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Analytical Study of the Distance Change on IEEE 802.11ah Standard using Markov Chain Model

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***Abstract*—This research proposed a model of Enhanced Distributed Channel Access (EDCA) scheme which is one of the techniques used in reducing collision and usually prioritized due to its contention window to determine the impact of distance change on the IEEE 802.11 ah standard. The proposed model was analyzed using the Markov Chain approach to determine the effect of distance change on collisions levels while the numerical were simulated using MATLAB. Moreover, the Markov chain solution was used to evaluate parameters such as throughput, energy consumption, and delay. The results showed the increment in RAW slot duration and the distance change for each station can reduce the performance on the standard and the scenario when the RAW slot duration was changed by 50 ms performed better than 100 ms and 250 ms.**

***Keywords*—Enhanced Distributed Channel Access; Markov Chain; 802.11ah; RAW**

I. Introduction

IEEE 802.11ah (Wi-Fi hallow) is developed from a standard Wireless Local Area Network (WLAN) with the ability to increase the reach of an (AP) up to 1 km^2 and handle up to 8000 stations (STA) [1], [2]. Also, the user characteristics of the IEEE 802.11ah standard are static and mobile [2], [3]. Massive devices, however, have issues with the IEEE 802.11ah standard as observed from the high level of collisions caused by a large number of devices or stations connected at the same time. This is reduced by using an EDCA (scheme Enhanced Distributed Channel Access) which has three parameters including AIFS (Arbitration Inter-Frame Space), Contention Window, and TXOP Limit [4]. Previous studies conducted to analyze the mobility traffic performance showed the value of throughput was 0.53811 Mbps, PDR was 96.75 %, and energy consumption was 5.25302 Joule [3]. Moreover, another research focused on the changes in the performance of Restricted Access Window (RAW) Slot in the IEEE 802.11ah standard showed effective mechanism energy in the system [5]. These previous studies were conducted using NS3 simulation and none was found to have used Markov Chain. Therefore, this research was conducted to analyze traffic on the IEEE 802.11ah standard using Markov Chain with EDCA schemes to determine the performance by changing the node movement using MATLAB [6], [7]. In [8] discussed the fault tolerant system by using Markov chain. The proposed work shows the origin of failure, and average time to repair.

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II. Related Works

IEEE 802.11ah is a wireless network protocol developed using IEEE 802.11 standard. It operates in the 1 GHz sub-band to provide broadband network coverage which is comparable to Wi-Fi operating in the 2.4 GHz and 5 GHz bands [1]. The standard supports low power consumption due to the changes made to the MAC protocol such as the frame format with a smaller size, traffic sensor priority, and mode beacon less paging. Several devices can be connected to share signals, and also to support the IoT concept and this means the IEEE 802.11ah standard can accommodate devices or stations with a large number of connections.

The RAW mechanism is a new MAC layer feature [9] in the IEEE 802.11ah standard used in reducing the level of congestion and collision in channel access and also to support the deployment of the station to save energy [10]. Meanwhile, collision is a condition where packets hit each other due to the presence of two or more STA accessing a channel at the same time [11]. The RAW mechanism, therefore, reduces this high level of congestion and collision by restricting a group of stations from accessing the channel in a time window they are outside a predetermined slot [5].

In the RAW slot, STA scrambles to access the channel and this involves obtaining uplink data from the top layer after which the channel access is requested from the initial RAW slot previously allocated to the STA [12]. Therefore, in this research, we proposed a model to evaluate using an Enhanced Distributed Channel Access (EDCA) scheme. The techniques used to reduce collisions and are usually prioritized because of the contention window to determine the impact of distance changes on the IEEE 802.11 ah standard. The DCF procedure can be used for the channel access [10] and the EDCA scheme for the back-off procedure [12]. Back-off states is used to manage data exchange inside and outside the predefined RAW slots.

The Markov chain model [13], [14] in WLAN was according to the Bianchi approach [15], it was calculated the saturated throughput of IEEE 802.11 DCF. In [16], [17] was proposed the Bianchi model and a collision probability theory, respectively, according to the hidden nodes.

