UBAK

16TH INTERNATIONAL SCIENTIFIC RESEARCH CONGRESS

SCIENCE AND ENGINEERING

11 - 12 MARCH 2023

Full Text Book

Tam Metin Kitabı

ANKARA BİLİM ÜNİVERSİTESİ

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The 16th International Scientific Research Congress

- Science and Engineering –

16. Uluslararası Bilimsel Araştırmalar Kongresi

Fen ve Mühendislik Bilimleri

UBAK

11 - 12 March 2023

Ankara

Proceeding Book

Bildiri Tam Metin Kitabı

Editor

Prof. Dr. Bahri Bayram

Ankara 2023

Publishing Director / Yayın Yönetmeni

Muhammet ÖZCAN

Editor/ Editör

Bahri Bayram

Bu kitapta yayınlanan Bildiri Tam metinleri "Bookcites Kitap Atıf Dizini" tarafından taranmaktadır

Cover Design / Kapak Tasarımı

Bülent POLAT

Interior Design / İç Tasarım

Mahmut Sami TEMİZ

First Edition / BirinciBasım / ©

March 2023 - Ankara

ISBN

978-625-8190-75-5

Asos Yayınevi

1st Edition 30 March 2023

Address / Adres: Çaydaçıra Mah. Hacı Ömer Bilginoğlu Cad. No:67/2-4/Merkez/Elazığ

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Ankara 2023

Presentation ID / Sunum No:75

Oral Presentation / Sözlü Sunum

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Analyzing IEEE 802.11ax: The Standard for The Next Generation WLANs

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ABSTRACT: *The most recent version of the wireless local area networks (WLANs) standard is IEEE 802.11ax-2021, also referred to as high-efficiency wireless (HEW) or WiFi-6. The function of the Access Point (AP) in Wi-Fi networks has changed notably with the implementation of Orthogonal Frequency Division Multiple Access (OFDMA) in 802.11ax. This is because it gives the chance to use more sophisticated timing algorithms to manage Downlink (DL) traffic patterns and serve as a controller for Multi User Uplink (MU UL) transmissions at the same time. It becomes essential in this situation to develop a model for network analysis. In this paper, a model is developed to perform the network analysis of the IEEE 802.11 ax. The development of the model takes into account both UL and DL transmissions in addition to all the key performance-affecting variables. A theoretical study using Markov chains is presented. In addition, the simulation is used to validate the developed performance model.*

Keywords: *IEEE 802.11ax, OFDMA, WİFİ-6, WLAN*

1. INTRODUCTION

WLANs (wireless local area networks), are gaining popularity, raising concerns about how to handle the unavoidable overcrowding and slow communication that will inevitably result from the increase of new methods, technologies, and apps. Because there are many sites and access points in some environments, IEEE 802.11 evolved the IEEE 802.11ax standard.

Orthogonal frequency division multiple access (OFDMA) based up-link multi-user (UL MU) transmission, which splits a transmission into some sub-channels and concurrently sends data packets for numerous users, is realized by a later released standard known as 802.11ax (IEEE, 2021). Getting precise communication synchronization between communicating stations (STAs) that have been set up to function in a completely distributed way is one challenging aspect of using OFDMA in Wi-Fi (Son, 2018). 802.11ax's ability to manage OFDMA signals in the downlink (DL) and uplink (UL) paths helps to get around this problem. By assigning OFDMA resources to the stations and scheduling UL broadcasts for them, the access points (APs) gather the transmission purpose from the stations. More significantly, it broadcasts a "trigger frame" to the WLAN, which starts the stations' real UL communication. Nevertheless, this results in IEEE 802.11ax stations having entrance to the channel in a totally different manner from current older nodes, as well as in inevitable alterations to MAC layer.

