A Feasibility Analysis of the Use of IEEE 802.11ah to extend 4G Network Coverage

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ABSTRACT

The 4G LTE network has been launched in many countries including Indonesia, and all telecommunications operators are competing to expand their service coverage. Due to various reasons, there are a lot of areas that remains uncovered by the 4G LTE network. With the increase in cellular traffic, operators must continue to improve their service coverage. One of the scenarios to expand the service coverage is by offloading the traffic to a more cost-effective 802.11ah network in which one 802.11ah access point can serve thousands of mobile devices and support the Machine-to-Machine (M2M)/Internet of Things (IoT) communication. This study simulates the effect of the number of nodes on MCS performance evaluation of the 802.11ah protocol. The simulation is conducted by utilizing NS3 software to evaluate the throughput, delay, packet delivery ratio and energy consumption. This study also simulates 802.11ah coverage prediction to expand the LTE networks by utilizing Atoll Radio Planning Software. The results show that the performance obtained by varying the number of nodes/users from 100 to 1000 nodes is technically acceptable. In addition, the service coverage of 802.11ah network can solve the problem of blank spot area.

1. Introduction

Internet of Things (IoT) era is characterized by millions of devices connected to the network. There are two categories of communication technologies currently used for M2M applications. The first is Wireless Sensor Network (WSN) that id used for interconnecting multiple sensor nodes spread over a particular area. The second is a regular mobile network that is used for isolated nodes to allow the gateway of WSN to reach the internet (Adame et al., 2013). Several communication technologies, such as Zigbee, Bluetooth, LoWPAN, and 802.15.4, have been used for transmitting data in an M2M system.

IEEE 802.11ah working group (TGah) was created in 2010. It has released a new standardization of Wi-Fi, called Wi-Fi Halow, to support M2M wireless communication to cover the gap between the existing 3rd Generation Partnership Project (3GPP) mobile network and Wireless Sensor Network. IEEE 802.11ah technology uses unlicensed sub 1 GHz worldwide wireless local area network (WLAN) standard for future M2M communication to support a wide set of scenarios. It supports a large number of devices (up to 8.191 devices) to connect to one access point (AP). Other advantages of IEEE 802.11ah include efficient energy consumption, long-range coverage, up to 100 kbps data rates, and high throughput (Aust et al., 2012). The 802.11ah is a wireless communication PHY and MAC layer protocol. In the MAC layer, 802.11ah introduces mechanisms such as organizing the system that would be explained further in the next section. Related to simulation analysis of the Modulation and Coding Scheme (MCS) in various environments, it can be assumed that MCS 08 with bandwidth 2 MHz is suitable for high-density location in urban areas. Meanwhile, MCS 0 with bandwidth 1 MHz suitable for low-density location (rural area). In a rural environment, low-order modulation and coding can guarantee normal communication because of the better channel environment than in a dense urban area. 802.11ah have been studied in many research topics such as performance comparative study that compare 802.11ah with other technologies. For instance, Muteba et al (2019) compares 802.11ah with existing standard NB-IoT and LORA. Other researches focus on the optimization of 802.11ah. An example is a research by Tian, Famaey, et al (2016) that implement Restricted Access Window (RAW) to increase throughput and energy efficiency. Meanwhile, Šljivo et al (2018) carry out a study by optimizing

RAW grouping and Traffic Indication Map (TIM) segmentation to influence scalability, throughput, latency, and energy efficiency in the presence of bidirectional TCP/IP traffic.

This study will focus to investigate the ability of 802.11ah to complement the 4G LTE coverage blankspot and functioning as a wifi extension.

2. Literature review

2.1. Offloading methode

802.11ah protocol allows low rate wireless station to be used in the sub-gigahertz spectrum that enables various useful scenarios in numerous use-cases, such as smart cities, smart network sensors, autonomous device controlling, and wireless access service over a wide area (Khorov, Lyakhov, et al., 2015). In addition, 802.11ah is able to be used for offloading cellular data communication traffic. Mobile data offloading represents the idea of cost-efficient technology to release the overloaded traffic in cellular networks. The 802.11ah introduce the offloading infrastructure from existing radio network to gain extra capacity, to anticipate the increase of the number of user, and to improve overall network performance and user experience. Masek et al (2015) discussed two solutions for offloading between LTE and 802.11ah when the performance needs exceed the threshold of service provided by LTE network under an agreed-upon quality of service (QoS). The first solution is by offloading LTE traffic based on SNR measurement where the mobile node continuously measures the value of SNR every half second. When the SNR reaches the defined SNR threshold value (10 dBm) then the mobile will be switched to the 802.11ah access point. Second, offloading LTE traffic based on network throughput. Instead of conducting offloading by SNR measurement, this method approaches utilization of the real throughput as decision logic to switch the traffic from LTE to 802.11ah access point. The measurement is performed every 0.1 second. Based on the simulation, the throughput offload decision-based resulting Ping-Pong effect is caused by the similar value of throughput for both network. This effect can be reduced by redefining the minimum operation time period for both radio access network (RAN) to 3 seconds. Overall both decision methods have demonstrated the ability to reduce load/congestion of cellular networks and improve the user’s performance. The study will examine this type of scenario where some QoS will be evaluated and coverage simulation will be provided to shows the extension of 802.11ah in the cellular network.

2.2. Technical Specification of IEEE 802.11ah

IEEE 802.11ah is a Wireless LAN (WLAN) standard that can operate at sub 1 GHz, in contrast to other 802.11 WLAN standards that operate in the 2.4 GHz and 5 GHz frequency bands. This has several positive impacts, including not having to make compatibility of the system and reducing the protocol overhead of 802.11ah. The 802.11ah can be used for a variety of purposes, including a very large sensor network as depicted in Figure 1, increasing the range of hotspots and outdoors Wi-Fi that can be used for cellular traffic offloading. Another favorable characteristic for lower frequency provides more improved coverage than the other 802.11 standards that operate at higher frequencies (Sun et al., 2017).

The 802.11ah consists of 2 layers, the Physical (PHY) layer and the Medium Access Control (MAC) layer. 802.11ah PHY was designed using down-clocked operations on IEEE 802.11n, so it has a channel bandwidth distribution mode of 2 MHz, 4MHz, 8 MHz, 16 MHz, and one additional channel bandwidth of 1 MHz, as shown in Figure 2.

2.3. Distributed Coordination Function (DCF)

Distributed Coordination Function (DCF) is a fundamental Media Access Control (MAC) technique of the IEEE 802.11 standard based on WLAN. DCF is designed to provide best-effort services. DCF does not provide a mechanism for differentiating types of data streams, so this technique assumes that each data stream has the same priority, and the main focus of DCF is to reduce collisions between competing for data streams to access the wireless medium.

