude x = 107.677029002 and latitude y = -6.967808589. The condition around Taman The Marakesh is an area that is quite tolerable because, in the vicinity, there are residential residents, schools, and offices. Poor coverage occurs because of the uneven contours of the earth.

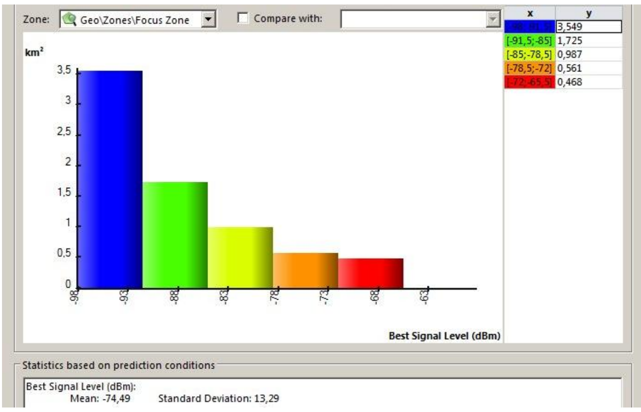

Figure 7 Signal Level Histogram (dBm) Histogram Area (km^2) Taman The Marakesh

Zone	Prediction	Legend	Zone surface (km^2)	Surface (km^2)	% of Covered Area	% Focus Zone
Focus Zone	Modulation to Coverage Analysis: TAMAN_THEMARAKESH_2		168,4	7,28977	100	4,3
		-72dBm - 256 QAM	168,4	0,4677	6,41584	0,3
		-78,5dBm - 64 QAM	168,4	1,02852	14,10909	0,6
		-85dBm - 16 QAM	168,4	2,01545	27,64765	1,2
		-91,5dBm - QPSK	168,4	3,7406	51,313	2,2
		-98 dBm - BPSK	168,4	7,28977	100	4,3

Figure 8 Area Coverage Based on Signal Strength in Taman The Marakesh

The area covered successfully after implementing the IEEE 802.11ah standard technology is 7.28977 km^2. The average power or signal level successfully received by end-users is -74.49 dBm, with a standard deviation of 13.29 dBm. That means that by installing an IEEE 802.11ah access point (AP) standard in The Taman Marakesh area, the Bandung area that was successfully covered was 4.3% of the total area of Bandung. Predicted users based on coverage around

Taman The Marakesh are 36,551 smart electricity meter users.

3.) The following is the coverage prediction in the city of Bandung:

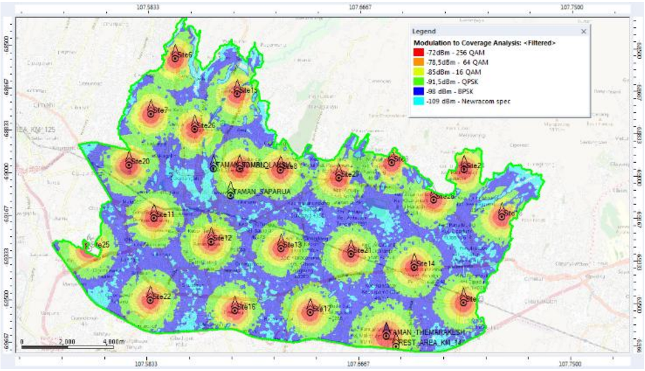

Figure 9 Coverage Prediction of Bandung

The implementation of IEEE 802.11ah standard technology has successfully simulated in Bandung with a total of 23 sites. with longitude x = 107.609810 and latitude y = -6.914744. In the coverage simulation, which aims to cover the total smart electricity meter user in Bandung, the BPSK (newracom) receiver sensitivity is -109 dBm (Newracom, 2019), used to be able to optimize user coverage at the cell edge. Based on the results of the analysis above, it can be concluded that the number of existing sites that are fulfilled only consists of 2 sites.