For future WiFi use-cases, single-user communication technologies like orthogonal frequency division multiple (OFDM) may not be successful, so 802.11ax has depended on MU technology. Each channel is split into numerous orthogonal sub-carriers (SCs) in the MU-OFDMA method, and a collection of these SCs constitutes re-source units. MU multiple input multiple output (MIMO) operation, i.e., the simultaneous transmission of data from multiple users over the identical resource unit (RU) utilizing multiple antennas, is feasible in each resource unit with a capacity of 106 sub-carriers or more. The channel status information (CSI) should be accessible at the AP in order to precisely decrypt this data. Additionally, the channel traits are more likely to affect this CSI information. As a result, the access

point must use the channel sampling (Son, 2018; Bellalta, 2017; Choi, 2016) procedure to ask for CSI information from the stations more frequently. The MAC layer access method of 802.11ax networks is significantly impacted by these MU-OFDMA + MU-MIMO characteristics.

According to (Bellalta, 2017), utilizing specified factors when configuring an IEEE802.11ax network can result in effective utilization of both MU-MIMO and OFDMA. Additionally, the study using math and simulations demonstrates that MU communications can be secured in big-picture situations. Along with MU-MIMO and OFDMA, non-continuous channel sharing and link adaptation are assessed to confirm the performance enhancement of IEEE 802.11ax. The computer outcomes demonstrate this amendment's unmistakably higher output, improved quality of service (QoS), as well as increased multi-channel effectiveness (Lin, 2016).

The contributions made by this study are listed below:

- In order to analyze IEEE 802.11ax performance, the paper provides an analytical study.
- The efficiency of the system may be impacted by certain parameters. A theoretical study based on the Markov's chain model derives relationships among performance measures.
- The numerical results are presented to verify the analytical study.

The rest of the paper is ordered as follows: Section 2 describes an overview of IEEE 802.11ax. Section 3 provides the system model. Section 4 gives the numerical results. Lastly, Section 5 provides the conclusions.

2. OVERVIEW IEEE 802.11ax

IEEE 802.11ax suggests a number of important technologies in reaction to the high-density implementation situations and the technological and objective criteria.

Some novel transmission and encryption methods are adopted by IEEE 802.11ax. First, the highest transfer rate could be increased even more by adding 1024-QAM. The IEEE 802.11ax can theoretically attain a high transfer speed of 9.6 Gbps. Second, dual carrier modulation improves the resilience of communications in UL transmission as well as outdoor situations. Ultimately, IEEE 802.11ax has decided to make binary convolutional encoding and low-density parity check mandatory encryption methods.

A new SC division technique is used for IEEE 802.11ax that is more precise than standard IEEE 802.11. The 20 GHz frequency is split into 256 subcarriers spacing in IEEE 802.11ax, which is four times as many as in the original IEEE 802.11. With the help of this novel subcarrier division method, OFDMA resources can be scheduled more precisely and effectively, further enhancing frequency economy. The numerous access technique built on OFDMA and MU-MIMO is improved by IEEE 802.11ax to ensure MU simultaneous propagation in both the frequency and geographic domains. This offers a strong basis for raising WiFi effectiveness.

Access points and/or stations can send frames on non-continuous channels thanks to the improved channel boundaries in IEEE 802.11ax, which increases channel usage and completely utilizes the increased capacity. The improvement of MU-MAC is the most significant change made to IEEE 802.11ax's MAC layer. High-efficiency multiple-access (MU-MAC) technology allows multiple users to adhere to predetermined access guidelines to send UL data simultaneously (familiar as UL MU-MAC) or DL data simultaneously (familiar as DL MUMAC) through predetermined network access resources (i.e. time domain, frequency domain, and space domain resources). MU-MAC includes the MU-MIMO-based and OFDMA-based multiple access techniques that IEEE 802.11ax debuted.

First, IEEE 802.11ax is the earliest to implement UL MU-MAC for WiFi. Two specific methods are presented in depth, namely UL MU-MIMO and UL OFDMA. Second, IEEE 802.11ac only allows DL MU-MIMO for DL MUMAC, whereas IEEE 802.11ax adds DL OFDMA to improve DL concurrent access.

Additionally, to further increase MAC efficiency, IEEE 802.11ax suggests a cascaded MU MAC that enables the DL and UL MU transmissions to happen alternately during a transmission chance time period.