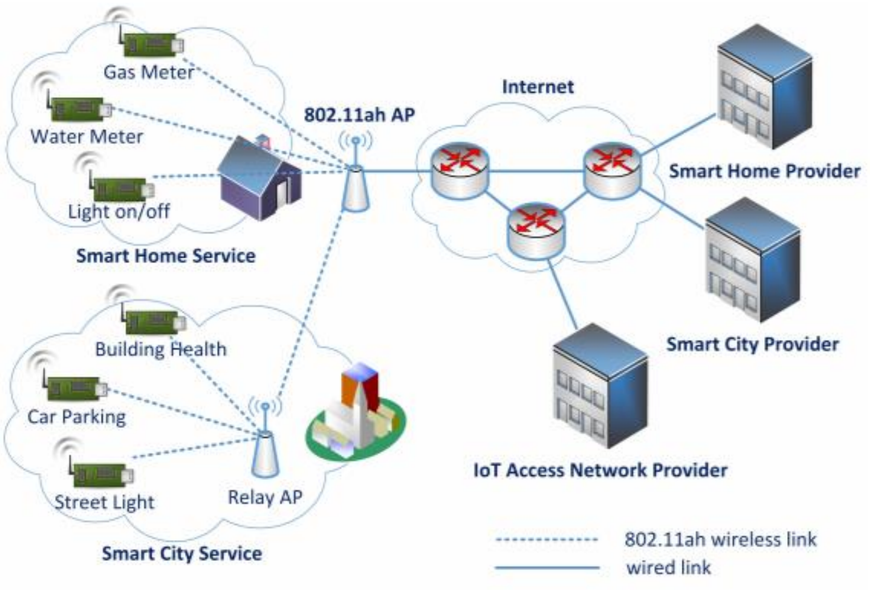

Figure 1. 802.11ah Network Model (Kim et.al., 2017)

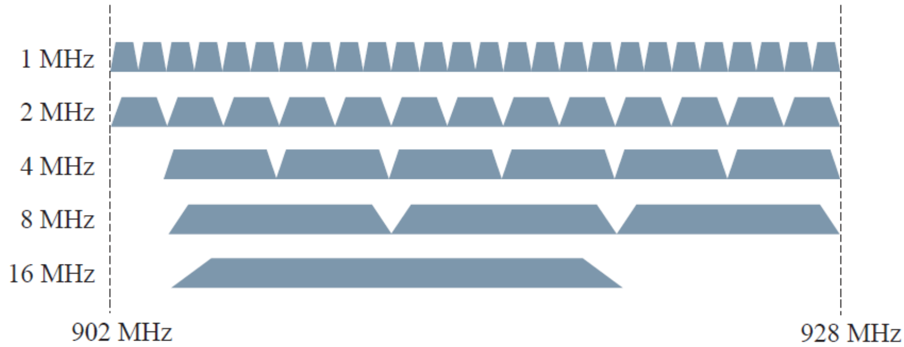

Figure 2. IEEE 802.11ah channelization (Sun et al., 2017)

DCF works in "listen before talk" or more commonly known as Collision Sense Multiple Access with Collision Avoidance (CSMA/CA), where stations pay attention to the condition of the medium (in this case the wireless medium) before determining whether the medium can be used or not by using a carrier sensing. If a station that has a packet to be sent finds the medium busy, the station will suspend its transmission and sensing the channel again until the channel is idle. After the station gets an idle medium on the DCF Interframe Space (DIFS) duration, the station performs a backoff procedure by decreasing the backoff counter value for the channel in idle condition every 1-time slot. The backoff counter value for the channel in idle condition every 1-time slot. The backoff counter is a random value that is uniformly distributed between 0 to the value of the Contention Window (CW). If the backoff counter value has reached zero and the medium is still free, the station starts packet transmission. If the medium is busy again when the station performs the backoff procedure, the station will pause the backoff counter countdown and will continue the countdown after delaying for a period of time (Tian et al., 2018).

2.4. MAC Layer

The 802.11ah MAC layer provides additional system specifications such as reduced power consumption that can be obtained by creating two modes of the radio component, namely the active mode and the power saving mode. In addition to the MAC layer, some features allow the addition of the number of stations that can be served, increase the efficiency of media access and throughput.

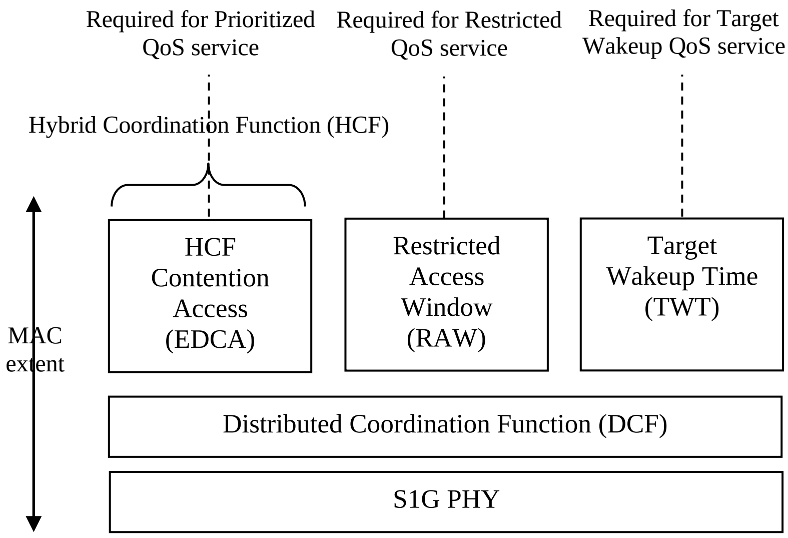

Figure 3. 802.11ah MAC Architecture (Seok & Law, 2016)

2.5. Physical Layer

Physical layers for IEEE 802.11ah inherit the characteristics of 802.11ac and adapt them to sub 1 GHz frequencies. The IEEE 802.11 ah standard has a channel width of 1MHz, 2MHz, 4MHz, 8MHz, and 16MHz. Channels that are commonly used 802.11ah are 1MHz and 2MHz. Therefore, the physical layer can be classified into two categories, namely transmission mode with channel bandwidth 2 MHz and transmission mode with channel bandwidth 1 MHz. When operating at low frequencies and small bandwidth, it is possible to transmit over a longer range (up to 1 Km) with considerably less power consumption compared to traditional Wi-Fi technology (for example 802.11n and 802.11ac) which usually works at wider bandwidth at 2.4 and 5 GHz frequencies.

PHY transmission is an OFDM-based wave consisting of 32 or 64 tones/sub-carriers with 32.25 kHz spacing. As shown in Table 1, IEEE 802.11ah uses several forms of modulation and coding schemes (MCSs), number of spatial streams (NSS), and duration of guard intervals (GI). GI consists of short GI and normal GI, of which short GI can produce more data rates 11% higher than normal GI (Tian et al., 2018).