The 802.11ah standard derived its characteristics from 802.11ac, it was use 1 GHz sub-band frequency [10]. Furthermore, at the PHY layer, IEEE 802.11ah supports multiple transmission data rates, uses the Modulation and Coding Scheme (MCS) [18].

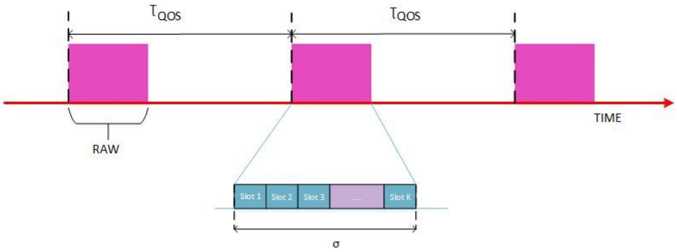

Fig. 1. Restricted Access Window (RAW) [1]

Fig. 1 shows that the 802.11ah was defined the time interval called RAW duration σ and the STA list to reduce contention in RAW (σ) [16], [18]:

$$\sigma = 500s\mu s + C \times 120\mu s \tag{1}$$

The C was expressed the packet length consequently, AP schedules the Resource Allocation frame was transmitted at the beginning of the RAW with the channel access rules [18], [28].

III. Research Method

A. Chain Model

The Markov chain model applied by [29], [30] was modified and applied in this study as shown in Fig. 2.

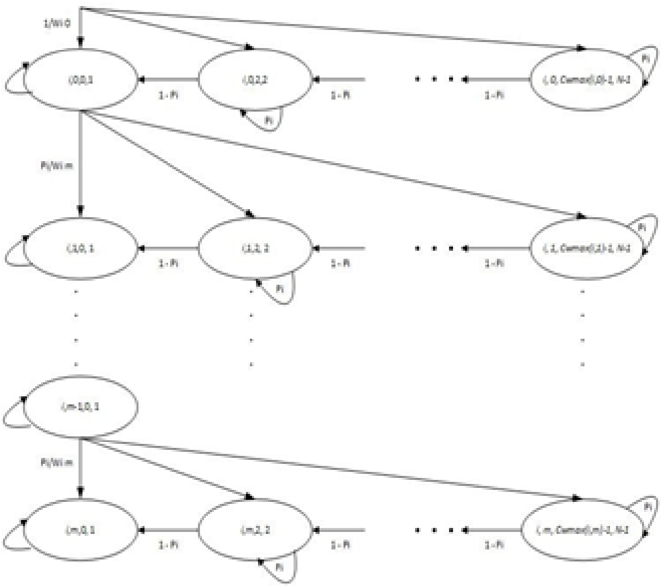
Fig. 2. Markov Chain Model for EDCA

All the nodes in the model readily access the medium but when the medium is busy, collisions occur, and this causes the system to duplicate the contention window and calculate a new back-off time [22], [23]. Moreover, the back-off stage and contention window increase up to the maximum value when there is an unsuccessful transmission.

$$\begin{cases} P\{i,m,k|i,m,k+1\} = 1 - p_i \\ P\{i,m,k|i,m,k\} = p_i \\ P\{i,k|i-1,0\} = \frac{p_i}{CW(i,m+1)} \\ P\{i,0,k|i,m,0\} = \frac{(1-p_i)}{CW(i,0)} \end{cases} \tag{2}$$

The calculation of the throughput requires knowing the parameter of the randomly selected probability transmitted by the node or STA at a time slot. For m > 0, the value was calculated as follows [24]:

$$\tau = \frac{b_{0.0}}{1-p} = \frac{2\,(1-p)}{(1-2p)(W+1) + pW\,(1-(2p)^m)} \tag{3}$$

$$b_{0.0} = \frac{2\,(1-p)\,(1-p)}{(1-2p)(W+1) + pW\,(1-(2p)^m)} \tag{4}$$

The ρi value was also calculated using the following equation [25].

$$p_i = 1 - e^{-p_c} \tag{5}$$

The equation to determine the value of ρi is as follows [34].

$$p_c = \lambda \times T \tag{6}$$

Where λ= 8,125 packages / s and T = 0.016 s [34].

