

# The Evaluation of IEEE 802.11ah Performance Based on W K H ( I I H F W R I O R E L O L W \ traffic Using the Markov Chain Model

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Abstract <sup>2</sup> The Internet of Things (IoT) is currently growing rapidly and one of the technologies supporting it is wireless fidelity (Wi-Fi) standard IEEE 802.11ah. This technology supports mobility and has a large number of nodes or devices with small energy consumption; hence it is capable of functioning for a long time. In this study, three work scenarios were proposed, namely 1) the mobility, which involves changing the distance between the access point (AP) D Q G W K H Q R G H V F K D Q J L Q J W K H O R G H I W E E 8 0 2 . 1 1 a h D Q G testing the variations in traffic by changing the collision possibilities and the RAW (Restricted Access Window) (the full title). slot duration in order to analyze the IEEE 802.11ah network performance parameters. The results showed that there was a decrease throughput, an increase in energy consumption, and a delay due to changes in the nodes  $\uparrow$   $\downarrow$  and movement/mobility. Also, the variation in traffic by changing the collision probability causes a change in throughput, hence when the collision probability is large, the throughput decreases, while the delay value increases, and vice versa. In conclusion, this study proved W K D W F K D Q J H V L Q W K H Q R G H V  $\uparrow$  Q X P L E H M a r k o v C h a i n m a t h e m a t i c a l m o d e l i n g c a n i m p r o v e the IEEE 802.11ah network performance quality even though it is affected by the number of nodes, movement/mobility, and changes in traffic by changing the collision probability.

Keywords <sup>2</sup> IoT, 802.11ah throughput, delay, energy consumption

## I. INTRODUCTION

The Internet of Things (IoT) is a technology that is currently growing rapidly into the Internet of Everything (IoE), in which all devices are connected for data exchange [1, 2]. IoT can connect humans, devices and software over the Internet, thereby creating intelligent technology as a service solution for people.

One of the supporting technologies is Wireless Fidelity (Wi-Fi), which does not require much infrastructure and offers fast network access [4].

A wireless network standard issued by the IEEE that works at frequencies below 1 GHz is the IEEE 802.11ah. Furthermore, it is capable of reducing energy consumption and supporting mobility because the range reaches 1 kilometer [5]. and can communicate with about

8,000 stations [6]. has a large number of nodes/stations, which causes collisions. Meanwhile, one way of reducing the collision is to use the EDCA Enhanced Distributed Channel Access (EDCA) algorithm technique. This research has not conducted a traffic analysis.

Another study focused on the performance of changing RAW slot duration and found an energy efficiency mechanism in IEEE 802.11ah but did not perform any collision mechanism [8].

A Markov chain that works under saturation and non-saturation conditions was proposed [9], this study proposed a Markov chain that works in saturation and non-saturation conditions. The study focused on how access points (APs) overcome network bottlenecks using voice data.

Consequently, this work proposes to use the Markov Chain Model in IEEE 802.11ah networks. This is due to the Markov Chain mathematical modeling can improve the IEEE 802.11ah network performance quality even though it is affected by the number of nodes, movement/mobility, and changes in traffic by changing the collision probability.

## II. RELATED WORKS

Previously, a mobility impact was analyzed using a traffic pattern change scheme with three models, namely Random Walk, Gaussian Markov, and Random waypoints [2]. In [7] the Enhanced Distributed Channel Access (EDCA) algorithm system was used to reduce collisions. The EDCA algorithm here focuses on the contention window parameter settings implemented in IEEE 802.11e networks.

Furthermore, the EDCA algorithm was applied on the IEEE 802.11ah network by changing the Arbitration Inter-Frame Space (AIFS) parameters [8].

In [10], W K H ' R S S O H U  $\uparrow$  I E E E 8 0 2 . 1 1 a h W R network performance was conducted by analyzing changes in the parameters of the RAW slot and its duration using Random Waypoint Mobility modeling.

The study of [11], the author simulated five mobility models, namely the Entity, Group, Urban, City Sector, and realistic mobility. All this modeling is used in the Vehicular Ad-Hoc Networks (VANET).

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Also, the author of [12] analyzed proactive Destination Sequence Distance Vector (DSDV) and reactive Ad-hoc On-demand Distance Vector (AODV), and Dynamic Source Routing (DSR) ad hoc network routing protocols using three mobility models which include Random way Point, Manhattan Grid, and Gauss-Markov. Another simulation and analysis were performed using a UDQG R P Q H V V L Q G L u s s M a r k o v M o b i l i t y K H model with a certain number of nodes.