Table 1. Modulation and coding scheme 802.11 ah

MCS Index	Modulation	Coding rate	Measurement	
			1Mhz	2Mhz
0	BPSK	1/2	300	650
1	QPSK	1/2	600	1330
2	QPSK	3/4	900	1950
3	16-QAM	1/2	1200	2600
4	16-QAM	3/4	1800	3900
5	64-QAM	2/3	2400	5200
6	64-QAM	3/4	2700	5850
7	64-QAM	5/6	3000	6500
8	256-QAM	3/4	3600	7800
9	256-QAM	5/6	4000	Not Valid
10	BPSK	1/4	150	Not valid

Source: Tian, Deronne, et al (2016)

2.6. Restricted Access Window (RAW) Mechanism

RAW system was created to reduce the possibility of collisions with thousands of stations in networks and to increase power efficiency. The main idea of RAW system is to limit the collection of stations that will access the channel and to divide the efforts of each station to access the channel within the interval period. In other words, RAW divides stations into groups and divides channels into slots then place each slot in each group. Stations can send only during the slot. By broadcasting information elements in the form of special RAW Parameter Set (RPS) beacons, the AP will allocate some restricted medium access intervals, called RAW. During the RAW period, only the status group determined by the associated identifier (AID) characteristics from the same page can access the medium. During RAW, every station is prohibited from accessing a channel before its time slot arrives. It means that the stations outside the RAW slot is not protected at all from the collision. The devices would be in sleep mode to save energy until turning to their RAW to access the channel (Khorov, Krotov, et al., 2015). Unlike other IEEE 802.11 technologies, each station uses two back-off states for Enhanced Distributed Channel Access (EDCA) to manage transmissions both inside and outside the specified RAW. The first Back-off is used outside the RAW slot, and the second is used inside the RAW slot. For the first back-off state, the station suspends the back-off at the beginning of each RAW and returns it to continue the back-off at the end of the RAW. For the second back-off state, the station starts the back-off with the beginning of the back-off state in the RAW slot and removes the back-off state at the end of the RAW slot.

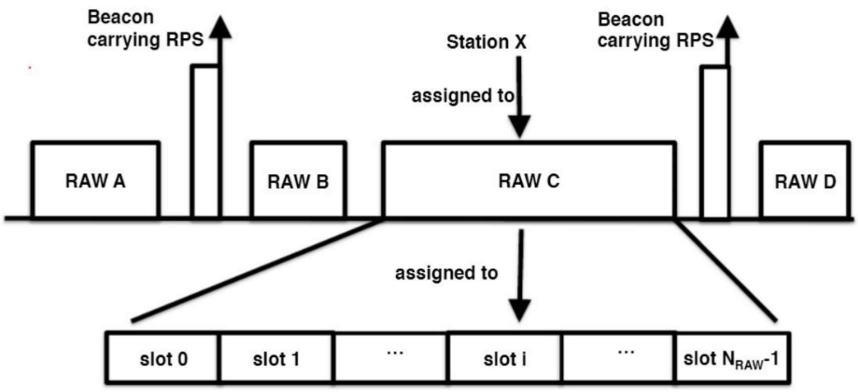

Figure 4. RAW Mechanism (Tian, Deronne, et al., 2016)

At the current 802.11 standard, beacons are the trigger for power saving (PS) station contention on the channel, which is a bottleneck in the entire power management framework since the station will be prepared to capture every beacon signal. IEEE 802.11ah introduces the traffic indication map (TIM) segmentation mechanism that divides information sent in TIM into several segments and to transmit TIM segments in rotation. The station that comes from the TIM segment only needs to be prepared to listen according to its TIM beacon, so it can overcome the situation for long period of power savings. Power consumption can be further reduced by TWT for stations that rarely transmit data. TWT stations can set a time slot with an AP when they have to prepare to exchange frames. Therefore, the station can be in a state of long power-saving during its TWT interval. Since there is no mechanism to determine the RAW size, an estimation algorithm has been proposed by Park et. al. (2014) that the optimal size of uplink RAW of the 802.11ah massive devices can be determined to yield better uplink access channel efficiency.

3. Research Method

3.1. Coverage assessment Scenario and Requirements of IEEE 802.11ah

IEEE 802.11ah (Halow) is simulated by using Network Simulator and taking case of situation in Indonesia. Currently, NS-3 comes with support for several IEEE 802.11 standards (Tian et al., 2018). Their implementations are modular. The NS-3 of 802.11ah has 4 main components:

1. Wi-fi Channel: an analytical approximation of the physical medium over which data is transmitted (i.e., the air in case of Wi-Fi), consisting of propagation loss and delay models.
2. Wi-fi Phy Layer: the PHY part of the protocol that takes care of sending and receiving frames and determining loss due to interference.
3. Mac Low Layer: implements RTS/CTS/DATA/ACK transactions, distributed coordination function (DCF) and enhanced distributed coordination Access (EDCA), packet queues, fragmentation, retransmission and rate control.
4. Mac High Layer: implements management functions such as beacon generation, probing, association and authentication.

The first step of technical requirement is performing MCS change scenarios. For instance, MCS 0 to MCS 10 for 1 MHz bandwidth and MCS 0 to MCS 8 for 2 MHz bandwidth until obtaining optimum QoS parameter (throughput, delay, and power consumption). This study chooses the working frequency according to literature study about Indonesia's situation and regulation in frequency band of 900 MHz to 1000 MHz. Later, this study will continue analyzing the scenarios to assess 802.11ah coverage analysis by using using planning tools Forsk Atoll in two sample areas, namely Bandung city to represent a dense urban area and Bandung regency to represent a sub urban area.

3.2. Simulation Model

The simulation will utilize one 802.11ah access point with up to 1000 users or nodes connected to the access point.

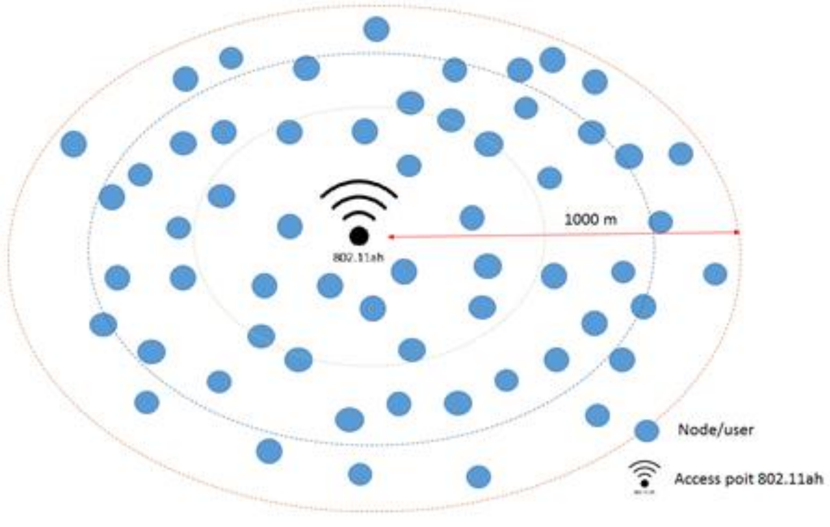

Figure 5. Simulation Network Model

3.3. Research Framework

The research framework can be seen in Figure 6, starting from defining technical requirement for NS3 setup, followed by calculating QoS, producing coverage simulation, and providing analysis and recommendation.