1) Throughput

Throughput is the data transfer speed measured in bits per second (bps). It is the number of packets received divided by the delivery time [27]. Throughput can be calculated using the following equation [21]:

$$S = \frac{P_s\,P_{tr}\,\mathrm{lpayload}}{(1-P_{tr})\sigma + P_{tr}P_s\,T_s + P_{tr}\,(1-P_s)\,T_c} \tag{7}$$

Where, σ is the slot duration, Ts is the time needed for the transmission to be successful, Tc is collisions time, Ptr is the probability that at least one transmission has occurred during the slot time, and Ps is defined as the probability of successful transmission. The values of Ptr, Ps, Ts, and Tc were calculated using the following equation [21], [28]:

$$P_{tr} = 1 - (1-\tau)^N \tag{8}$$

$$P_s = \frac{N\tau\,(1-\tau)^{N-1}}{1-(1-\tau)^N} \tag{9}$$

$$T_s = DIFS + T_{DATA} + T_{ACK} + T_{PHY} \tag{10}$$

$$T_c = DIFS + T_{DATA} + T_{PHY} \tag{11}$$

Where N is the number of nodes used in the simulation while W is the value of CW_{Min}.

2) Delay

Delay is defined as the time elapsed between the generation of a frame and successful reception by the STA [31]. This parameter was calculated using the following equation [15]:

$$\mathrm{Delay} = \frac{(1-P_{tr})\sigma + P_{tr}\,(1-P_s)T_c\,P_{tr}P_sT_s}{P_{tr}\,P_s} \tag{12}$$

3) Energy Consumption

The Energy Consumption can be calculated by reversing equation (8) and this means the average duration of a slot is used as the numerator while the average length of the packet is the denominator. Moreover, the time interval used in equation (11) and (12) was multiplied with the energy consumption values presented in Table I and calculated using the following equation [29]:

$$e = \frac{(1-P_{tr})\sigma + P_{tr}P_s T_s + P_{tr}(1-P_s)T_c}{P_s P_{tr}\ \text{payload}} \tag{13}$$

TABLE I
ENERGY CONSUMPTION VALUE [21]

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

The transmission mode was in DATA and the receiving mode was ACK while the idle mode was applied for other times. The value of the RAW slot duration was calculated using the following equation [18]:

$$\sigma = 500\ \mu s + C \times 120\ \mu s \tag{14}$$

The simulation scenario in this study was to represent normal network conditions by changing the duration of the RAW slot and the network conditions affected by changing the distance of the node as shown in Table II. Meanwhile, the network specifications were adapted from [38], [39].

TABLE II
SPECIFICATION SCENARIO

Parameters	Value
Node Quality	70, 80, 90, 100, 110, 1200
Slot Duration	52 µs
Backoff Stage (m)	6
CW_{Min}/CW_{Max}	32/1023
Payload	8184 bits
SIFS	160 µs
DIFS	SIFS + 2 Slot Duration
T_{SYM}	40 µs
T_{PHY}	$6 \times T_{SYM}$
T_{ACK}	6
T_{DATA}	348 µs

IV. RESULT AND DISCUSSION

The Analytical study of the IEEE 802.11ah standard with Markov chain models was conducted using MATLAB and the parameters analyzed include throughput, delay, and energy consumption.

Fig. 3 shows the throughput value obtained by changing the duration of the RAW slot with the highest, 0.35529 Mbps, recorded at a duration lower than nodes 70 while the lowest, 0.06555 Mbps, was at 120 nodes.

RAW slot duration is the period required by the STA to access a channel and has been observed in Equation (13) to be affected by the length of the packet sent. A greater packet size leads to a higher duration thereby leading to longer waiting times for the STA in RAW and a reduction in the results from several packets due to the length of the queue and packet delivery process [40]. This, therefore, reduces the value of throughput.