In [13], it was observed that each interval has only one RAW group, hence it was further divided into multiple RAW slots, with stations having equal priority placed evenly. This proposal uses a random discrete time Markov model

Meanwhile, the author of [14] studied the Underwater Wireless Sensor Network (UWSN) by simulating the nodes as sensors that change due to seawater movement. The study was conducted using the Energy Efficient Localization Scheme algorithm based on mobility and propagation Delay Prediction (EEL-MPDP).

In [15], Underwater Wireless Sensor Network (UWSN) was examined by increasing the wireless network performance using Mobile Sink (MS) as a cluster head instead of existing sensor nodes. Subsequently, the data is directly sent from the MS in order to detect leaking pipes.

The author of [16] further attempted to improve performance by reducing costs, in terms of time, power consumption, and computing resources using the Cloud Assisted Energy Saving and Performance Improving Routing Mechanism (CEPRM) applied to the MANET network

### III. SYSTEM MODEL

#### A. IEEE 80211

The IEEE 802.11 standard was released by the IEEE (Institute of Electrical and Electronic Engineers) in 1997. In the beginning, IEEE 802.11 exclusively used the 2.4 GHz and 5 GHz frequencies, but it is now more widely used

The derivatives of the IEEE 802.11 standard included

- x 802.11a [17]  
The IEEE 802.11a was first published in September 1999. Furthermore, it operates at a frequency of 5 GHz, with a 5, 10, and 20 MHz bandwidth, and reaches a maximum speed of 54 Mbps
- x 802.11b [17]  
The IEEE 802.11b was introduced together with IEEE 802.11a in September 1999. It has a 2.4 GHz working frequency and a bandwidth of 22 MHz, with a maximum speed of 11 Mbps
- x 802.11g [18, 19].  
IEEE 802.11g ini di perkenalkan pada Juni 2003 dengan frekuensi yang digunakan 2,4 GHz bandwidth 5, 10 dan 20 MHz serta memiliki maksimum kecepatan 54 Mbps
- x 802.11n [20]

In October 2009, the IEEE 802.11n was introduced and it has 2.4 and 5 GHz working frequencies. It also has bandwidths ranging from 20 to 40 MHz and a maximum speed of 288.8 Mbps to 600 Mbps

802.11ax [21]

The September 2019 release of 802.11ax operates at 2.4 GHz, 5 GHz and 6 GHz, with bandwidths of 20, 40, and 80 MHz and a throughput of 9608 Mbps

802.11ad [22]

802.11ad was first introduced in September 2019 and operates at 60 GHz with a 7 Gbps throughput and a 2160 MHz bandwidth.

802.11af [23]

In February 2014, 802.11af was released with a frequency range of 54 to 790 MHz, a bandwidth between 6 to 8 MHz, and a maximum speed of 568.9 Mbps

IEEE 802.11ah [24]

The IEEE 802.11ah was introduced in December 2016, with frequencies below 1 GHz (700/800 MHz), bandwidth ranging from 1 MHz to 16 MHz, and 346 Mbps maximum speed

Markov Chain

Markov Chain is the model used for the packet transfer function in the Distributed Coordination Function (DCF) system of the IEEE 802.11 standard. In this study, a 802.11ah network was used, which is then proposed with the Markov chain model shown below [25]:

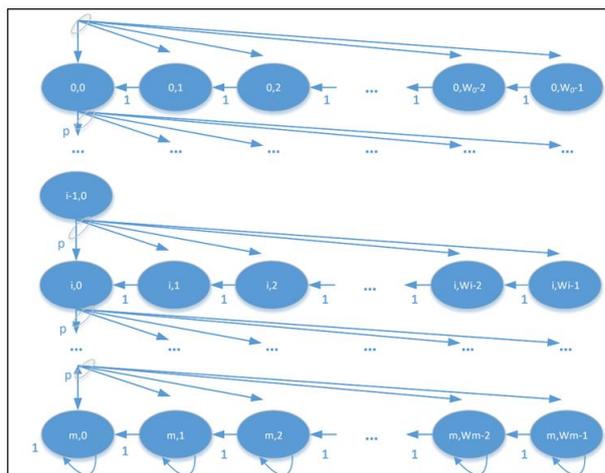


Figure 1. Model markovchain[25].