The existing site, which fulfilled, is located in the Taman Lansia and Taman The Marakesh. Sites in Taman Lansia, Taman Saparua, and Taman Jomblo located in the adjacent area, as are sites in Taman The Marakesh and Rest Area Km 147 - Toll Purbaleunyi. Therefore, one of the sites with the best coverage must be chosen among these adjacent sites so that the implementation of the IEEE 802.11ah network technology is more efficient. Taman Lansia was chosen because it has a larger surface ($\boldsymbol{km^2}$) compared to Taman Gor Saparua and Taman Jomblo. Surface ($\boldsymbol{km^2}$) in Taman Lansia is 10.15337 $\boldsymbol{km^2}$, with the number of predicted users based on coverage is 50,909 smart electricity meter users. Whereas Taman The Marakesh was chosen because it has a larger surface ($\boldsymbol{km^2}$) compared to the Rest Area Km 147 - Toll Purbaleunyi. The surface ($\boldsymbol{km^2}$) in The Taman Marakesh is 7,28977 $\boldsymbol{km^2}$, with the number of predicted users based on coverage being 36,551 smart electricity meter users. Therefore, the number of sites that met is 2 sites. To cover the entire city of Bandung, 21 additional sites are needed, because, in the calculation, it requires 23 sites to cover the entire city of Bandung.

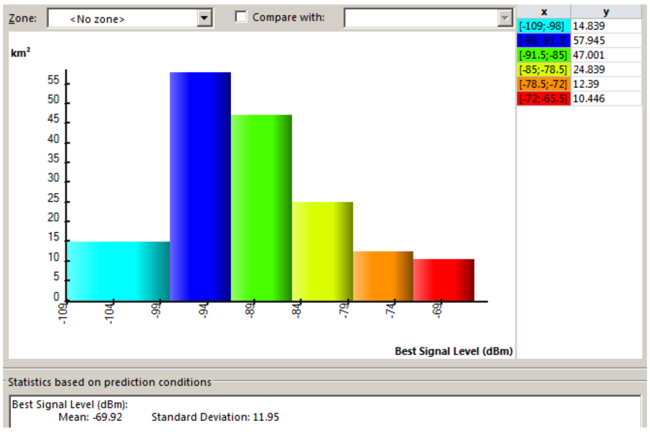

Figure 10 Signal Level Histogram (dBm) Histogram Area (km^2) Bandung City

Zone	Prediction	Legend	Zone surface (km^2)	Surface (km^2)	% of Covered Area	% Focus Zone
Focus Zone	Modulation to Coverage Analysis: <Filtered>		168,4	167,46089	100	99,4
		-72dBm - 256 QAM	168,4	10,4464	6,23811	6,2
		-78,5dBm - 64 QAM	168,4	22,83635	13,63683	13,6
		-85dBm - 16 QAM	168,4	47,67562	28,4697	28,3
		-91,5dBm - QPSK	168,4	94,6766	56,53654	56,2
		-98 dBm - BPSK	168,4	152,62172	91,13872	90,6
		-109 dBm - Newracom spec	168,4	167,46089	100	99,4

Figure 11 Area Coverage Based on Signal Strength in Bandung City

The area that successfully covered after implementing the IEEE 802.11ah standard technology is 167.46089 km^2. The average power or signal level successfully received by end-users is -69.92 dBm, with a standard deviation of 11.95 dBm. That means that by installing 23 access points (AP) IEEE 802.11ah standards in the city of Bandung, the area successfully covered is 99.4% of the total area of Bandung. Predicted users based on coverage in all areas of Bandung City are 839,649 smart electricity meter users. The following is a graph of the number of users by type of Modulation Coding Scheme (MCS):

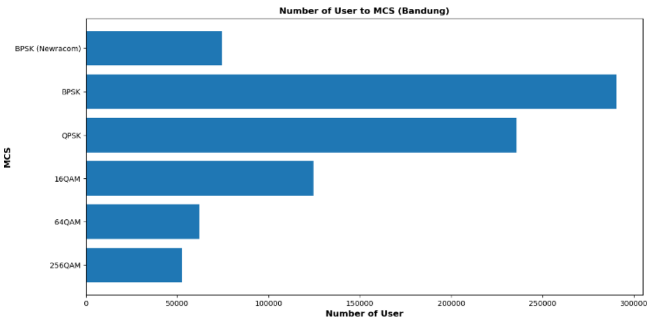

Figure 12 Number of User to MCS

Figure 12 shows the number of successful users that are covered by the type of MCS in the city of Bandung. BPSK obtained the highest number of users, namely 290,537 users and the least number of users was obtained by BPSK (Newracom), which was 52,379 users out of a total of 839,649 smart electricity meter users in all areas of the city of Bandung who were able to be covered based on coverage prediction. The following is a surface km2 graph of based on the Modulation Coding Scheme (MCS) type:

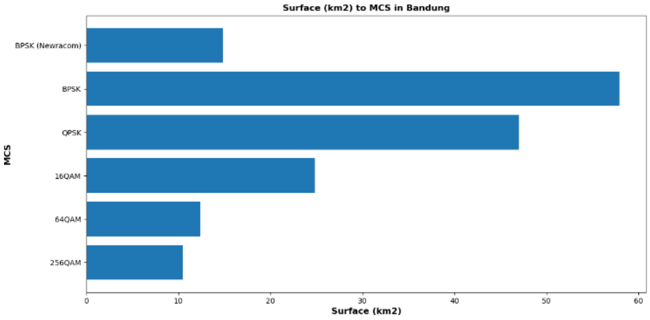

Figure 13 Surface (km^2) to MCS in Bandung City

Figure 13 shows the Surface km^2 in Bandung that was successfully covered by the type of MCS. The largest surface km^2 obtained by BPSK, which is 57,94512 km^2 and the smallest surface km^2 obtained by 256 QAM, which is 10,4464 of the total area of the city of Bandung, which has an area of 168.4 km^2. From Figure 4.26, it can be concluded that the greater the MCS, the smaller the surface km^2, and the smaller the MCS, the greater the surface km^2.

Capacity Analysis

In the capacity analysis, the capacity calculation is performed to determine the number of users per site that can be covered and the number of users that can be covered based on the Modulation Coding Scheme (MCS) type. The following is the available Tx slots within 1 hour with duty cycle 1%:

tx1	tx2	tx3	-->	tx100
8191	8191	8191	8191	8191

Figure 14 Transmission Slot in One Hour

Based on the capacity parameter, with a payload of 20 bytes with 30% overhead, possible users that can be covered are 8,191 smart electricity meter users per tx slot, out of a total of 100 tx slots in 3600 seconds or 1 hour. 100 tx slots can hold as many as 819,100 smart electricity meter users. The bigger the payload, it will lower user capacity. That is, with a duty cycle of 1%, the available time slot in 1 hour is 100 tx slots. 802.11ah can support STA or users up to 8, 191 (= $2^{13} - 1$) (Domazetovic et al., 2017).

The figure below is occupied user capacity to MCS:

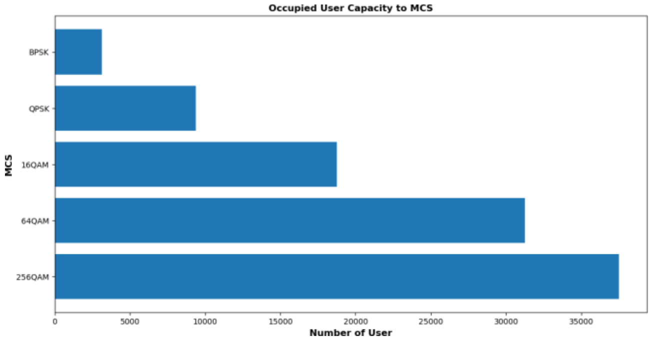

Figure 15 Occupied User Capacity to MCS

Figure 15 shows the number of possible users that can be covered by the type of Modulation Coding Scheme (MCS). Possible users get the most from 256 QAM, with 37,500 smart electricity meter users. The least possible user was obtained by BPSK, with 3,125 users. But in the capacity specification of 802.11ah, it can only accommodate a maximum user load of 8,191 users. Smart meter payload is 20 bytes, with 30% overhead. That is, MCS that can accommodate the number of users with a maximum load, namely QPSK, 16 QAM, 64 QAM 256 QAM. Meanwhile, the number of users that can be accommodated by BPSK is 3,125 users. It can be concluded that the greater the MCS, the more users will be covered, and vice versa. Therefore, a larger MCS will produce a large data rate, thus allowing users to be covered will be greater, and vice versa. However, the greater the MCS also affects the coverage obtained, because the greater the MCS, the smaller the coverage will produce, and vice versa. Here are the maximum users based on MCS:

MCS	User
256 QAM	8,191
64 QAM	8,191
16 QAM	8,191
QPSK	8,191
BPSK	3,125

Figure 16 Maximum Users based on MCS

Site in Taman Lansia is used as an example to calculate user capacity per site, assuming the site is active only in Taman Lansia. Users are assumed to be concurrent users. Concurrent users are the number of users requesting a system with the same payload simultaneously. The figure below is the Number of users to MCS at Taman Lansia (per site):