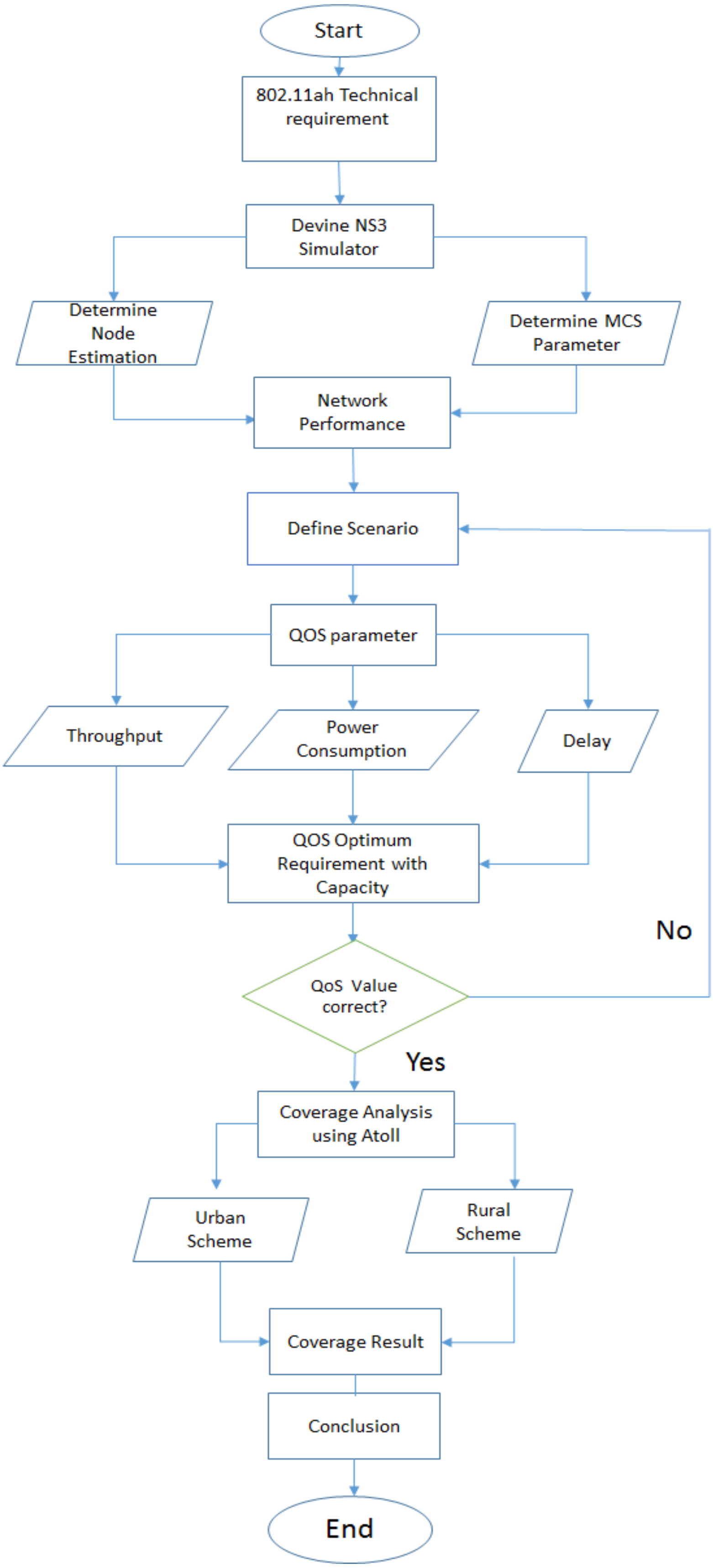

Figure 6. Research Framework

3.4. Technical Requirement

3.4.1. Network Simulator Setup

Simulation in Network Simulator 3 starts from setting the experiment parameter, planning, running the simulation, obtaining the result, and providing a conclusion. This steps are shown inFigure 7, while the setup parameters can be seen in Table 2.

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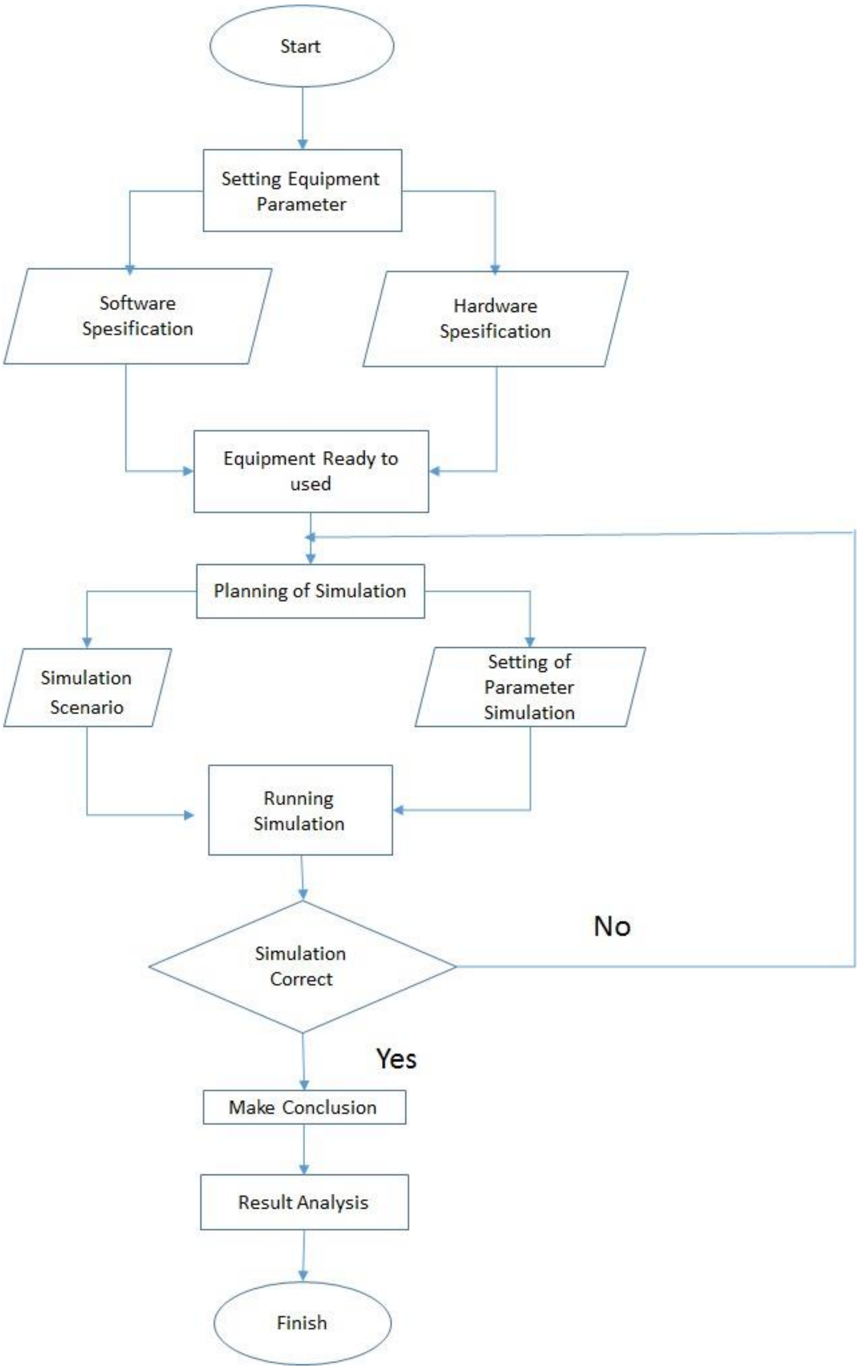

Figure 7. Simulator Setup Design

Table 2. Simulator parameter

Parameter	Value
Simulation Time	30s
PHY	S1G
Channels	YnasWifiChannel
MAC	802.11ah
MCS	01,2,3,4,5,6,7,8,9,10
Rho	250 m
Nsta	100,200 until 1000
WifiApNode	1
Payload	100 Bytes
Ipv4GlobalRoutingHelper	PopulateRoutingTables
PossitionAllocator	UnivformDiscPositionAllocator
MobilityModel	RandomDirection2dMobilityModel
RAW Slow	1
RAW Group	1

Source: Sun et al (2017), Tian, Deronne, et al (2016), Tian, Famaey, et al (2016) Tian et al(2018)

3.4.2. Bandwidth Usage

To simulate the frequency allocation in Indonesia, this study follows Indonesian Government regulations (Regulation of Minister of Communications and Informatics, 2018, 2019). After conducting a literature study, a frequency allocation map that can be used by the Internet of Things communication technology in Indonesia is proposed at frequency 920-925MHz for 802.11ah. The assumption of the frequency allocations of the Internet of Things protocol that are used in this study are shown in Table 3.