All nodes access the medium but when it is busy, the system duplicates the contention window and calculates the backoff time [17]. The Markov Chain model shown in Figure 1 is interpreted as follows:

m = The Maximum Number of Back Stages

W = Contention window (CW)

$\rho$  = Transmission failure probability

The following is a calculation of the transition probability (P) on the Markov chain [17]:

$$\begin{cases}
 P\{i,k | i,k+1\} = 1 & k \in (0, W_i \pm 2) & i \in (0, m) \\
 P\{0,k | i, 0\} = (1-p)/W_0 & k \in (0, W_0 \pm 1) & i \in (0, m) \\
 P\{i,k | i \pm 1, 0\} = 1/W_i & k \in (0, W_i \pm 1) & i \in (1, m) \\
 P\{m,k | m, 0\} = 1/W_m & k \in (0, W_m \pm 1) & 
 \end{cases} \quad (1)$$

The respective conditions for:

- Back-off timer down,
- Successful transmission, back off stage 0 for new packets,
- Transmission not successful, back off stage increased,
- If the backoff stage is maximum, will not grow in the subsequent packet transmission

Then calculate the Probability (2) using the Eq. (2) below [17]:

$$2 = \frac{b_{0,0}}{1-p} = \frac{2(1-p)(W-1)}{(1-2p)(W-1) + pW(1-(2p)^m)} \quad (2)$$

where

$$b_{0,0} = \frac{2(1-p)(1-p)}{(1-2p)(W-1) + pW(1-(2p)^m)} \quad (3)$$

Furthermore, the  $\rho$  value is calculated using the following equation [25, 26].

$$\rho = 1 - e^{-\lambda T} \quad (4)$$

The value of  $\rho$  is determined with Eq. (4) [27]

$$\rho = \frac{\lambda T}{1 + \lambda T} \quad (5)$$

where [27]:

- $\lambda$  = Average packet length in one second
- T = the time it takes to send the package

### C. Analysis Parameter

The parameters analyzed in this research include:

- x Throughput  
Throughput is the data transfer rate measured in bits per second (bps). The throughput equation is as follows [25]:

$$S = \frac{P_s P_{tr} I_{payload}}{(1 - P_{tr}) + P_{tr} P_s T_s + P_{tr} (1 - P_s) T_c} \quad (6)$$

where

- S = Throughput
  - $\sigma$  = slot duration
  - $T_s$  = successful transmission time
  - $T_c$  = Collision Time
  - $P_{tr}$  = Transmission probability (at least one transmission)
  - $P_s$  = Probability of successful transmission
- After that, it will look for other parameter  $P_{tr}$ ,  $P_s$ ,  $T_s$ , and  $T_c$  with the following Eq.(7-10) [28]:

$$P_{tr} = 1 - (1 - P_s)^N \quad (7)$$

$$P_s = \frac{N(1 - P_s)^{N-1}}{1 + (N-1)P_s} \quad (8)$$

$$T_s = DIFS + T_{DATA} + T_{ACK} + T_{PHY} \quad (9)$$

$$T_c = DIFS + T_{DATA} + T_{PHY} \quad (10)$$

where

- N = number of nodes
- W = equal to value  $CW_{min} = 15$
- $T_{data}$  = Data Frame Duration
- $T_{ack}$ ,  $T_{PHY}$  = Control Frame Duration

### x Delay

This is the time delay in the process of sending data from source to destination. The delay value is calculated with the following Eq. (11). [28]:

$$\text{Delay} = \frac{(1 - P_{tr}) + P_{tr} (1 - P_s) T_c + (P_{tr} P_s T_s)}{P_{tr} P_s} \quad (11)$$

### x Energy Efficiency Analysis

The energy consumption amount for transmitting a data packet in Joules is as follows [25, 28]:

$$E = \frac{(1 - P_{tr}) + P_{tr} P_s T_s + P_{tr} (1 - P_s) T_c}{P_s P_{tr} I_{payload}} \quad (12)$$

### D. System Design

In this study, Matlab software version 2021a was used to simulate and obtain the results of the parameters being tested

Fig. 2 shows the block diagram of this study system. The Markov parameter was implemented in the IEEE 802.11ah network and tested with three simulation scenarios, namely changes in 1) distance, 2) slot duration and 3) Collision Probability. After the simulation, three IEEE 802.11ah network performance parameters were analyzed for each scenario, namely throughput, delay, and energy consumption. These three parameters represent an analysis of IEEE 802.11h network performance