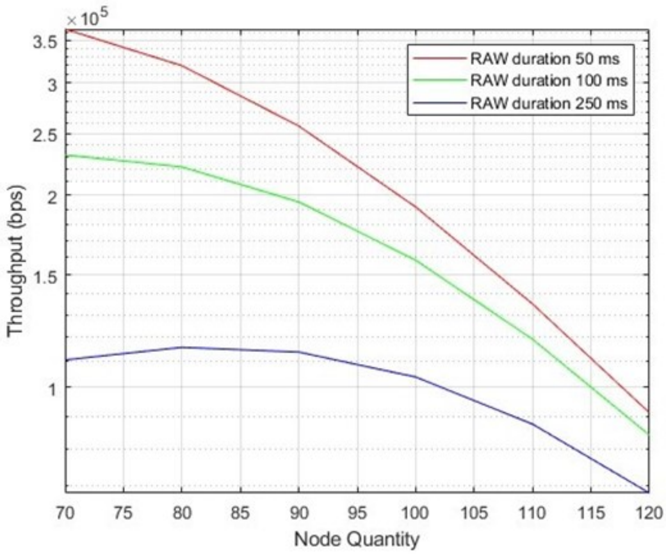

Fig. 3. Throughput with Changes in RAW Slot Duration

Equation (6) was used to calculate the value of throughput with the duration of the RAW slot functions applied as the denominator and this means it is expected to cause a decrease in the throughput value at higher values.

Fig. 4 shows the throughput value also decreased when the distance between the node and AP was increasing due a large number of nodes. This is in line with the findings of previous research that a higher distance reduces the value of throughput [41].

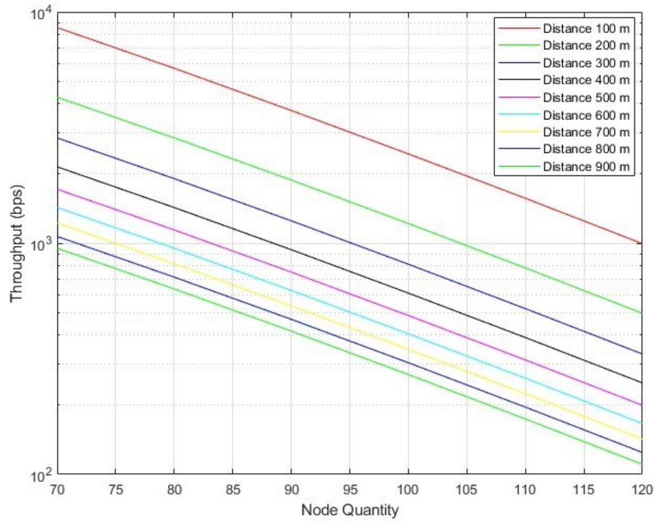

Fig. 4. Throughput with Changes in Movement Node

Fig. 5 shows the delay values increase at a higher duration of the given RAW slot with an increase in the number of nodes. The lowest delay was, however, found to be 0.023s when the RAW slot duration was 50 ms and the number of nodes was 70. The RAW mechanism puts other STA into sleep mode and restricts their access to the channel for a while, thereby, causing a large value of delay [34]. The duration of the RAW slot also affected the delay value. This is observed from equation (13) was a greater number of packets sent leads to a longer RAW slot duration as well as the queue of nodes/STA. This further caused an increase in the time needed for the packet to arrive at the destination.

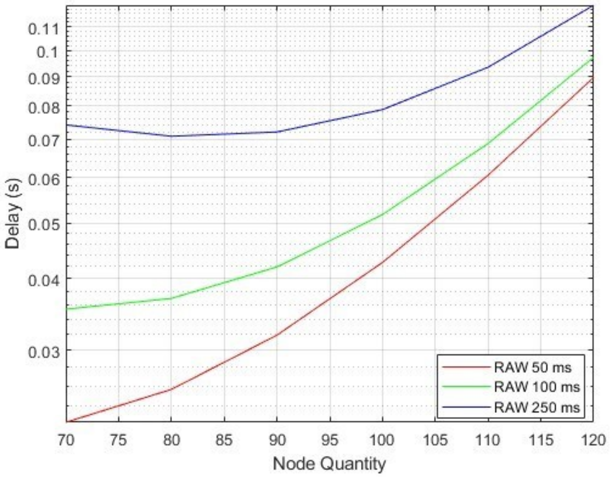

Fig. 5. Delay with Changes in RAW Slot Duration

An increase in the RAW slot duration causes a delay and its position as a numerator in equation (11) shows it has a linear relationship with the value of the delay. This, therefore, means the delay increases with the RAW slot duration.