Table 3. Assumption of frequency allocation for 802.11ah in Indonesia

Frequency	Usage
920 MHz	Other IoT Protocol
922 MHz	802.11ah
923 MHz	802.11ah
924 MHz	802.11ah
925 MHz	802.11ah

3.4.3. The number of nodes

To simulate 802.11ah network quality performance in the frequency band previously described, this study changes the number of users or nodes connected to the access point. The change in the number of nodes is expected to represent 802.11ah user demographics. The research uses the number of nodes 100, 200, 300, and set to reach 1000 nodes. The number of node users assumed in this simulation can be machines, sensors, or other telecommunications devices used by humans.

3.5. Key Performance Indicators (KPI)

This research will discuss KPIs of 802.11ah as revealed by NS-3 simulator. The KPIs include:

a. Throughput. Throughput is defined as the rate of effective data transfer. It is measured in bytes per second (Bps) as the total number of packets received in bits and divided by the amount of time sent.

b. Delay. Delay is an average time needed for packet delivery from the sender end node to the receiver end node. In this research, the examined package is only limited to the data package obtained through the flow monitor module found in NS-3.
c. Energy Consumption. Energy consumption is the amount of energy needed by a node to send frames and receive packets in a 30 second simulation period in NS 3 network simulator.
d. Packet Delivery Rate. Packet Delivery Rate represents the percentage of the packets successfully reach destination versus the number of generated packets.

3.6. Coverage Simulation

The planning in this research is carried out by simulating existing 4G LTE coverage by using Atoll. Atoll will show good signal areas as well as weak signal or blank spot areas. The 802.11ah simulation will then be carried out in the weak signal or blankspot areas. The initial planning data consist of SiteID, cell, coordinates, Azimuth, and antenna height. There are two types of area analyzed in this study, namely high density area (CBD, dense urban area) and lower density area (Suburban, rural area). These two types of areas are distinguished by their density (total pipulation per km^2). This study selects Greater Bandung area as the simulation area as it has various clutters which are challenging for MNOs in providing full coverage. Bandung city is categorized as a high-density and flat area with a total population of 2.404.589 and a total area of 167,67 km^2. Meanwhile, Bandung regency is a sub-urban area with more various contour and less dense area. Bandung regency has population about 119.112 people and total area of 24,26 km^2. These two areas are used as simulation areas for the deployment of 802.11ah. The scenarios are described in Figure 8.

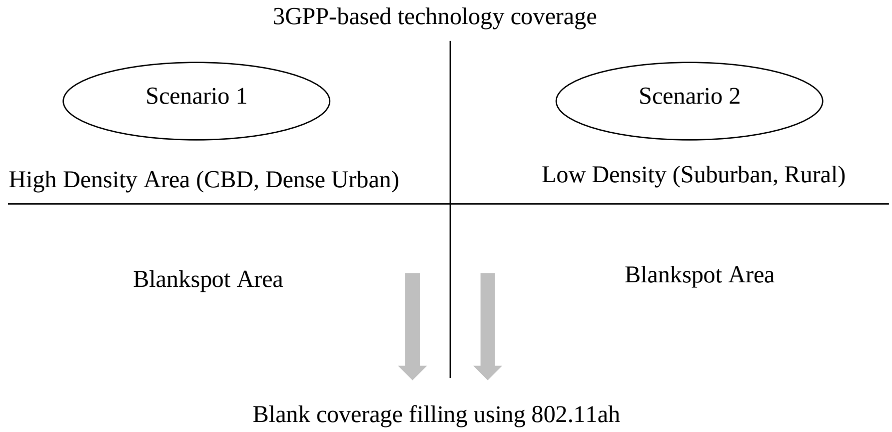

Figure 8. Simulation Scenario

4. Result and Discussion

The simulation aims at measuring 802.11ah network performance to obtain optimum throughput, packet delivery rate, delay, and energy consumption, and optimum MCS (Modulation and Coding Scheme) suitable for 802.11ah in the range of 923-925 MHz frequency band. The number of nodes is varied starting from 100, 200, 300 until 1000 nodes. The QoS will then be measured for each number of nodes in every MCS. Two bandwidths are used in the analysis, namely 1 MHz and 2 MHz.

4.1. KPI Analysis

4.1.1. Throughput

Throughput is the average data rate that is successfully received by the recipient. This parameter describes how much actual data rate can be sent over the network. Throughput is measured in unit data size per time (bytes per second). Figure 9 and Figure 10 show obtained throughput of 1 MHz and 2 MHz bandwidth, respectively. We can see that for all MCS value of 2 MHz bandwidth, the throughputs are higher than in the 1 MHz bandwidth. The average throughput for the two bandwidths are 382 Kbps and 286 Kbps, respectively. For wireless sensors communication, typical 250 kbps throughput that is achieved on the number of nodes of 40-220 is considered as acceptable even with a higher number of nodes (Tian et al., 2018). Samir Dawaliby (2017) have similar result when evaluating LTE-M througput performance with multi nodes scenario.