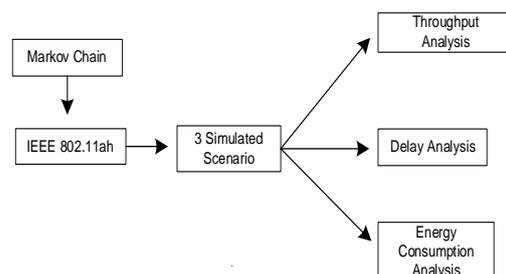


Figure 2. Research System Model

The flowchart for this study is shown in Fig. 3, and it starts from the IEEE 802.11ah network standard, which is incorporated with the Markov Chain scheme and the existence of mobility. Furthermore, the basic Matlab parameters highlighted in Table 1, namely nodes, backoff stage, payload, contention window, RAW slot duration, SIFS, DIFS, physical layer time, ACK time, and data time were inputted into the system. Followed by entering the simulation scenario parameters, which are prepared for 1) the distance between nodes and access points (AP), such as 100 m, 200 m, 300 m, 400 m, 500 m, 600 m, 700 m, 800 m, and 900 m, 2) the RAW slot duration, including 100 ms, 200 ms, and 400 ms, as well as 3) the collision probability, namely 0.15, 0.20, 0.25, 0.30, 0.35 and 0.40. The flow chat design utilized is shown in Fig

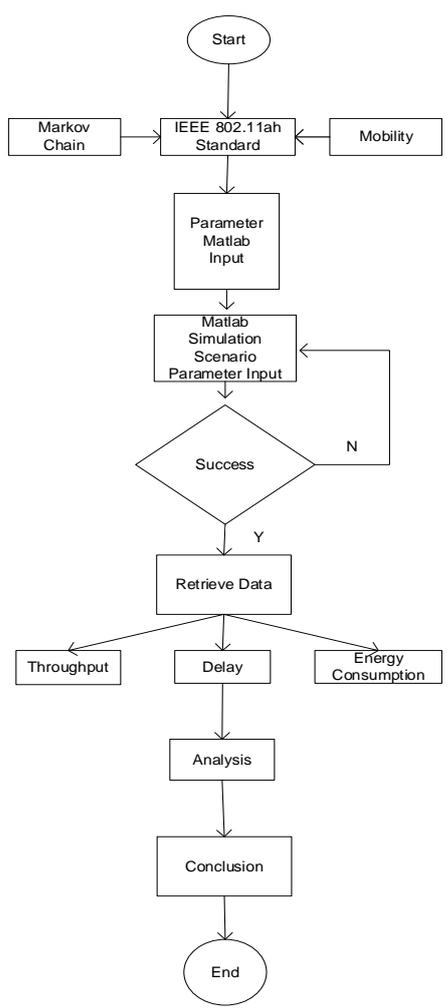


Figure 3. Research flow diagram.

A test was conducted using a network model according to the IEEE 802.11ah standard. The parameters analyzed include throughput, delay, and energy consumption. Additionally, the changes in the distance between nodes and access points (AP) were observed in the simulation 100 m, 200 m, 300 m, 400 m, 500 m, 600 m, 700 m, 800 m, and 900 m.

The test scenario was then intended to describe normal network and conditions influenced by changes in

distance, as well as the effect of fixed and changing collision probability value. The simulation scenario is as follows:

- 1) Distance Change  
The changes in distance between nodes and access points (AP), which include 100 m, 200 m, 300 m, 400 m, 500 m, 600 m, 700 m, 800 m, and 900 m, were analyzed. This was performed under the condition that the distance between the AP and RAW slot duration UHPDLQV V
- 2) Change of nodes and RAW slot duration  
The simulation scenario has RAW slot durations of 100 ms, 200 ms, and 400 ms
- 3) Collision probability change  
The scenarios for changing the collision probability include 0.15, 0.20, 0.25, 0.30, 0.35, and 0.40, with a fixed number of 100 nodes, while the duration of the 5 s: VORW UHPDLQV V

The network specification in this research is as follows

TABLE I: NETWORK SPECIFICATIONS

Parameter	Value
Number of nodes	50, 100, 150, 200, 250, 300
Slot Duration	52 s
Backoff stage (n)	6
CWmin	15
Payload	8184 bits
SIFS	160 s
DIFS	264 s
AIFS	316 s
T <sub>sym</sub>	40 s
T <sub>PHY</sub> , T <sub>ACK</sub>	240 s
T <sub>Data</sub>	348 s

The table below contains the energy consumption values. It is important to note that energy consumption is a significant parameter because it affects network performance. Furthermore, it shows the energy consumed by each STA/node and is measured in units of Joule/Package [25, 29].