This part employs the standardization procedure of IEEE 802.11ax as an illustration to make the comprehension of the IEEE 802.11 standardization process easier. High efficiency WLAN (HEW) is the designation of the study group (SG) that IEEE 802.11 instantly forms following the introduction of IEEE 802.11ac in March 2013 (Hew, 2014). A number of characteristics have been verified as the primary technologies for the next-generation WLANs through thorough debate. The criteria for standards development (CSD) (IEEE, 2014a) and the PAR (IEEE, 2014b) were the next two significant papers that HEW finished. While CSD defines the technical criteria standardization process, PAR, one of the most crucial papers in the standardization procedure, explains the goals and technical standards. HEW was superseded by the IEEE 802.11 task group (TGax) in March 2014 (IEEE, 2017). This is the first time, MU and SR were considered the most crucial study paths during the creation of TGax. TGax made the decision to first create a standard framework document (SFD) (IEEE, 2016) in order to create the ultimate IEEE 802.11ax revision. SFD is typically used to describe the standard update and specify which technologies the document should include. SFD's work came to a close at the beginning of 2016, and the initial version of IEEE 802.11ax was published in March of that same year. Draft 3.0 of IEEE 802.11ax was published in October 2018 (IEEE, 2018). Additionally, IEEE 802.11ax's ultimate form will be made available in 2019. The timetable for the IEEE 802.11ax standardization procedure is depicted in Figure 1.

2013	2014	2015	2016	2018	2019
Study Group	PAR TASK Group	Space Frame Document	Draft 1 Draft 1.3	Draft 2	Final 802.11ax

Figure 1. Standardization Process of IEEE 802.11ax.

3. SYSTEM MODEL

We model the performance study of IEEE 802.11ac (Machrouh, 2016) on the Bianchi model, which we use for the mathematical model of our network. In terms of evaluating WiFi networks and determining traffic, the model performed remarkably well. We take into account a single AP and a number of STAs that are close to one another and have similar powers. It is assumed that the STAs and AP always have packets available for delivery; these packets are then combined. Figure 2 shows single user transmission for UL and DL. Figure 3 and 4 show DL and UL for multi-user transmissions, respectively.

The MU-RTS frame, which contains details about the STAs and the channel lengths, is a variation of the trigger frame. The AP only sends to the STAs that have responded, and each STA responds with a CTS frame. Aggregating ACK packets into a single MU-STAs Block ACK to minimize latency is another appealing feature.

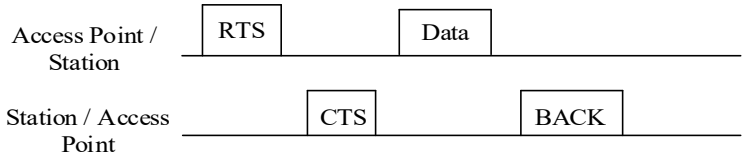


Figure 2. Single User Transmission For UL and DL.

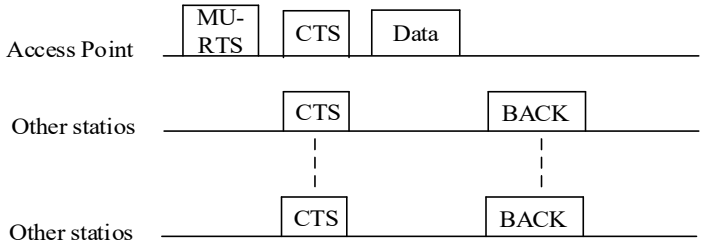


Figure 3. Multiple User Transmissions for UL.

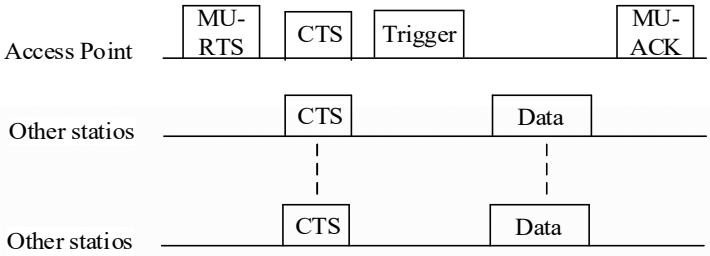


Figure 4. Multiple User Transmissions for DL.