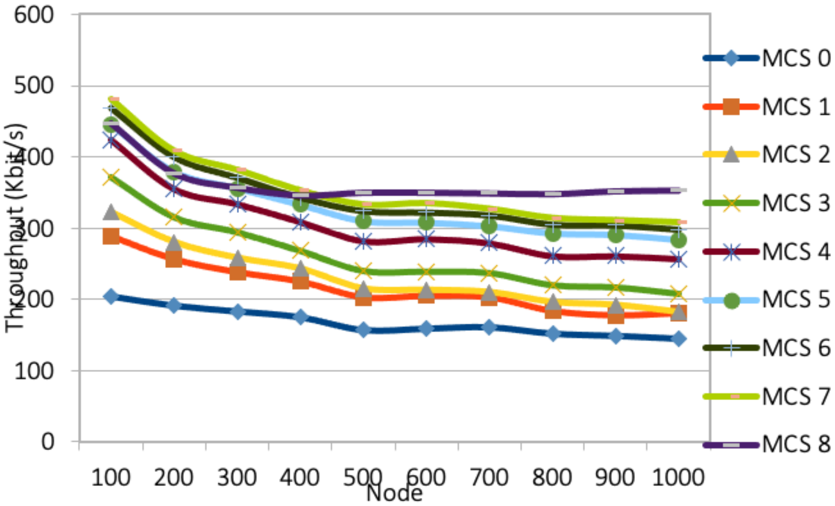

Figure 9. Throughput at 1 MHz Bandwidth

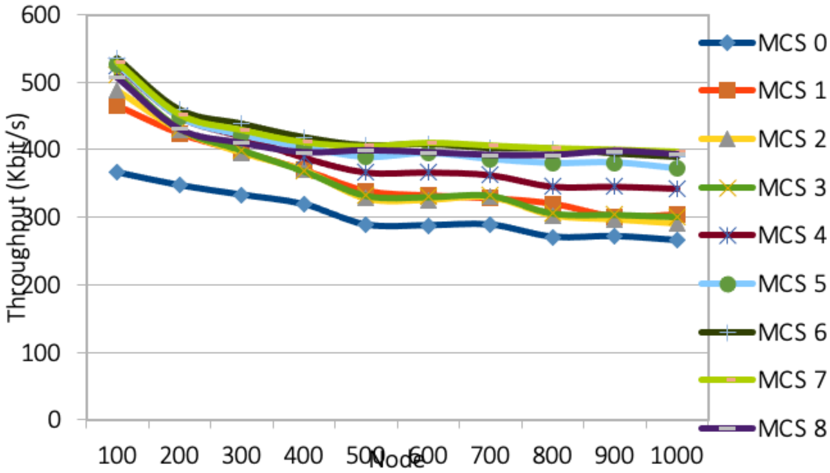

Figure 10. Throughput at 2 MHz Bandwidth

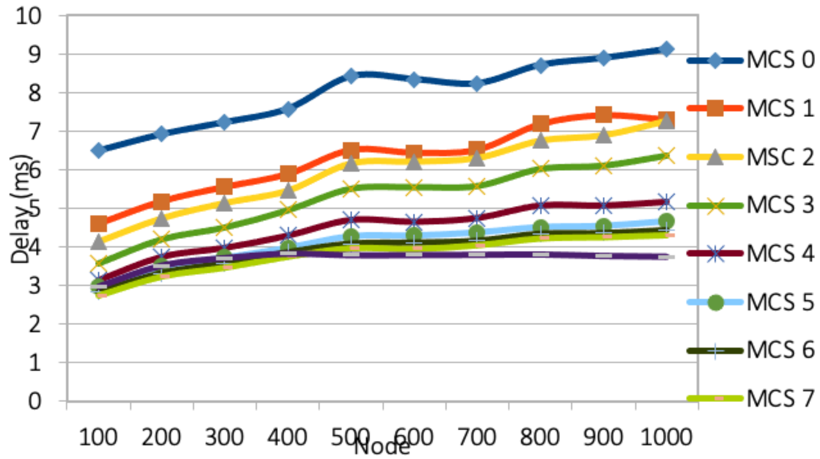

Figure 11. Delay at 1 MHz Bandwidth

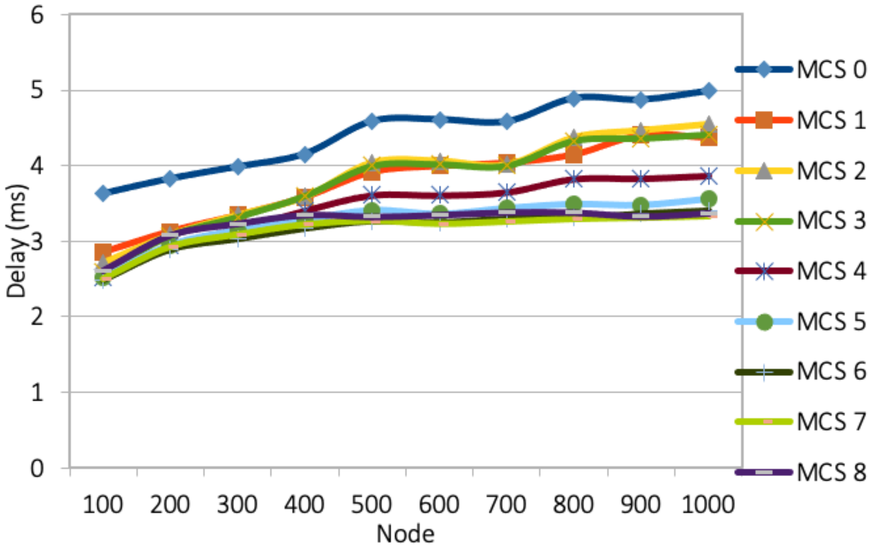

Figure 12. Delay at 2 MHz Bandwidth

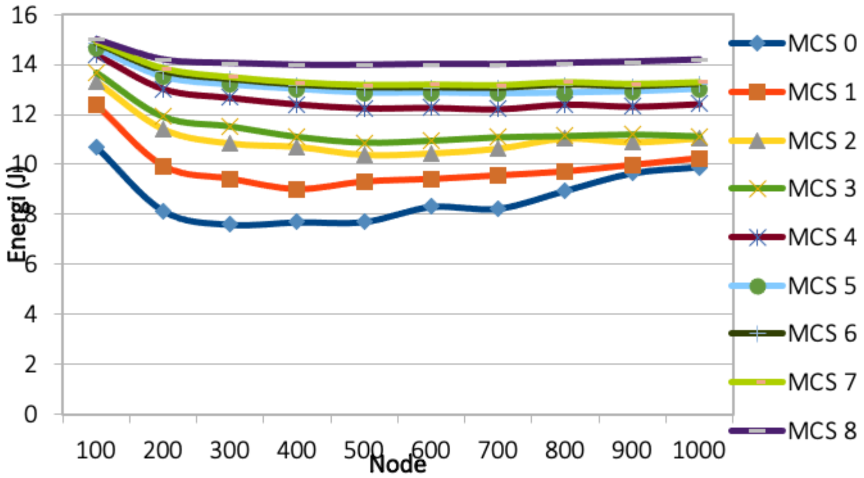

Figure 13. Energy Consumption at 1 MHz Bandwidth

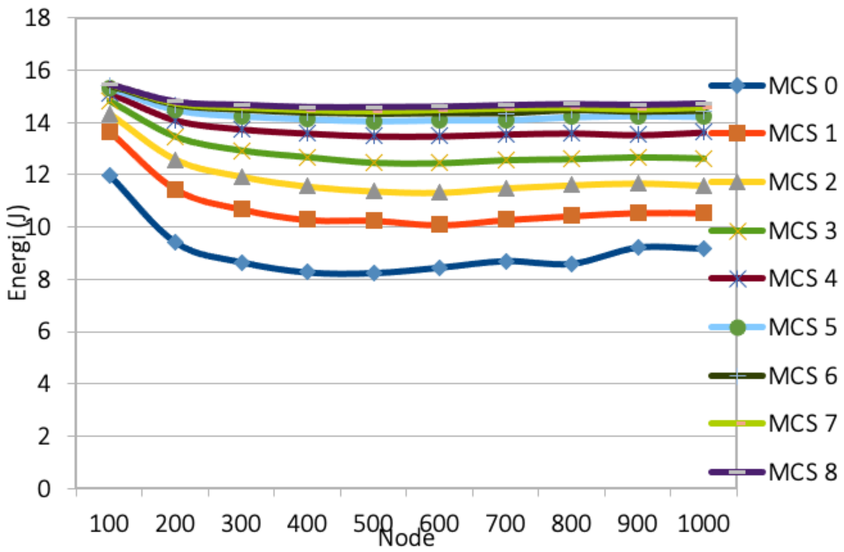

Figure 14. Energy Consumption at 2 MHz Bandwidth

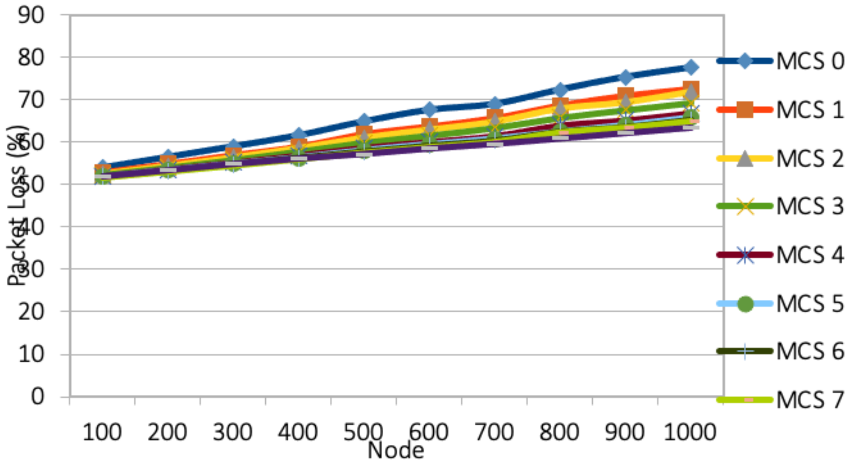

Figure 15. Packet Delivery Rate at 1 MHz Bandwidth

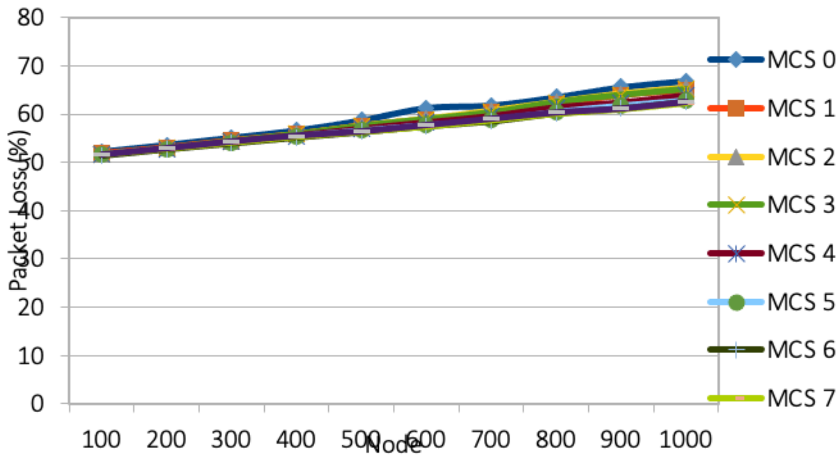

Figure 16. Packet Delivery Rate at 2 MHz Bandwidth

4.1.2. Delay

Figure 11 and Figure 12 show the delay comparison between bandwidth of 1 MHz and 2 MHz, respectively. It can be seen that all MCS at 2 MHz bandwidth has better performance (average delay of 3.56ms) than 1 MHz bandwidth (average delay of 5.03ms). These delays are better than the required delay for 4G LTE with a packet delay budget range of 50-300ms depending on resource type and its priority (Ameigeiras et al., 2016).

4.1.3. Energy Consumption

Figure 13 and Figure 14 show that all MCS in 1 MHz bandwidth has less energy requirements (average of 11.99 J) than in 2 MHz (average of 12.97 J). This study observes that in a low number of nodes, the energy is more convenient. However, when the number of nodes increases, the energy consumption also increases. Santi et. al. (2019) evaluated the energy efficiency comparison between RAW and CSMA/CA with various numbers of nodes. In the case of fewer nodes in the network, CSMA/CA outperformed RAW because of low amount of traffic. When the traffic is high, RAW clearly provides more fairness and better efficiency than CSMA/CA. Target Wake Time (TWT) implementation is also studied in the research, and found that it doubles the energy efficiency.

4.1.4. Packet Delivery Rate

From Figure 15 and Figure 16, it is indicated that bandwidth 1 MHz have better performance (average PDR=60.38%) than 2 MHz (average PDR=57.82%) in every trial of various user numbers. Evaluation by

Oktaviana et al (2018) showed similar PDR result by optimizing Arbitration Inter-Frame Space (AIFS) parameter.

4.2. Coverage Plot Analysis