TABLE II: ENERGY CONSUMPTION

Mode	Energy Consumption(mW)
Transmit	250
Receive	135
Idle	1.5

The specification of the simulation scenario used in this study is as follows

TABLE III: RESEARCH SPECIFICATIONS

Parameter	Variable
Number of nodes	50, 100, 150, 200, 250, 300
RAW slot duration	100 ms, 200ms, 400 ms
AP and node distance	100, 200, 300, 400, 500, 600, 700, 800, 900
Collision Probability	0.15, 0.20, 0.25, 0.30, 0.35, 0.40
Analysis	Throughput, delay, Energy consumption

#### IV. RESULT

The three scenarios considered in this study were analyzed in the form of IEEE 802.11ah network performance parameters, namely throughput, delay, and energy consumption

##### A. Throughput

###### x Throughput with distance change

The effect of changes in distance and node number on throughput is as follows

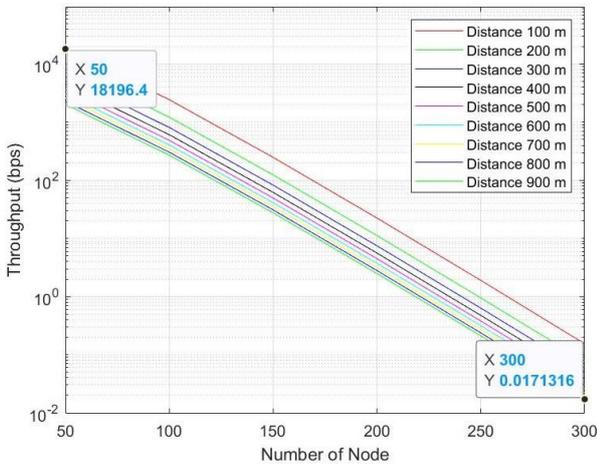


Figure 4. Throughput with change in AP to Node distance

Fig. 4 shows that the largest throughput was 18196.4 bps/0.0181964 Mbps and the maximum distance between the AP and the node was 100 m. Also, the smallest decrease of 0.0171 bps was obtained when the distance between AP and node was 900 m

This simply means that the throughput value was inversely proportional to the distance between the AP and the node. Specifically, when the distance between the AP and the node increases, the channel becomes full, and the more difficult it is for nodes to access the channel, thereby decreasing the throughput value. Also, as the distance between the AP and the node becomes farther, the throughput value is lowered because there is a delay in data transmission

###### x Throughput with changing RAW slot duration

The effect of changes in RAW slot duration and the number of nodes on throughput is as follows

According to Fig 5, the largest throughput value of 201396 bps/0.201396 Mbps was obtained at 50 nodes and a RAW slot duration of 50 ms. When the RAW slot duration was 400 ms, the throughput value was 15.4177 bps at 300 nodes

In Eq (5), the RAW slot duration value is in the denominator, hence it is inversely proportional to the throughput. In other words, the increase in the RAW slot duration value causes a decrease in the throughput. Considering Eq(6) ( $P_{tr}$  = transmission equation) and Eq(7) ( $P_s$  = successful transmission equation), the  $P_{tr}$  and  $P_s$  values are the denominator. This implies that when the

number of nodes increases, the  $P_{tr}$  and  $P_s$  values tend to increase, thereby causing the throughput value to decrease since it is inversely proportional

It can be concluded that RAW slot duration value affects the IEEE 802.11ah network performance, specifically the throughput parameter