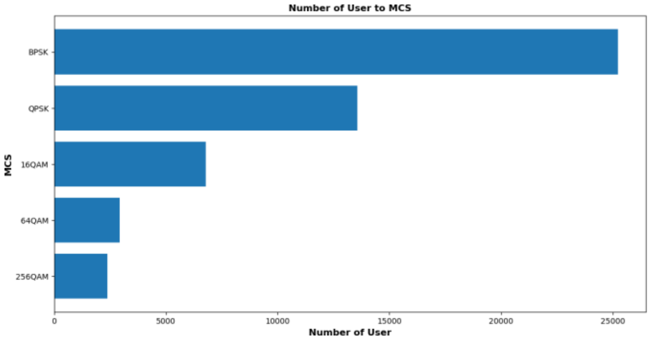

Figure 17 Number of the user to MCS in Taman Lansia (per site)

Figure 17 shows the possible smart electricity meter users in Taman Lansia. BPSK has the most number of users, namely 25,225 smart electricity meter users, and the least is MCS 256 QAM, which is as many as 2,392 smart electricity meter users. Smart meter payload is 20 bytes, with 30% overhead, then the maximum of the user that can be accommodated by BPSK is 3,125 users. While other MCS, such as QPSK, 16 QAM, 64 QAM 256 QAM, can accommodate a maximum user load, which is as much as 8,191 smart electricity meter users. Because BPSK obtains most users, users at BPSK prioritized to be served, and users can use the remaining connection slots at other MCS. In 1 transmission slot, there are 8,191 connection slots for 8,191 users. In 1 transmission slot, BPSK users who served as many as 3,125 users, and the rest of the connection slot, can be used to accommodate 5,066 users, which can be used by other MCS users. The figure below shows the total tx completed to the period:

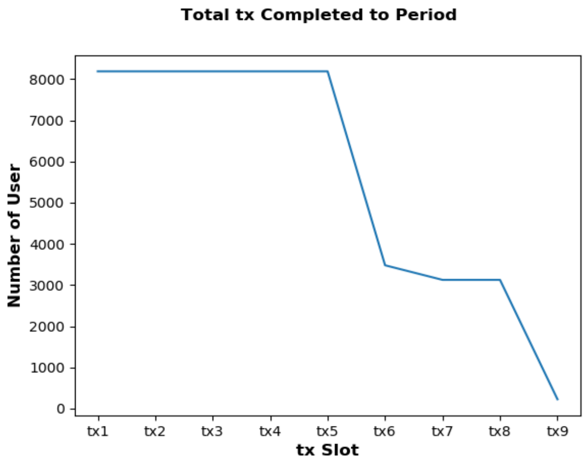

Figure 18 Total Tx Completed to Period

Possible users based on capacity in the Taman Lansia site are 50,909 users. While 1 tx slot can only hold as many as 8,191 smart electricity meter users, meaning that for complete all transmissions with 50,909 smart electricity meter users, 9 tx slots are needed. Tx1 to tx5 can accommodate as many as 8,191 smart electricity meter users. Tx 6 holds 3,479,721 smart electricity meter users, tx 7 and tx 8 holds 3,125 smart electricity meter users, and tx 9 holds 224.2813 smart electricity meter users. So, to complete the transmission as much as 9 tx, it takes 5.4 minutes or 324 seconds. If the maximum total tx in 1 hour is 100 tx slots, that means there are still 91 tx slots that not used. Tx slots that not used can be used for the Internet of things applications other than smart meters.

CONCLUSION

IEEE 802.11ah network planning for the internet of things application with a smart electricity meter case study using the WiFi.id network has been successfully carried out. To cover the entire area of Bandung, 23 sites are needed. After 802.11ah is implemented on the site / the existing network owned by WiFi.id then, it is fulfilled by only 2 sites, which means it requires 21 additional sites to cover smart mater in all areas of the City of Bandung. In capacity, each site has 100 tx slots in 1 hour time period. 1 tx slot can hold as many as 8,191 users. The tx slot that is used or needed to cover possible user smart electricity meter in each site is only 9 tx slots, meaning that there are still 91 tx slots that are empty or not used. 91 empty tx slots can be used for another internet of things applications other than smart electricity meter.

On the other hand, IEEE 802.11ah has not been included in the Low Power Wide Area (LPWA) standard in Indonesia. And in fact, the IEEE 802.11ah standard can be used as a solution for the standardization of connectivity on the Internet of Things (IoT) networks and services. This study still does not consider interference with other technologies, such as NB-IoT, LoRa, Sigfox, and another internet of things technology. For further research, we can consider the interference problem if we are going to do network planning for the internet of things application.

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