A coverage simulation has been run by taking the case of one of the 4G operators in Bandung. Two clutters are simulated, namely Bandung city for urban area and Dayeuh Kolot sub-distruct for suburban area. The simulation aims to provide an overview of 802.11ah planning and to provide solutions for telecommunications operators that due to several reasons failed to develop infrastructure in some areas and caused blank spots.

4.2.1. Urban Area

An urban area is an area that is built up a city or large town with large buildings. Okumura-Hata channel model (Seybold, 2005) for the city is used to calculate the distances between a base station/gateway and 802.11 ah Access point. The simulation results are presented in Figure 17. The strongest signal is represented by a light blue colour (RSRP: -70 dBm) and the weakest signal is represented by a dark-red colour (RSRP: -140 dBm). The measured blank spot area is in a red polygon area of 2.96 km^2. It shows that only 30% of the polygon area have acceptable service quality. The remaining area (lower than -95dBm) is expected to be enhanced by using 802.11ah technology. Figure 17 and Figure 18 show the comparison of a 4G LTE networks coverage, with and without 802.11ah technology.

4.2.2. Suburban Area

The Okumura-Hata model for suburban environments applies to the transmissions for out of the city and rural areas where man-made structures are there but not as dense as in the cities (Seybold, 2005). Figure 19 displayes the plot of coverage area based on prediction results of 4G operators in the sub-urban area. This study choose 22.67 km^2 polygon area at the edge of the network for 802.11ah simulation which has not been covered by operators' coverage. It can be seen that the prediction calculation shows almost all areas have unacceptable service quality, so it will be enhanced by 802.11ah technology. Figure 19 dan 20 show the comparison of 4G LTE coverage, with and without the implementation of 802.11ah technology. Due to the wide of polygon area to be covered, two 802.11ah access points are used in this simulation. The results are quite evident that the planned 802.11ah network provides sufficient coverage. It can be seen that each site can serve around 3 km distance, and by observing histogram statistics, all blank spot areas can be covered with an acceptable minimum received signal (>-105 dBm).