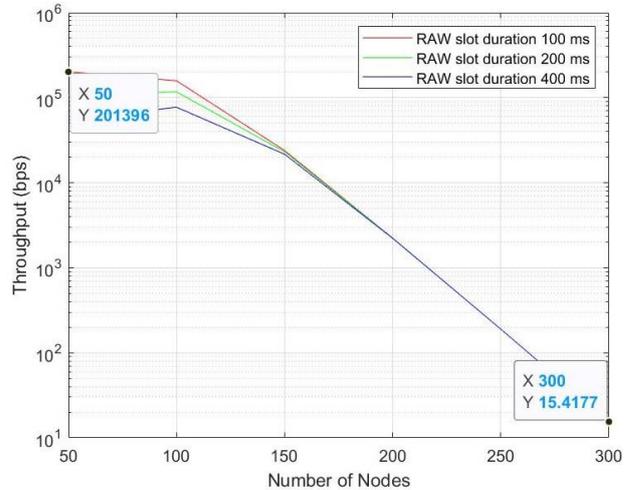


Figure 5. Throughput with RAW Slot Duration

###### x Throughput with Change in Collision Probability

The effect of changing the collision probability on throughput with a fixed number of nodes at 50 and RAW slot duration of 100 ms is expressed as follows

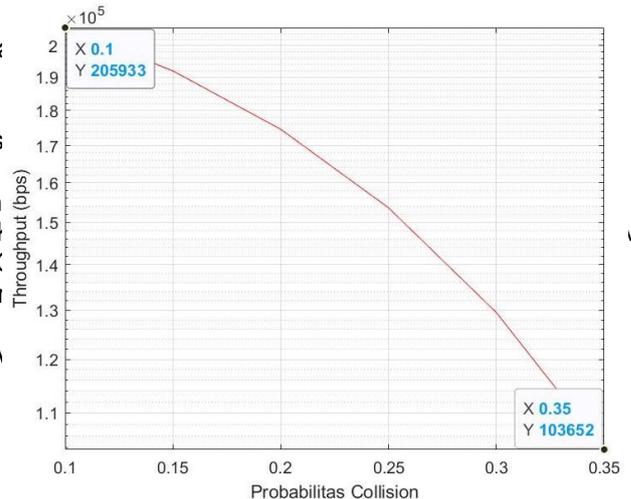


Figure 6. Throughput with Change in Collision Probability

Fig. 6 shows that the fixed RAW slot duration was 100 ms and the collision probability was 0.1, hence the throughput value was 205,933 bps or 0.205933 Mbps (highest throughput). When the collision probability was 0.35, the throughput was 103,652 bps or 0.10362 Mbps (lowest throughput)

The throughput is inversely proportional to collision probability, hence when the collision probability is large, the throughput value decreases, and vice versa. This is because the probability value is related to the packet drop rate. In other words, as the collision probability increases, the packets dropped also rise

## B. Delay

### x Delay with Distance Change

The effect of changes in the number of nodes on delay is as follows

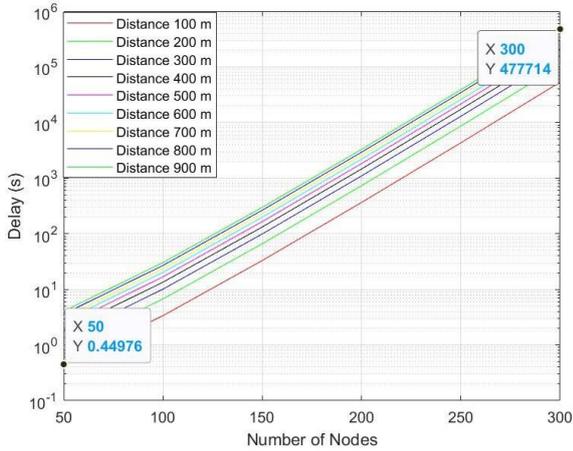


Figure 7. Delay with change in AP distance to node

Fig. 7 shows the smallest delay of 0.44976 s when the node number was 100 m. It was also observed that the highest delay value of 477,714 s was obtained when there are 300 nodes with a 900 m distance between the AP and the node.

This proved that as the nodes connected to the AP increase, there is a queue, and it eventually causes delay. Also, the change in distance causes the time required to communicate with the AP to be longer, thereby causing more delay. Well as the distance between the AP and the nodes greatly affect the delay value. In other words, when there are more nodes and the nodes, then the delay value tends to be greater.