A DL transmission begins when the counter of AP backoff hits zero, whereas STAs begin UL transmissions when their backoff counters also reach zero. The Markov Chain Model can be used to calculate the likelihood that a station will broadcast and the likelihood that there will be accidents. Additionally, it is possible to calculate the energy efficiency, which is the amount of energy spent to transferred data over a given time period.

The drawback is that the AP must collect channel and buffer status data from user units, which could result in a substantial amount of waste. As a result, there is a trade-off between the waste caused by such information and the quantity and pace at which it is needed. The two scenarios covered by the mathematical model are effective transfer and impact.

We describe the transmission probability τ and the collision probability P_c using the same Markov Chain Model in (Karabulut, 2020). τ can be written as

$$\tau = \frac{2(1-P_c)}{(1-2P_c)(CW+1)+P_cCW(1-(2P_c)^{m_r})}. \quad (1)$$

P_c can be given as

$$P_c = 1 - P_c^{UL} - P_c^{DL}, \quad (2)$$

where P_c^{UL} and P_c^{DL} are collision probabilities for UL and DL transmission, respectively. They can be expressed as (Lee, 2019)

$$P_c^{DL} = \tau(1-\tau)^N, \quad (3)$$

$$P_c^{UL} = N\tau(1-\tau)^{N-1}. \quad (4)$$

The channel will be occupied if any one of the N nodes transmits a message during a time period. Consequently, P_b can be given as

$$P_b = 1-(1-\tau)^N. \tag{5}$$

P_s stands for the probability that a message will be properly transmitted and conveyed, and it can be written as

$$P_s = \frac{N\tau(1-\tau)^{N-1}}{1-(1-\tau)^N}. \tag{6}$$

S, the ratio of data sent in a slot time to the typical slot time length, is the normalized system throughput. It can be depicted as

$$S = \frac{E[payload\ information\ transmitted\ in\ a\ slot\ time]}{E[length\ of\ \ slot\ time]} \tag{7}$$

The operator for the mean value is shown here as $E[.]$. Then, it could be stated as

$$S = \frac{P_s P_b L}{T_e}. \tag{8}$$

Here, L refer data size. In the instance of a Markov chain, T_e is the expected duration of a node and is written as

$$T_e = (1-P_b)T_{slot} + P_b P_s T_s + P_b(1-P_s)T_c. \tag{9}$$

Here, the durations of successful and colliding packet transfer are denoted by T_s and T_c, respectively, which can be given as

$$T_s = T_{SIFS} + T_{RTS} + T_{CTS} + \frac{L}{R_d} + T_{ACK}, \tag{10}$$

$$T_c = T_{RTS} + T_{SIFS} + T_{ACK}. \tag{11}$$

Here, T_{RTS}, T_{CTS}, T_{ACK}, T_{SIFS} are request to send (RTS), clear to send (CTS) acknowledgment (ACK), short inter-frame space (SIFS), times, respectively. R_d refers transmission rate.

4. NUMERICAL RESULTS

In this part, the analytical model is verified, and network performance is examined through numerical analysis carried out in MATLAB.

We concentrate primarily on output because it has been significantly improved by the ax change. In our tests, we selected a base service set with a single entry point and a number of stations that were distributed at random within one another's broadcast range. We investigate how aggregation affects speed and emphasize how well different modulation and coding algorithms work when used with varying channel lengths. We then demonstrate how the number of nodes affects WiFi performance. The values used for the numerical results are listed in Table 1.

Table 1. Parameter Values Utilized in Numerical Results

Parameters	Values
T_{SIFS} , T_{DIFS} (μs)	16, 34
RTS, CTS, ACK, L, (bytes)	26, 20, 14, 6000
R_d (Mbps), N	11, 100
CW, m_r	32, 5

Figure 5 shows the throughput according to the number of STAs. The number of stations is considered as 50 and the comparison is made. The lower number of stations provides higher throughput as well as supports more efficient communication. The throughput is decreasing as the number of stations is increased. Because there will be increased competition and more collisions due to excess packets in the channel for transmission. Channel bandwidth has been studied. An increase in throughput is observed with the increase in channel bandwidth.