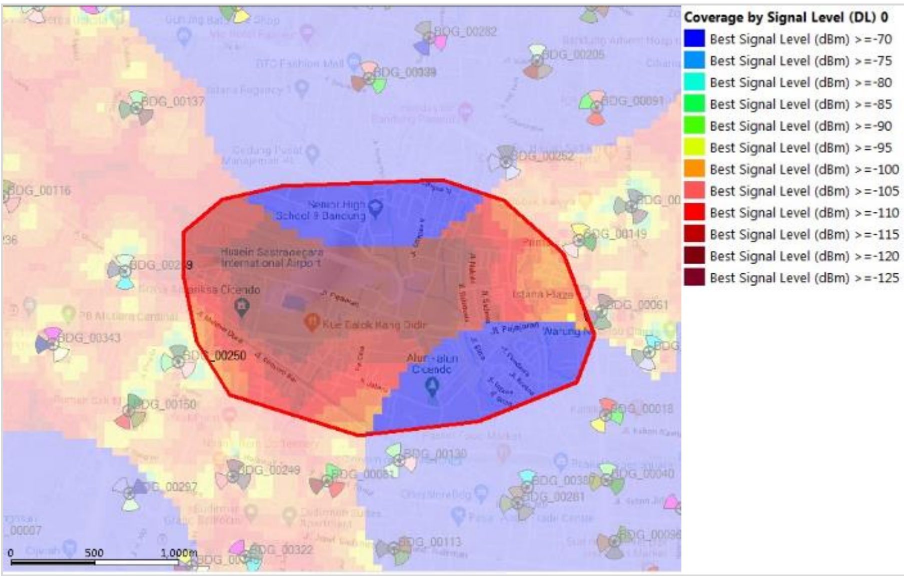

Figure 17. Blankspot Urban LTE Network Polygon

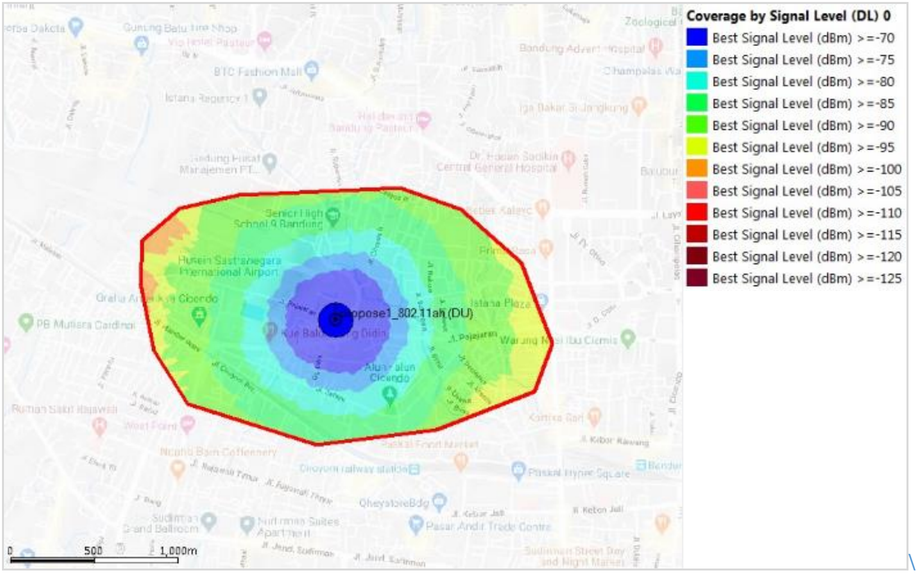

Figure 18. . 802.11ah Fills Urban LTE Blankspot area

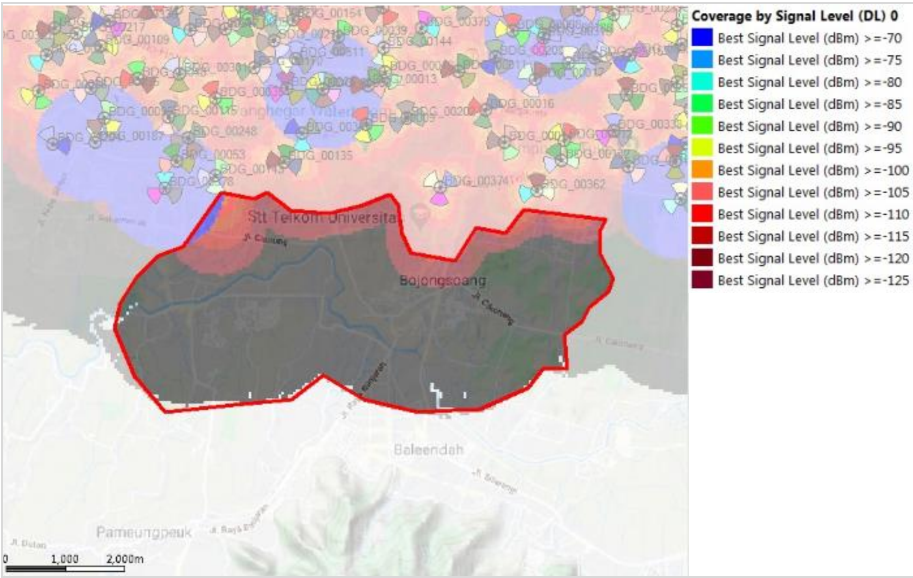

Figure 19. Blank spot polygon of LTE Network in suburban area

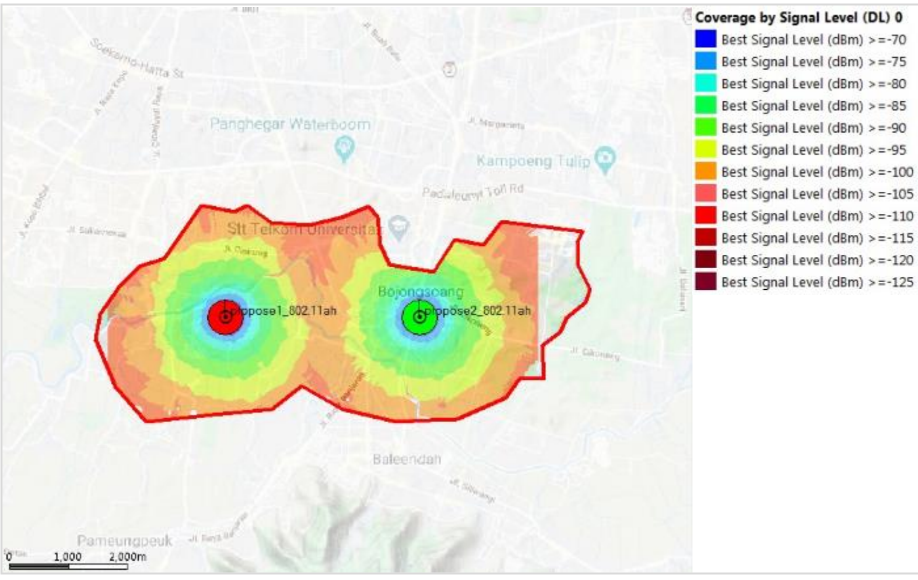

Figure 20. 802.11ah fills Suburban LTE Blank spot area

5. Conclusion

This study analyses the implementation of 802.11ah at a frequency of 922 to 925 MHz by using 1MHz and 2 MHz bandwidth. From the simulation results on Network Simulator 3 by calculating throughput, delay, and power consumption, it can be seen that the increasing number of users influences the performance of QoS. Simulation analysis of the Modulation and Coding Scheme (MCS) in various environments show that for urban areas, MCS 8 with bandwidth 2 MHz is good for high-density location and MCS 0 with bandwidth 1 MHz is good for low-density location (suburban and rural area). This study also shows that IEEE 802.11ah can become a complementary solution to enhance coverage of 4G LTE network that due to several reasons can not be deployed in several areas. In line with this research, further studies are conducted to optimize 802.11ah performance in various terms including RAW evaluation, energy evaluation, etc. Additionally, aside from technical issues, the techno-economic evaluation also can be studied regarding the implementation of 802.11ah within the cellular network.

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