### x Delay with Change of RAW Slot Duration

The effect of changes in RAW slot duration and changes in the number of nodes on delay is as follows

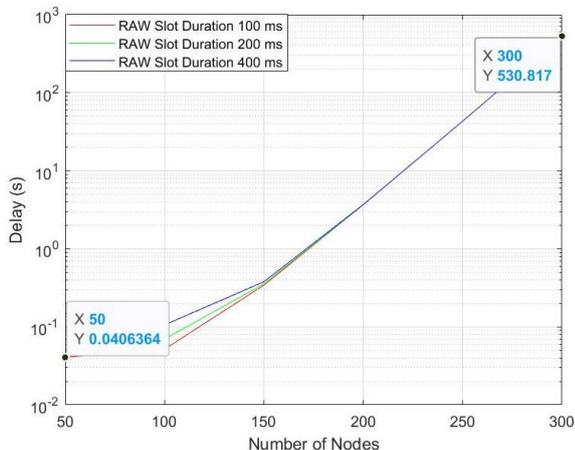


Figure 8. Delay with change of RAW slot duration.

Fig. 8 shows the smallest delay value of 0.0406364 s when the RAW slot duration was 100 ms. Also, the biggest delay value was

530,817 s when the node number was 300 and the RAW slot duration was 400 ms.

It was observed that as the packet sent increases coupled with longer slot duration, the node queues in RAW, causing the packet to be sent late, thereby leading to delay. It is important to mention that there is a change when more nodes are connected, the RAW slot duration tends to be longer.

These parameters greatly affect the IEEE 802.11ah network performance, particularly the delay value. are directly proportional to the delay parameter

### x Delay with Change in Collision Probability

The following is the effect of changing the collision probability RAW slot duration of 50 and 100 ms, respectively

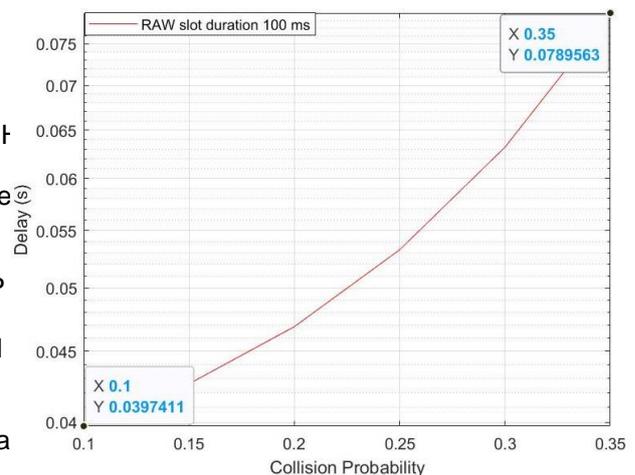


Figure 9. Delay with change in collision probability.

In Fig. 9, the smallest delay value of 0.0397411 s at a collision probability condition of 0.1 is shown. Furthermore, the largest delay value of 0.0789563 s was obtained at a collision probability condition of 0.35. It was observed that as the collision probability value increases, there seems to be higher delay. This is expressed in equation 10 which relates to the collision probability value calculated from equations 6 ( $P_{tr}$ ) and 7 ( $P_s$ ). Based on equation 10, the delay is directly proportional to  $P_{tr}$  and  $P_s$ , this simply indicates when the collision probability increases, then the values of  $P_{tr}$  and  $P_s$  are large, thereby causing the delay to also increase and vice versa.

## C. Energy Consumption

### x Energy Consumption with distance change

The effect of changes in the number of nodes on energy consumption is as follows

Fig. 10 shows that the smallest energy consumption was 0.00942964 Joule/DataPacket under the condition of the distance between the AP and the node being 100 m. Meanwhile, the largest energy consumption was 1.0622 Joule/DataPacket under the

FR QGLWLRQ WK Number WKSH300 And Hf distance between the AP and the nodes was 900.m

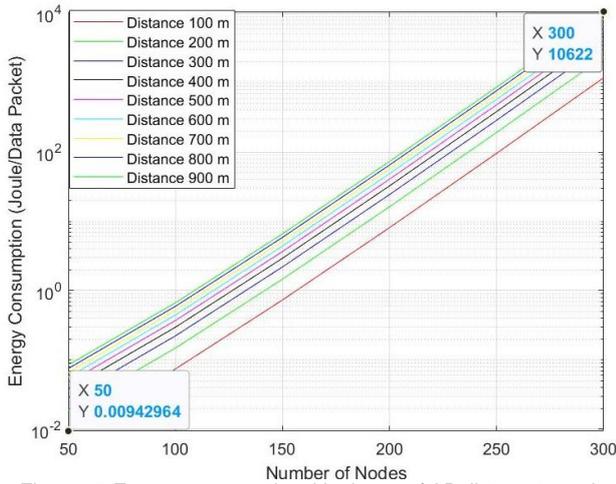


Figure 10. Energy consumption with change of AP distance to node.