Figure 6 shows the throughput versus packet size for several key parameters of the standard. The number of stations is compared between 25 and 100. The lower number of stations provides higher throughput. Throughput is increased with the increase in the packet size. The usage of channel improves as the packet length increases.

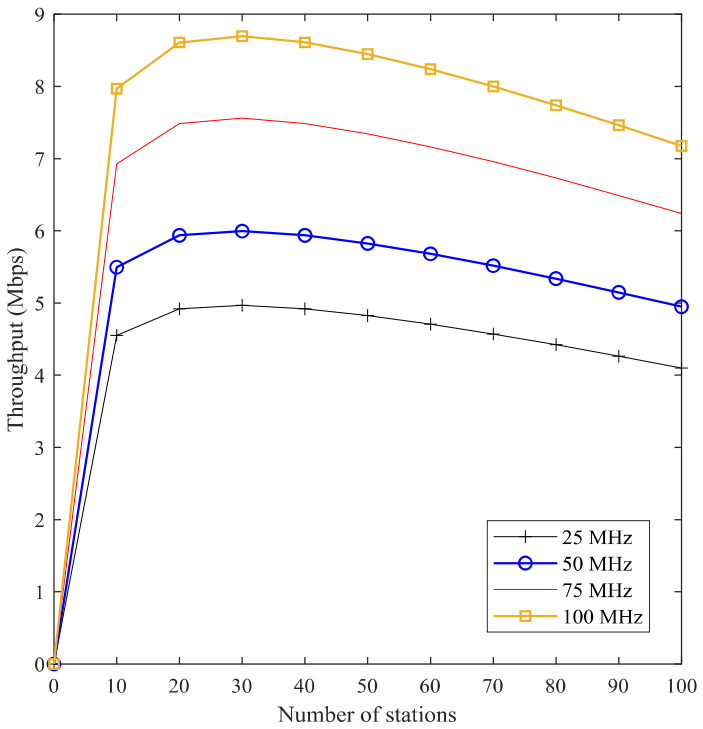


Figure 5. Throughput for Different Channel Bandwidth.

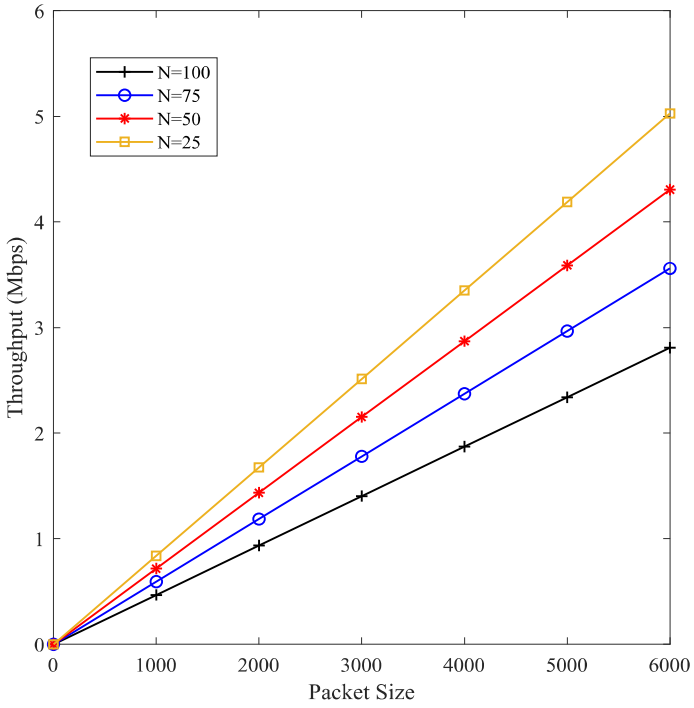


Figure 6. Throughput for Different Packet Size with Different Number of Stations.

5. CONCLUSION

In this paper, we show a numerically validated mathematical model for the IEEE 802.11 ax standard. The suggested model is validated analytically under saturated circumstances, and the WLAN is assessed for different network characteristics. Depending on the context of the situation, changing one or more of these factors can result in significant changes in efficiency.

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