Fig. 6 shows the delay values generated by changing the duration of the RAW slot and those obtained by varying the distance of nodes were found to have increased between the increasing number of nodes connected to the AP.

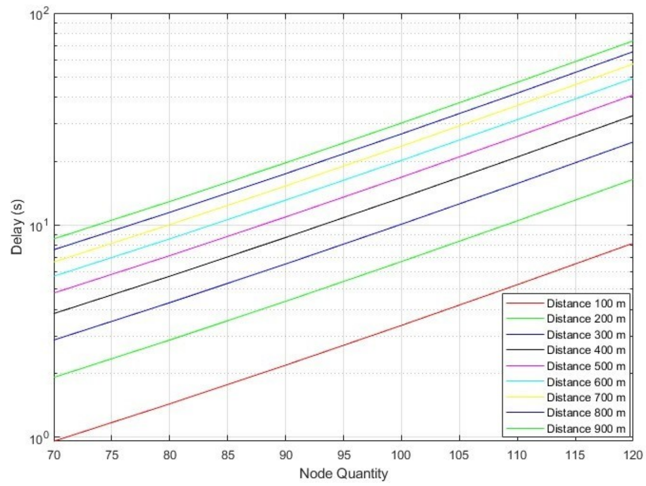

Fig. 6. Delay with Changes in Movement Node

The energy consumption in the IEEE 802.11ah standard was obtained from the simulation results using the scenario which involves changing the duration of the RAW slot as shown in Fig. 7 and this is in line with the findings that a longer duration causes high energy consumption [35]. Moreover, equation (14) shows that packet length affected the duration as observed in the greater number of nodes connected to the AP which caused an increase in energy consumption. The same trend was observed with varying the distance as presented in Fig. 7.

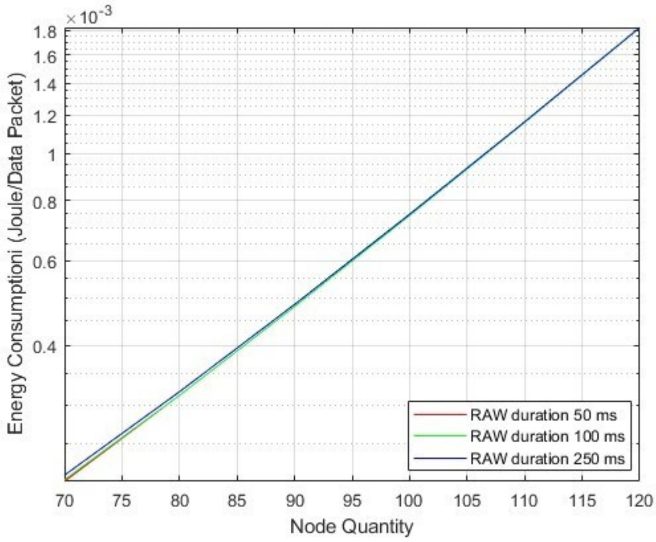

Fig. 7. Energy Consumption with Changes in RAW Slot Duration

Equation (12) shows a high energy consumption is produced when the value of the RAW slot used as the numerator is high. Moreover, changing the number of nodes also affected the P_{tr} and P_s and, according to equations (8) and (9), there was an increase in the number of linear nodes with P_{tr} values and inversely proportional to P_s. The addition of a higher number of nodes also led to the consumption of more energy.

V. Conclusion

We conclude that the values of throughput, delay, and energy consumption were analyzed using Markov chain models. The variations in the RAW slot duration, distance, and node density were discovered to have affected the performance of IEEE 802.11ah. An increase in the duration of RAW slots also led to a reduction in the throughput, increment in delay, and an increase in energy consumption. Moreover, changing the distance between node and AP decreased the throughput while the delay and energy consumption was increased.

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