The two parameters affecting the delay value in Figure 10 are the number of nodes and the distance between the AP and the node. It was observed that when the network performance, particularly the throughput, delay, and energy consumption parameters. When there is an order to communicate with the AP, and vice versa. Meanwhile, when there is a short distance between the AP and the node, the energy consumption is low, hence large amount of energy is not required to transmit data packets and vice versa

x Energy Consumption with Change of RAW Slot Duration

The effect of changes in RAW slot duration and the number of nodes on energy consumption is explained below.

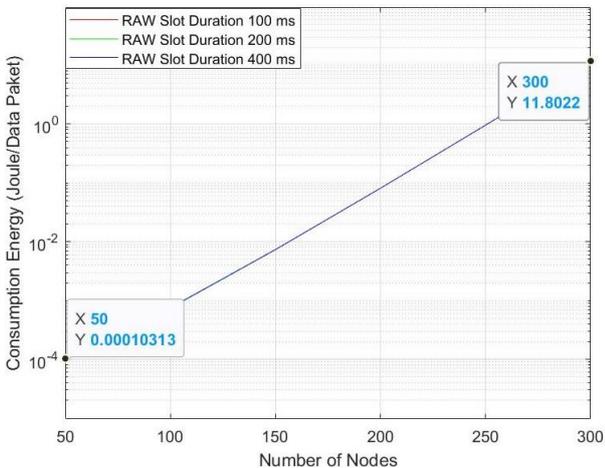


Figure 11. Energy consumption with change of RAW slot duration

Fig. 11 shows the smallest energy consumption of 9.87121 u 10<sup>-5</sup> Joule/Data Packet when the number was 50 and the RAW slot duration was 100 ms of 900 m. This energy consumption was also affected by the RAW slot duration parameter. Meanwhile, the highest energy consumption value was 9.87121 u 10<sup>-5</sup> Joule/Data Packet when the number was 300 and the RAW slot duration was 400 ms

It was observed that when more nodes are connected and with a high duration of RAW slots, the energy consumption tends to increase, and vice versa. Therefore, the duration of RAW slots greatly affect the IEEE 802.11ah network performance, particularly the energy consumption value. In equation 11, the effect of changes in the number of nodes and the duration of RAW slots are derived from  $P_{tr}$  and  $P_s$  in Eq. (6-7), written at the numerator

V. CONCLUSIONS

alteration in the distance between the AP and the node. Also, the changes in traffic due to the variation in collision probability affected the IEEE 802.11ah network performance regarding throughput, delay, and energy consumption parameters.

It was discovered that the change in the number of nodes and the distance between the AP and the node affected the network performance, particularly the throughput, delay, and energy consumption parameters. When there is an increase in the number of nodes and the distance between the AP and the node, the throughput was decreased. For example, when the number of nodes was 50 and the distance between the AP and the node was 100 m, the throughput was 0.0181964 Mbps but when the number of nodes was 300 and the distance between the AP and the node was 900 m, the throughput decreased to 0.0171316 bps. Similarly, when the RAW slot duration was 100 ms, the throughput value decreases. For example, when the RAW slot duration was 100 ms, the throughput was 0.1396 Mbps. Meanwhile, when there is a change in the RAW slot duration of 400 ms, the throughput decreased to 154,177 Kbps.

It was also discovered that the delay value increased when there is a change in the number of nodes and the distance between the AP and the node. At 50 nodes with a distance of 100 m, the delay value was 0.44976 s. This value increased to 477,714 s when the number of nodes was 300 and the distance between the AP and the node was 900.

The result also showed that when there was an increase in the number of nodes and the distance between the AP and the node, the energy consumption was increased. For example, when the number of nodes was 50 at a distance of 100 m, the energy consumed was 0.00942964 Joule/Data Packet. Moreover, it increased to 10,622 Joule/Data Packet when the number was 300 at a distance of 900 m. This energy consumption was also affected by the RAW slot duration parameter. When the RAW slot duration was 100 ms, the energy consumption was 0.00010313 Joule/Data Packet. Meanwhile, the highest energy consumption value was 11.8022 Joule/Data Packet when the number of nodes was 300 and the RAW slot duration was 400 ms

